

Nicolas Balacheff
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Sally Barnes
Editors

Technology- Enhanced Learning

Principles and Products



Springer



kaleidoscope

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Ard Lazonder · Sally Barnes
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Technology-Enhanced Learning

A Kaleidoscopic View

Nicolas Balacheff, Sten Ludvigsen, Ton de Jong, Ard Lazonder,
and Sally Barnes

Abstract The purpose of this book is to present and discuss current trends and issues in technology-enhanced learning from a European research perspective. Being a multifaceted and multidisciplinary topic, technology-enhanced learning is considered from four different viewpoints, each of which constitutes a separate part in the book. Parts include general as well as domain-specific principles of learning that have been found to play a significant role in technology-enhanced environments, ways to shape the environment to optimize learners' interactions and learning, and specific technologies used by the environment to empower learners. A postface part is included to discuss the work presented in the preceding parts from a computer science and an implementation perspective. This chapter introduces the origin of the work presented in this book and gives an overview of each of the parts.

Keywords Technology-enhanced learning

1 Introduction

This book builds and capitalizes on the work carried out in the Kaleidoscope Network of Excellence financed by the European Commission from 2004 to 2007. Networks of Excellence (NoE) are a new type of instrument that was first introduced within the 6th Framework Program. Networks of Excellence primarily aim to strengthen European research areas in all sectors, but may be especially relevant to emerging areas – which is the case of research concerning technology-enhanced learning (TEL).

This book does not describe Kaleidoscope itself, but focuses on the outcomes of several of its content-based activities that has been organized over the past 4 years (some other activities were dedicated to the building of a common infrastructure¹).

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¹ e.g., the Open Archive Telearn (www.telearn.org).

The book describes the theoretical rationale, emerging trends, state of the art, and key empirical results of TEL research. This is done both at a more aggregated level and for key knowledge domains in the TEL field and Kaleidoscope achievements are linked to the development of research worldwide. Before presenting the organization of the book first a brief description of Kaleidoscope is given.

2 The Kaleidoscope Network of Excellence

When the European Commission proposed the NoE as a new instrument to structure scientific communities, several expressions of interest emerged from the TEL sector. These covered different trends of research, with different emphases, and mainly involved education, computer-supported collaborative learning, artificial intelligence and technology for human learning. The research communities within these fields of study have different histories when it comes to theoretical and methodological approaches. The most important decision was to take up the challenge of breaking down the (artificial) walls separating these approaches and build a Kaleidoscope to open up a new and more integrated view of the field with approaches crossing the barriers, a wide scope and a strong long-term research and structuring potential.

Kaleidoscope aimed at fostering integration of different disciplines relevant and necessary to TEL research, bridging educational, cognitive and social sciences, and emerging technologies. This ambition was both scientific and strategic:

- It was scientific by its aim “to develop a rich, culturally diverse and coherent theoretical and practical research foundation for research and innovation in the field”, exploring “the different conceptual frameworks of relevant disciplines in order to delineate the commonalities and differences that frame the research objectives in the field”.²
- It was strategic by its aim “to develop new tools and methodologies that operationalize an interdisciplinary approach to research on TEL at a European-wide level” with the expectation of a significant impact at the international level.

To bring this ambition to reality a set of instruments was planned to support the integration process at both the content and the infrastructure level. At a content level *European Research Teams* (ERT) and *Special Interest Groups* (SIG) provided the basic context of collaboration, at an institutional level for the former, at an individual level for the latter. ERTs and SIGs had specific research agendas but altogether covered a large number of topics – several of which are represented in this book. Transversal to ERTs and SIGs, *Jointly Executed Integrating Research Projects* (JEIRP) created an added value by organising for a year a cluster dedicated to a common problem that was interdisciplinary in nature.

² The complete Kaleidoscope proposal can be downloaded from [http://telearn.noe-kaleidoscope.org/open-archive/file?KalPartBfinal_\(001771v1\).pdf](http://telearn.noe-kaleidoscope.org/open-archive/file?KalPartBfinal_(001771v1).pdf).

Over the 4-year period Kaleidoscope stimulated and created integration between different fields of TEL. A good example is the convergence between computer-supported collaborative learning (CSCL), mobile learning, and inquiry learning. This convergence was evidenced by concrete collaborations in the context of the different shared instruments (e.g., courses of the virtual doctoral school) and a dedicated workshop in 2006 that stimulated the emergence of a number of common themes. These themes included using the inquiry learning approach across different domains, testing the notion of scripted collaboration, and using mobile devices. In all these sub-fields different analytical approaches were used that focussed on cognitive performance and cognitive development within socio-cultural environments where technologies are implemented and used.

We believe it is reasonable to say that TEL has grown out of five main areas of research:

1. *The design area* – a focus on the design and co-evolution of new learning activities.
2. *The computational area* – a focus on what technology makes possible.
3. *The cognitive area* – a focus on what the individual can learn under certain conditions in different types of contexts.
4. *The social and cultural area* – a focus on meaning-making, participation, and changes in activities in schools, universities, workplaces, and informal settings.
5. *The epistemological area* – a focus on how the specificities of the domain impact the design and use of technologies.

All these areas contribute to the overall understanding of TEL. The design area explores new conditions for learning and new types of learning. The computational area connects the TEL field to computer science more broadly and technologies with their representational formats create possibilities not only for more efficient and effective learning but also for the learning of these new types of knowledge and skills. The cognitive area offers new knowledge about how new technologies change the conditions for cognitive performance based both on new types of instructional design and tools. The socio-cultural area increases awareness of how technologies are adapted and used in different settings. Without this understanding, major challenges for designing and using technology remain unexplained. Finally, the epistemological area explains how in different knowledge domains, the domain itself constrains what technologies can mediate. This tangle of research areas underlying TEL requires an integration of different specific concepts and methodologies in order to advance our understanding of learning supported by technology, as well as our views on the design of the best adapted technologies.

3 Organization and Content

The organization of this book reflects the multifaceted and multidisciplinary characteristic of TEL research. The book is composed of four parts. These parts include general as well as domain-specific approaches of TEL that have been found to play

a significant role in learning, ways to shape the environment to optimize learners' interactions and learning, and specific technologies used to empower learners. A postface part is included to discuss the work presented in the preceding parts from a computer science perspective and an implementation perspective.

3.1 Part I: Learning Principles

The first four chapters give an overview over four theoretical rationales for the analysis and design of TEL activities and environments. In these chapters knowledge domains serve as examples. This means that this first part summarizes problems and findings in CSCL, computer-supported inquiry learning, social and cultural dimensions of TEL environments, and narrative learning environments, all of which adds up to what different perspectives can contribute to the design of learning environments and how to analyze the use of these environments.

Chapter 1 by Dillenbourg, Järvelä, and Fischer gives a historical perspective and emerging trends in CSCL research. In addition, motivational and affective aspects of CSCL research are addressed. The CSCL research defines the problem of how technologies can support learning from a different angle than was the case up to the 1990s. The main focus before CSCL became established was mainly how technology could support individuals. The CSCL approach takes collaboration as a premise and starting point for understanding how people learn. CSCL research has been concerned with the myth of media effectiveness. Many CSCL studies, from different perspectives, have shown that the effort participants use in solving a problem and creating a shared understanding is the most important aspect. It is also important to emphasize that collaboration in itself cannot be seen as recipe to improve learning. A growing area in CSCL research addresses motivational and affective aspects of learning in CSCL environments. Here self-regulation is the perspective that is used to understand the effectiveness of collaboration. In this line of research different types of tools are developed so that students can increase their capacity to participate and learn in complex environments. From these different lines of CSCL research the theme of orchestration emerges, which points to the integrated design for both more macro level and social aspects of the learning activities and the micro level or cognitive action. At both levels the idea of scripts is central. Teachers are brought into the design as a significant aspect of the designed activities.

Chapter 2 by van Joolingen and Zacharia gives an overview of recent developments in computer-supported inquiry learning. There has been a growing interest in the TEL community for pedagogical models and how technologies can be used to support such models. Inquiry learning as a model is based on how experts in scientific practices work to solve problems. This model becomes an ideal version of scientific work and it represents key processes that students must go through in order to investigate and solve problems in different domains. The inquiry learning model makes it possible to combine a conceptual model of how students can learn and the need for building sequences of activities in order to make sure that students

go through the content and become capable of solving more advanced problems. In this chapter an overview is given of a large set of social and cognitive tools that can enhance learning. The second part of the chapter brings up two main trends in the TEL field, namely component-based design and learning objects ontologies. As the computational design of environments sets premises, the problem of integration and interoperability becomes central. The relation between the pedagogical model, social and cognitive tools and the technological architecture is discussed as part of new challenges in the TEL field.

Chapter 3 by Sutherland, Lindström, and Lahn addresses the social-cultural perspective on learning, cognition, and development. This perspective seeks to integrate how students and participants learn in the intersection between social and cognitive activities. Social and cognitive aspects are seen as intertwined in the learning process. The authors describe some of the core concepts in this perspective such as mediation, artifacts, and tools. The design and use of artifacts and tools involves the interdisciplinary community in TEL research from the computer scientist to the social scientist. The socio-cultural perspective is used across different subfields in TEL research. Studies based on this perspective can be found in CSCL, computer-supported inquiry learning, mobile learning, workplace learning, and in domain-specific areas such as mathematics, science, and languages. In the chapter the focus is on what the social organization of knowledge means in terms of what participants can learn, as individuals and collectively. In the case studies provided, the authors illustrate what the organization of the activities, the social norms, and division of labour means for what and how participants learn in institutional settings such as schools and workplaces. Two of the examples are based on longitudinal and large-scale studies that examine how specific technologies are implemented and used over longer periods of time. In addition, more detailed analyses are given of how students struggle to learn concepts in a physics domain. Together these examples show that the design and use of specific ICT tools should be analyzed at different social levels: individual, groups, and communities. Without this type of analysis one can neither understand the “uptake” of ICT in social settings and institutions nor their long-term impact.

Chapter 4 by Dettori and Paiva focuses on narratives as a key dimension for the design of learning environments. The narrative dimension is sometimes overlooked in other design approaches or used under a different name. By bringing narratives back as the focus a fundamental aspect of human learning and knowing is brought to the forefront of our attention. The narrative dimension has been discussed in both cognitive and socio-cultural psychology. In their chapter Dettori and Paiva identify from different approaches a few common aspects that give direction to the design of narrative learning environments (NLE). From different traditions in the TEL field such as instructional design, artificial intelligence in education, and ideas from learning with multimedia, Dettori and Paiva develop a classification based on two key dimensions: story creation and story fruition. As part of this classification the authors describe how an NLE approach has been operationalized in different domains.

3.2 Part II: *Learning in Specific Domains*

Every knowledge domain raises specific issues either for learning or for the design of learning environments. Mathematics or natural sciences, medicine or language learning, just to name a few examples, have “ecological” characteristics that could be described in terms of the nature of the situations which give them meaning, the type of representations they use, as well as the actions and controls required over these actions. These characteristics influence the design of learning environments. Technology provides new opportunities or sometimes puts limits depending on the intended learning outcomes. This applies to all knowledge domains, and indeed to the ones mentioned above which were explored within Kaleidoscope. The four chapters in this part present a survey of the progress made in these domains. The variety of the accounts witnesses the variety of the potential impact of technology on learning depending on the maturity of TEL research in each case, but also on the maturity of the associated technology and of our knowledge of the considered learning. Each of the four chapters aptly illustrates different aspects of the role played by the specificity of a knowledge domain.

In the case of mathematics, Bottino, Artigue, and Noss in Chapter 5 address an issue which is at the core of the Kaleidoscope challenge. They explore the role played by theoretical frameworks and identify the conditions for sharing experience and knowledge in spite of the differences in the theoretical frameworks and the approaches chosen by the research teams. For this purpose a “cross-experiment methodology” was developed, and notions of “didactical functionality of an ICT based-tool” and of “key concern” (issues functionally important) were introduced. The chapter analyzes the gap between the role of theoretical frames in the design process of ICT tools and teaching experiments, and their role in the analysis and interpretation of the collected data. An original contribution of this chapter is the concrete description of the strategy and actions that enable sharing of concepts and methods. An additional original contribution is the emphasis on the need for mathematics in the workplace, and its consequence on TEL research in mathematics. Digital technology increasingly shapes the natural work environment which drastically raises the importance of capacities related to information problem solving and dealing with quantitative information presented in different visual and iconic representations. A special effort is expected from TEL research to enhance the design of technologies in order to offer genuinely novel epistemological as well as didactical opportunities to introduce modeling as mathematical knowledge.

Technology-enhanced language learning (TELL) requires a completely different focus due to its specific, and often problematic, relationship with research on natural language processing (NLP) and corpus linguistics (CL). Antoniadis, Granger, Kraif, Ponton, Medori, and Zampa report in Chapter 6 on the analysis of the relationships between these research domains, demonstrating the potential contribution of research on NLP and CL to TELL. A key conclusion is that the integration of these approaches is possible provided that certain conditions are satisfied (i.e., reliability, selection of contexts, teachers’ access to output control). This chapter supports

the idea that a possible fruitful collaboration between these research domains can be found in a new type of corpus: the learner corpus which contains written or spoken data produced by foreign language learners. Eventually, the authors notice that natural language is ubiquitous in TEL, being the main channel of interactive communication between the tutor and the learner and between the learners. They take in particular the case of medical TEL applications which would clearly benefit from an intelligent glossary linked to multimedia files and hyperlinked to domain-specific corpora for additional examples.

Medical TEL research is a theme which emerged during the Kaleidoscope project, addressing new issues mainly related to the gestures (i.e., embodied knowledge) doctors must perform in a theater. Luengo, Aboulafia, Blavier, Shorten, Vadcarrd, and Zottmann analyze in Chapter 7 different aspects of the contribution of technology in this area. The chapter notices the gain technology offers from a safety perspective and by the possibility to provide access to relatively rare cases. Three key issues that are more especially addressed in the chapter are the transfer of skills from one technique to another one, the epistemic character of the authenticity of simulation, and the role of feedback. Feedback is central to the learning of medical gestures. It requires models which ensures high-level realism (e.g., for spinal anaesthesia) although such a level of realism is not always required (e.g., in the case of minimal invasive surgery). In all cases, an epistemic analysis helps to decide which level and type of model is necessary. Eventually, the authors evidence a balanced interaction between technology and pedagogy, showing that TEL environments may require appropriate learning situations (e.g., collaboration scripts for problem-based learning) or that some learning situations require the use of specific tools (e.g., the orthopedic surgery case).

Chapter 8 takes the angle of learning and pedagogical theories to question the design and use of TEL environments for science learning. Kyza, Erduran, and Tiberghien, taking critical stance, contrast individual and socio-cultural views of learning as theoretical frameworks. Their analysis showed that learning environments cannot be only learner centered, but that they also have to take into account the specificity of the knowledge at hand, as well as the social and situational characteristics of the learning situation, and assessment aspects. From this analysis they derive a set of basic requirements for TEL environments, namely: adding authenticity to the learning environment (e.g., interactive simulations and modeling tools), providing learners with scaffolded tools to help them engage in independent inquiry (e.g., data collection and analysis tools, and inquiry support software), supporting the building of communities of learners and extending learning beyond the science classroom (e.g., web-based CSCL environments) and eventually by empowering teachers to design flexible and customizable environments for learning. Modern technologies have the potential to fulfill these requirements either from a learner perspective or from a knowledge perspective, as well as from a professional perspective by providing teachers with more efficient and adequate tools to design learning situations.

The chapters in this part demonstrate the value of research that focuses on specific knowledge domains, thus opening the possibility to carry out very accurate

studies from the learning outcome point of view. Their results are of a paramount significance and importance beyond the specific knowledge domain considered.

3.3 Part III: Shaping the Learning Environment

In this part the main focus shifts from the learner to the learning environment. People learning in TEL environments interact with learning content, possible co-learners, and the environment itself. Effective learning environments facilitate all three forms of interaction, and seek ways to exploit the results of the learners' activities to adapt and empower future support and learning. The chapters in this part propose ways to shape the learning environment to optimize learners' interactions and, hence, learning. Chapters 9 and 10 address the issue from a pedagogical/psychological perspective by identifying design recommendations for the use of external representations and the orchestration of peer-to-peer interaction, respectively. The arrangements described in Chapters 11 and 12 are more technical by nature and seek to offer support in adaptive response to the learners' own actions within the environment. Visualization occupies an important place in all four chapters, not only to represent learning materials but also to display the result of the learners' (inter)actions.

In Chapter 9, de Vries, Dementriadis, and Ainsworth demonstrate that there is more to learning with external representation than meets the eye. They acknowledge the powers of computer technology to develop dynamic and interactive representations. Although often appealing, not all of these external representations are beneficial to learning; their effectiveness to a large extent hinges on the ease with which learners can construct adequate internal representations from the external representations offered to them by the learning environment. To understand how internal representations come about, the authors distinguish a dyadic and triadic view on representations. As the latter is more in keeping with contemporary notions of learning, it might be the preferred view for designing TEL environments. Yet such a unified view does not guarantee a uniform appearance and usage of digital representations: TEL environments are developed in different cultures using different technologies, and often try to incorporate principles of multiplicity, adaptability, and externalization of mental processes. TEL environments thus place a heavy burden on the learners' ability to deal with a multitude of external digital representations. As these demands are typically unproductive to learning, synchronization of the ways in which external digital representations are to be designed, understood, and studied seems called for.

In Chapter 10 Weinberger, Kollar, Dimitriadis, Mäkitalo-Siegl, and Fischer address the issue of how collaboration scripts can enhance student learning in CSCL environments. It is long since recognized that simply putting learners together does not guarantee that effective collaborative learning takes place – and online collaboration certainly complicates matters even further. Scripting is considered a promising approach to scaffold learners in their collaborative learning efforts by specifying, sequencing, and distributing roles and activities. Well-known and effective examples date from the 1980s, and served as starting point for the design of adaptable

CSCL scripts proposed by Weinberger and colleagues. These scripts start from the notion that the ability to collaborate is stored in memory in the form of internal scripts. CSCL scripts aim to compensate for the deficiencies found in the learners' internal scripts. In order for CSCL scripts to be effective, they need to be adapted to the individual needs of the collaborative learners, and faded as function of their increasing abilities to collaborate. This ideal operation of CSCL scripts poses heavy challenges on educational psychologists and computer scientists and is an interesting avenue for future research on CSCL.

Collaborative learning is also pivotal to Chapter 11, where Harrer, Martínez-Monés, and Dimitracopoulou describe ways to exploit the trails from the users' communication, collaboration, and coordination activities within TEL environments. These data have traditionally been used for research purposes only, but nowadays attempts are being made to offer support in adaptive response to the learners' interactions. Toward this end the authors first define the key elements of interaction analysis and propose a process model that describes how these elements should be derived from interaction data. This conceptual integration is complemented with a technical integration that aims to increase interoperability between different interaction analysis methods and tools by means of unified data formats and interfaces, so as to enable the cross-usage of tools and data beyond their initial scope. Despite promising results, computer-supported interaction analysis remains less robust and sophisticated than its manual counterpart. Its possibilities in offering adaptive learner support are nevertheless quite appealing and should be strengthened and elaborated in future TEL research projects.

Another approach to the analysis of users' data is discussed by Choquet, Iksal, Levene, and Schoonenboom in Chapter 12. They too consider the users' trails a fruitful source for selecting tailor-made learner support, but go beyond the mere analysis of interaction data by incorporating the results of *all* of the users' actions in the analysis. Doing so will enable learners to reflect on their activity and provide designers with session feedback to improve the quality of their systems. The authors propose a three-phased process to transform the (non-)digital record from the different actors within a TEL environment into meaningful pieces of information. This process starts by modeling the requirements for acquiring and understanding a trail. The specifications that result from this phase are used to obtain and analyze the data and deliver the results to the end user. The use of this trails analysis process is exemplified by the work in two Kaleidoscope projects.

3.4 Part IV: Special Technologies

The chapters in this part concentrate on three of the many specialist research areas which have developed through Kaleidoscope. They explore how different formulations of technologies can be used within different types of learning scenarios. Computer technology is ubiquitous and the interest in TEL is enormous. Children and young people adopt new technologies quickly for multiple purposes and in very interesting ways. This part highlights research being carried out to exploit this interest

in technology which young people have, first in the chapter by Pratt et al. on how games might be designed and used for learning mathematics in classrooms settings; followed by the chapter by Sharples et al. on the use of hand-held devices which can support learning in a whenever and wherever way; and finally on the ways in which hypermedia and multimedia provide platforms for learning in the chapter by Gerjets and Kirschner. These three chapters build on the need educators have for designing learning environments which entice, challenge, and support young people's learning.

In Chapter 13, Pratt, Winters, Cerulli, and Leemkuil review the literature on the popularity of computer games and the early uses of games in drill and practice learning activities. They argue that there is a need to develop and expand the design of games for learning rather than the more prevalent study of games. The distinction is relevant because as the authors elucidate the more we know and understand about the design of games for the learning of specific educational purposes the better able we will be to develop appropriate games for learning. In this chapter, Pratt et al. focus on a pattern-based approach to explore how design patterns in mathematics can highlight and therefore accentuate solutions and recurring techniques. This is developed in games using the format of "Guess-My-X."

In a completely different arena in Chapter 14 mobile learning is an area which has gained much prominence in recent years. There is much interest in the use of mobile devices to transmit learning materials to and from learners in a variety of situations. Technologies which allow learners to collect and send data collected as part of field trips, or homework, or to communicate with teachers and other experts outside of the classroom are key features of mobile learning. These features blur the boundaries between formal school-based learning and learning in other settings. In this chapter Sharples, Milrad, Arnedillo-Sanchez, and Vavoula draw together the key elements and features of this area of work into a theoretical model and its place within TEL.

In Chapter 15, Gerjets and Kirschner develop the case for links between learning and the technological provision of multiple representations through multi- and hypermedia. This area of work has developed out of research on the psychology of learning and semantic episodic distinctions. Another strand of this work comes from learner autonomy and the way people navigate learning materials. In this chapter, the authors remind us of some of the early psychological bases for understanding how people learn using multimedia. They then present work on the use of hypermedia and multimedia for learning and related to educational versus experimental research.

3.5 Part V: Postface

The postface of this book takes up two basic themes that cross through all of the chapters and that influence developments in TEL. The first one concerns the computer science perspective. In the part on special technologies we have already

seen how new computer technologies find their way to TEL environments and how this influences the way we think about learning and instruction. There is always a criticism that TEL developments are too often “technology-driven” but if taken with care and supported by dedicated research, developments in computer science may certainly help to create effective new TEL approaches. It is here where the second theme in the postface comes up which is the implementation perspective. TEL environments in the end have to function in real learning situations, and the constraints that these render have to play a role in the design of TEL environments. It is not only constraints, however, that come from the implementation perspective but also inspirational views on new ways of learning and teaching. When a balanced influence of both the computer science and implementation perspective play a role in the design of TEL environments this may lay the basis for real innovations that are actually used in practice.

In Chapter 16 on the computer science perspective, Tchounikine, Mørch, and Bannon emphasize that the development of new computer technologies (e.g., Web 2.0 and data mining techniques) is just one of three ways in which computer science influences the TEL field. The second way is the development of models and modeling concepts that guide the design of software, including TEL, environments. New techniques from computer science allow for modeling at higher levels of abstraction that are very suited for TEL design. The third way in which computer science is related to the TEL area is when TEL designs need to be realized in software and this is done by existing techniques (the more engineering approach) or by new techniques (the computer scientist approach) as was evidenced in the research on intelligent tutoring systems. Tchounikine et al. further point to differences in levels of conceptual granularity and differences in evaluation standards that may hinder fruitful collaboration between education and computer science and plea for the search for new approaches to bridge these gaps.

Laurillard, Oliver, Wasson, and Hoppe, in Chapter 17, take up the issue of the development of new skills that society requires and how technology can help to encourage the acquisition of these new skills. Bringing these new developments to the classroom requires a thorough analysis of how the educational system functions and which characteristics hamper or facilitate changes. Laurillard et al. envisage implementation as a research endeavor in its own right in which co-development (by teachers, researchers, and developers) may play a pivotal role. As was also signaled by Tchounikine et al. when it concerns the communication between computer and educational scientists, Laurillard et al. warn of miscommunications between the different actors that may occur in co-development and list a few characteristics of TEL that may obstruct implementation. These include differences in goals between TEL researchers and practitioners, the “disruptive” character of TEL in the sense that it requires changes of current practices and changes in skills of teachers, and the need for new assessment approaches. All these factors may hinder the adoption of TEL in school practice. The authors, however, also see potential for TEL to act as a catalyst for fundamental changes in education if necessary supportive conditions, such as a systemic instead of a fragmentary approach, are fulfilled.

Both chapters in the postface present many leads to chapters in the other parts to indicate where trends they have signaled from their own perspective can be recognized in more specific developments.

4 Acknowledgements

This book is conceived as the “legacy” of the Kaleidoscope Network of Excellence. All authors have played a pivotal role in this network and the chapters reflect their commonly developed expertise.

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Part I
Learning Principles

Chapter 1

The Evolution of Research on Computer-Supported Collaborative Learning

From Design to Orchestration

Pierre Dillenbourg, Sanna Järvelä and Frank Fischer

Abstract This chapter summarizes two decades of research on computer-supported collaborative learning (CSCL). We first review the key idea that has emerged, namely the fact that collaboration among peers can be “designed”, that is, directly or indirectly shaped by the CSCL environment. Second, we stress the fact that affective and motivational aspects that influence collaborative learning have been neglected by experimental CSCL researchers. Finally, we point out the emergence of a new trend or new challenge: integration of CSCL activities into larger pedagogical scenarios that include multiple activities and must be orchestrated in real time by the teacher.

Keywords Learning technologies · Collaborative learning · Collaboration scripts · Technology-enhanced learning · Shared knowledge · Motivation · Self-regulation

1.1 Introduction

Collaborative learning describes a variety of educational practices in which interactions among peers constitute the most important factor in learning, although without excluding other factors such as the learning material and interactions with teachers. The term “computer-supported” refers not only to connecting remote students but also to using technologies to shape face-to-face interactions. Collaborative learning is used across all age levels of formal schooling, from children doing handicrafts together to teams of university students carrying out a project. In lifelong education, collaborative learning is a key paradigm in informal learning (e.g. sharing

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knowledge among communities of practices) but has been somewhat underutilized in corporate training.

The evolution of research on computer-supported collaborative learning (CSCL) can be depicted as being divided into three ages (Dillenbourg & Fischer, 2007). In the first age (1990–1995), CSCL emerges after the neglect of collaborative learning in educational technology for more than 20 years. These first years led to the understanding (1) that collaborative learning results from the effort necessary for co-construction of a shared understanding of the field and (2) that productive social interactions can be engineered by careful design of CSCL environments. The second age (1995–2005) is characterized by the growth of a scientific community (it acquired its own conference cycle, book series, society and journal). This community developed some engineering expertise for the whole life cycle of social interactions: the design of environments and activities, their real-time analysis and their later utilization by the environment. The third age (since 2005) will probably be characterized by the disappearance of CSCL as a distinct pedagogical approach. Instead, collaborative activities are becoming integrated within comprehensive environments that include non-collaborative activities stretching over the digital and physical spaces and in which the teacher orchestrates multiple activities with multiple tools. We set these three ages at 5, 10 and 15 years, respectively, but of course there are no clear-cut ends or beginnings.

The second section of this chapter summarizes the ideas that emerged in the first and second ages. CSCL actually covers a broad range of scales. For instance, on the “small-scale” end of the continuum we find studies of a group of two students working for 30 minutes in a rich synchronous environment. CSCL is not restricted to online remote collaboration and includes many studies of collaboration among students sitting in front of the same computer. On the “large-scale” end, we find studies of a community of several thousand members who interact asynchronously online over several years to develop a piece of software or an encyclopedia, for instance. Naturally, sociocognitive theories of learning have had more influence on the small-scale end while sociocultural theories have been more present at the other end of the scale. At the methodological level, quantitative experimental methods were more often used in research on small-scale CSCL while qualitative ethnographic methods were applied at the large-scale end. However, this distinction is not clear-cut, as understanding how peers co-construct meaning is a challenge that pervades all levels. Many studies combine quantitative and qualitative methods. While this chapter is slanted towards the small-scale end, another chapter in this book leans more towards the large-scale end (Chapter 3).

The third section of this chapter reviews a whole dimension of collaborative learning that has been neglected in CSCL, namely the affective and the motivational factors.

The fourth section describes the third age of CSCL with the shift in focus towards the integration of CSCL activities into more comprehensive pedagogical activities. This section also sets up some research issues for future work in this community.

This chapter reviews contributions from the whole CSCL community, in which the Kaleidoscope Network of Excellence members have been very active, but does not discriminate their specific contribution.

1.2 CSCL in a Nutshell

The field of CSCL produced a complex set of models, ideas and results that we artificially divide into 11 points for the sake of clarity.

1. *More interaction balances out less individualization.* Nowadays, group learning with computers is so widespread that one can hardly imagine that this was not the case a few years ago. Actually, following the introduction of computers in education, the key educational principle was rather the adaptation of instruction to individual needs. Nonetheless, it appeared that when we did have to put two children in front of a computer, the results were actually positive: the imperfect individualization was compensated for by the benefits of social interactions (Dickson & Vereen, 1983). The focus moved progressively from learner–system interactions to social interactions. The emergence of CSCL reflects both the evolution of learning theories, namely situated and distributed cognition (see point 2), and also technological evolution. Nowadays, almost any laptop comes by default with three built-in networking possibilities (LAN, WiFi and Bluetooth). We live in a networked world. The notion of adaptation to users is still of interest for CSCL research but is applied nowadays to a variety of group situations.
2. *There is an illusion of convergence.* CSCL practices lie at the crossroads of two different perspectives. From an instructional and educational psychology perspective, activities that foster social interactions are methods by which individuals construct knowledge. Within a sociocultural perspective, social interaction is more than a method, it is the essence of cognition and hence the goal of learning. These approaches may be compatible at the practical level but induce confusion at the theoretical level: one may develop collaborative learning methods for enhancing individual learning without necessarily viewing cognition as a social process. More precisely, some scholars in CSCL consider social cognition as an extension of individual cognition, as in Perkins' concept of person-plus, while pure sociocultural scholars view cognition as intrinsically social and thinking as a dialogic activity (Wegerif, 2007). While both perspectives have been represented within Kaleidoscope, the authors of this synthesis are closer to the instructional than to the sociocultural pole, while the opposite is true for Sutherland et al. (Chapter 3).
3. *The formal/informal border is blurred.* One specific feature of CSCL has been its relevance for both formal and informal learning, without separating these two worlds hermetically. Empirical studies investigated not only informal learning that emerges in communities of practice but also attempts to transfer

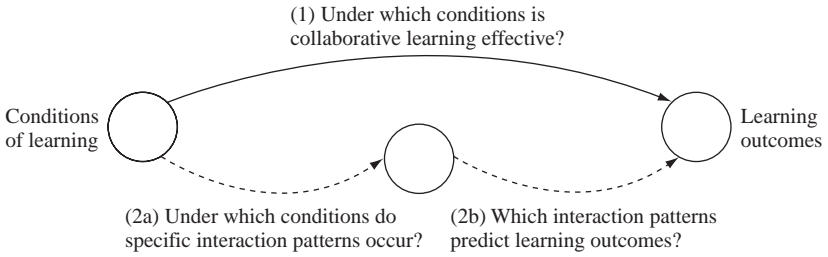


Fig. 1.1 Research questions in CSCL

successful practices into classrooms, by transforming schools into learning communities (Bielaczyc & Collins, 1999; Scardamalia & Bereiter, 1994).

4. *Collaborative learning is not a recipe.* A majority of empirical studies show a significant advantage for collaborative over individual learning but other studies report no significant difference or even negative effects (Johnson & Johnson, 1999). Collaboration per se does not produce learning outcomes; its results depend upon the extent to which groups actually engage in productive interactions. As illustrated in Fig. 1.1, CSCL research not only raises the global question “(1) Under which conditions is a CSCL environment effective?” but splits it into two sub-questions: (2a) “Under which conditions do specific interactions occur?” and (2b) “Which interactions are predictive of learning outcomes?” (Dillenbourg, Baker, Blaye, & O’Malley, 1996). All research on learning tries to understand main effects by zooming on process variables but this phenomenon is more salient in CSCL, possibly because social interactions are easier to observe than cognitive process. Three main categories of interactions have been found to facilitate learning: explanation, argumentation/negotiation and mutual regulation. The key consequence is not at the methodology level but at the design level: the purpose of a CSCL environment is not simply to enable collaboration across distance but *to create conditions in which effective group interactions are expected to occur.*
5. *Media effectiveness is a myth.* Each time a new medium enters the educational sphere, it generates over-expectations with respect to its intrinsic effects on learning. The myth of media effectiveness has been less salient within CSCL research, perhaps because CSCL tools have produced very controversial results. The best example is the use of online asynchronous communication tools (forums): positive learning outcomes were found under certain conditions (e.g. Schellens & Valcke, 2005) but in many studies students posted so few messages that no learning could be expected (Hammond, 1999; Goodyear, Jones, Asensio, Hodgson, & Steeples, 2004). Nonetheless, a myth never dies and signs of its survival occur periodically in CSCL when new artefacts (PDAs, mobile phones) or new tools (WIKIS, Blogs, etc.) emerge.
6. *What matters is the effort required to construct shared knowledge.* A key question that has driven CSCL research is the following: How do learners build a shared understanding of the task to be accomplished? Roschelle and

Teasley (1995) defined collaborative learning as the co-construction of shared understanding. Therefore, the CSCL community paid attention to the psycholinguistic concept of “grounding” (Clark & Brennan, 1991) which refers to the mechanisms by which two interlocutors detect whether their partner has understood what they meant and repair eventual misunderstandings. A theoretical gap nonetheless remains, because grounding mechanisms have mostly been studied at the language level while CSCL needs to understand how they bear on the underlying knowledge level. The notion of shared understanding should not be taken simplistically. Peers never build a fully shared understanding. The actual degree of sharedness depends upon the task (this has been called the grounding criterion by Clark & Brennan, 1991). Through phases of convergence, pairs find out new differences of viewpoint that they may need to overcome, and so forth. Although students quickly adapt mutually in interaction, they share surprisingly little knowledge after collaboration (Fischer & Mandl, 2005; Jeong & Chi, 2007). During this cycle of divergence/convergence phases, what matters is not only the final result but also the intensity of the interactions required for detecting and repairing misunderstandings, what Schwartz (1995) conceptualized as the effort towards shared understanding. CSCL methods, such as the JIGSAW and ARGUEGRAPH scripts (see Chapter 10), increase the initial divergence among students and hence increase the effort necessary to build a joint solution. CSCL environments combine convergence and divergence functionalities such as providing learners with both shared graphical representations and the visual identification of individual contributions or viewpoints (namely in so-called awareness tools).

7. *A greater resemblance to face-to-face interactions is not necessarily better.* The imitation bias (Hollan & Stornetta, 1992) is the belief that the more a medium resembles face-to-face interactions, the better. As a corollary, media richness is erroneously considered to predict effectiveness, despite empirical counter-evidence. For instance, video-supported collaborative work is not necessarily better than audio-only situations (Anderson, Smallwood, MacDonald, Mullin, Fleming, & O’Malley, 2000; Fussell, Kraut, & Siegel, 2000; Olson, Olson, & Meader, 1995). The consequence of this myth is not simply that it generates unfounded expectations, but also that it leads to the neglect of some technology benefits. The CSCL question is no longer “how to compensate for not being face-to-face” but rather “how technology can fulfil collaborative functionalities that are not available in face-to-face situations”, for instance by maintaining links between the verbal utterances in a chat and the graphical object referred to in a shared space (Haake, 2006). These new features apply both to computer-mediated communication (making it different from face-to-face) and also for “augmenting” face-to-face collaboration (Dillenbourg, 2005) in the same sense as “augmented reality”.
8. *Task representations mediate verbal interactions.* Should the design of educational software be different if we know there will be two users in front of the machine? Early insights came from the previously reported work of Roschelle and Teasley (1995) based on a physics microworld that was “designed for

conversations”. Another prominent example is the graphical argumentation tool Belvedere that provides students with some argumentation grammar (Suthers, Weiner, Connelly, & Paolucci, 1995). The way representations shape social interaction is referred to by Suthers and Hundhausen (2003) as “representational guidance”. As postulated for various cognitive tools (Kuutti & Kaptelinin, 1997), these representations not only shape social interactions but, if they get internalized, also shape the way students reason about the domain.

9. *Structuring communication is a subtle compromise.* Semi-structured communication tools are tools that aim to scaffold productive interactions by making them easier: for instance, “sentence openers” such as “Please explain why. . .?” are intended to trigger productive interactions (see point 3). The idea behind these tools is “flexible structuring”, which means that students have the freedom to use or not use the available communicative widgets. The effects of these tools on learning outcomes are rather poor (e.g. Baker & Lund, 1997) compared to somewhat more proactive conversation micro-scripts. For instance, a micro-script will prompt a student to provide counter-evidence to her peer’s previous statement (Weinberger, Ertl, Fischer, & Mandl, 2005). We call them micro-scripts to discriminate them from pedagogical methods, called collaboration scripts or macro-scripts (O’Donnell & Dansereau, 1992): these are pedagogical scenarios that structure collaboration by defining a sequence of activities and assigning roles to individual learners. While micro-scripts stimulate and scaffold argumentation with prompts, macro-scripts may, for instance, collect opinions of students (online) and automatically pair students with conflicting opinions (Dillenbourg & Jermann, 2007). The triangular relationship depicted in Fig. 1.1 is used here for reverse engineering: a script scaffolds the emergence of interaction patterns (2a) which have been shown (2b) to predict the cognitive outcomes of collaborative learning. For both micro- and macro-scripts, the right level of scaffolding is a subtle compromise between the need for structuring and the risk of over-scripting (Dillenbourg, 2002). Depending on the learners’ internal (cognitive) scripts regarding to how to communicate and collaborate effectively in a learning situation, external (instructional) scripts can allow more or fewer degrees of freedom (Kollar, Fischer, & Hesse, 2006). The effects of scripts are further developed in another chapter in this volume (Chapter 10).
10. *Interaction analysis can be partly automated.* Because verbal interactions are the key to collaborative learning, the analysis of interactions is at the heart of CSCL. The degree of processing of these interactions varies from mirroring to guiding (Jermann, Soller, & Muhlenbrock, 2001). Mirroring simply consists of providing the learners with a visualization of their interactions. Social interactions constitute a new raw substance from which designers may create various forms of functional or artistic representations: for instance, the Sputnik environment displays the ratio of actions and dialogues for each peer and for the pair while the “Reflect table” embeds a matrix of LEDs that displays the conversation patterns around the table (Dillenbourg, 2005). More complex analyses enable CSCL environments to provide feedback to groups or even to

suggest changes regarding their teamwork. There is a growing body of research on interaction analysis methods relying on natural language processing that are useful for feedback and for adapting instructional support (Rosé, Wang, Arguello, Stegmann, Weinberger, & Fischer, 2008). Some recently developed tools can be used to analyse arguments and counter-arguments in online discussions after training (Rosé et al., 2008) and thus provide a basis for adjusting the script support provided by the system.

11. *There is a shift from personal to interpersonal computers.* As collaborative software should be different from the multi-user version of software designed for individuals (see point 8), hardware for collaboration might also differ from computers built for individual use. There is an evolution from the well-named “personal” computer to interpersonal computers (Kaplan et al., 2009), that is, artefacts that are designed for use by several users. These artefacts include multi-input devices (e.g. computers with two mice), tangible objects (Ullmer & Ishii, 2000) and roomware (Prante, Streit, & Tandler, 2004), that is, a variety of tools falling under the umbrella of “disappearing computer” (Russell, Streit, & Winograd, 2005) or “ubiquitous computing” (Weiser, 1993). While the concept of a CSCL environment for several years concerned some virtual collaborative space, the technological evolution mentioned in the previous point brings back the physical world. There has been intensive research in the last decade on two axes. The first axis includes “phidgets” and “tangibles” (i.e. peripherals such as a brush, a sandbox) that enable more physical experience than the traditional mouse and keyboard (Greenberg & Fitchett, 2001; Ishii & Ullmer, 1997), as well as work on wearables and roomware. The second axis concerns the work on location-based technologies, such as mobile devices (phones, PDA), that can locate themselves in space (based on GPS, WiFi triangulation, RFID tags, etc.) and hence afford specific collaboration processes (Nova, Girardin, & Dillenbourg, 2005). While CSCL originated with the notion of virtual collaborative worlds, this highlights that CSCL is becoming *less virtual and more physical*.

In summary, a CSCL environment is not simply a tool to support communication among remote students but a tool used in both co-presence and distance settings for shaping verbal interactions in several ways (graphical representation, sentence openers, micro-scripts, macro-scripts, etc.) and for capturing, analyzing and mirroring these interactions in real time.

1.3 Affective Issues in CSCL: The Neglected Aspect of Motivation

Research on motivation and self-regulation has traditionally focused on an individual perspective, but there is increasing interest in considering these processes at the social level. Theoretical extensions of mainstream motivational constructs, such as achievement goals or social goals, have emerged out of empirical work carried out in dynamic and collaborative learning environments characterized by new

opportunities for social and interactive activities (e.g. Järvelä, Volet, & Järvenoja, 2007; Summers, 2006) as well as in self-regulation with reference to concepts such as social regulation, shared regulation or co-regulation (Hadwin, Oshige, Gress, & Winne, in press).

Recent studies have described the kind of emotional and motivational experiences students have during computer-supported learning projects and have indicated that students with different socioemotional orientations interpret these novel instructional designs in ways which lead to different actual behaviours (Hickey, Moore, & Pellegrino, 2001; Järvenoja & Järvelä, 2005). These emotional and motivational experiences can also include negative affect and low motivation. Some CSCL environments may interfere with students' willingness to engage. For example, computer-based learning may create frustration or negative attributions about one's competence. Students need to adjust to a new relationship with the teacher, who becomes a facilitator rather than the primary source of information (Blumenfeld, Kempler, & Krajcik, 2006). Moreover, CSCL students must be committed to collaboration, which may cause socioemotional problems if the group dynamic is not functional (Salomon & Globerson, 1989). In CSCL to date, there is limited research on motivation and self-regulated learning, but the concern for motivational aspects is rising. Researchers in the field of self-regulated learning frame motivation from multiple conceptual perspectives. Sociocultural and situated cognition theories (Anderson, Greeno, Reder, & Simon, 2000) recognized that individual motivation is also affected by social values and the context in which the learning takes place. Motivation is no longer a separate variable or a distinct factor, which can be applied to explain an individual's readiness to act or learn – but reflects the social and cultural environment (Järvelä & Volet, 2004). Hence, CSCL research should investigate motivation in new pedagogical cultures and new learning environments (e.g. Järvelä & Niemivirta, 2001).

CSCL's focus on cognitive aspects of collaboration has already been extended to include social, affective and motivational issues (Jones & Isroff, 2005). Empirical studies have shown that while members of a group may co-operate, the group itself, as a social entity, does not always reach mutually shared cognitive and social processes of collaboration. For example, Järvelä and Häkkinen (2002) analysed an asynchronous virtual pre-service teacher education course and noticed that lack of reciprocal understanding between the interacting students contributed to the low quality of the discussions. Learning through collaboration is not something that just takes place whenever learners come together. In any joint venture, team members must be committed to ongoing negotiation and continuous update and review of progress and achievement. This involves both cognitive and motivational engagement. Social learning environments are expected to rely on smooth interactions between individuals, but at times group processes interfere with individual learning processes. Students who are required to form a group for a learning activity are expected to develop a shared goal for the joint activity (Roschelle and Teasley, 1995). Engaging in a collaborative venture means entering into an interpersonal exchange in which sustained investment in constructing shared meaning of the task is essential. Yet, in order to develop a shared meaning of the task, members of the group must commit themselves fully to the shared

activity (Resnick, 1991). True collaboration with shared understanding in this sense is difficult. Conflicting views may emerge and challenge motivational and affective processes. Motivation and emotion regulation processes within socially challenging learning activities are therefore situated, social, interactive, dynamic and reciprocal in nature (Järvelä, Volet, & Järvenoja, 2007). If group members are willing to invest their energy in shared regulation processes, then they become more closely attuned to the opportunities associated with the experience of shared understandings (Crook, 2000).

Several studies have shown how different elements, such as lack of common ground in shared problem-solving (Mäkitalo, Häkkinen, Järvelä, & Leinonen, 2002) or multiple cognitive perspectives and complex concepts (Feltovich, Spiro, Coulson, & Feltovich, 1996), can inhibit collaborative knowledge construction. These situations are also often socioemotionally challenging and such challenges can act as obstacles to motivated action. The regulation of motivation and emotion at both the individual and group levels is critical for successful collaboration. Socioemotional appraisals can compete with goal-oriented action at different phases of the learning process. Hence, the regulation of emotions and motivation is needed on a continual basis until task completion (Boekaerts & Corno, 2005; Järvenoja & Järvelä, 2005).

As widely documented in the educational literature, groups can face multiple types of social challenges (e.g. Salomon & Globerson, 1989). These can range from perceived incompatibility of personality characteristics to emerging problems in social relationships. During a group activity, group members can face challenges due to differences in their respective goals, priorities and expectations or conflicts generated by interpersonal dynamics, such as different styles of working or communicating, the tendency for some individuals to rely on others to do their share of the work and power relationships among members (Blumenfeld, Marx, Soloway, & Krajcik, 1996; Burdett, 2003; Webb & Palincsar, 1996). Groups that are culturally diverse often face further challenges due to more substantial differences in personal background characteristics. These can include language and preferred communication style as well as prior cultural–educational experiences which makes students feel unprepared to break out of their comfort zone and interact with less familiar peers (Volet & Karabenick, 2006).

Because detailed motivational analyses are still rare in CSCL it is difficult to specify the exact motivational challenges of CSCL. Obviously, the social challenges of CSCL already identified, such as group dynamics, contribute also to students' motivation (e.g. goals, interest, emotion control) and may partly explain low engagement in CSCL. Forthcoming analyses of social processes of motivation as well as co- and shared regulation processes in CSCL (e.g. Hadwin et al., in press) will reveal more about potentials of CSCL with respect to students' motivation, for example, in terms of opening up new opportunities for sharing goals and regulating their achievement.

Effective CSCL can be considered from a self-regulated learning research perspective. Self-regulated learning is a theory which explains effective learners' cognitive and motivational engagement. Self-regulated learners take charge of their own learning by choosing and setting goals using individual strategies in order to monitor, regulate and control different aspects which influence the learning process

and evaluating their actions (Boekaerts, Pintrich, & Zeidner, 2000). CSCL models (e.g. Singer, Marx, Krajick, & Chambers, 2000; Hakkarainen, Lipponen, & Järvelä, 2002) afford opportunities for students to engage in self-regulated learning that include encouraging students to set their own goals, emphasizing collaboration and negotiation and providing scaffolding during learning. The results of these studies have provided evidence that CSCL may create more challenging learning situations for students.

Researchers on self-regulated learning explore technologies to help students develop better learning strategies and regulate their individual and collaborative learning process as well as scaffolding their motivation and engagement (e.g. Hadwin, Winne, & Nesbit, 2005). The potential of these tools is not fully applied currently in CSCL but synergy can be seen between motivation and self-regulated learning theories, collaborative learning and instructional design, which no doubt will advance the CSCL field. Self-regulated learning tools are intended to promote motivated learning from the individual learning standpoint as well as social and interactive learning (Azevedo, 2005). Recent studies have put effort into designing computer-based scaffolds for self-regulated learning (Azevedo & Hadwin, 2005). For example, in a study within an online scientific inquiry learning environment, Manlove, Lazonder and de Jong (2005) examined the effect on students' model quality of a tool designed to support planning and monitoring. The results showed a significant correlation between planning and model quality. Winne and his colleagues (2006) have developed the gStudy software, integrated in the Learning Kit environment, which helps learners learn more effectively by enhancing self-regulated learning. The environment gathers detailed process data on students' actions that are displayed to students to enhance their awareness of their learning process. Tools in the Learning Kit are aimed at helping learners develop learning motivation and new tactics for managing individual and collaborative activities.

1.4 The Challenge of Orchestration

As technologies are becoming ubiquitous, the boundary between computer-supported collaboration and other forms of collaboration is vanishing. CSCL activities occur within broader learning environments, where they are integrated with activities occurring at various social levels (e.g. individual, group, class), across different contexts (classroom, home, laboratory, field trips, etc.) and media (with or without computers, video, etc.). Fischer and Dillenbourg (2006) spoke of "orchestration" as the process of productively coordinating supportive interventions across multiple learning activities occurring at multiple social levels. The orchestration refers to two types of interplay, the interplay between different activities (e.g. how individual work is integrated in team work) but also, within the same activity, the interplay of individual affective or cognitive processes on the one hand and social processes on the other. In other words, orchestration covers different forms of coordination:

1. *Orchestrating activities at different social planes.* The so-called macro scripts (see Chapter 10) integrate activities occurring at different social levels by implementing a “workflow”, that is, a flow of data between activities. For instance, the answers produced individually in a given activity are used for forming groups in a subsequent activity and the results of this group activity are then compiled to support the teacher debriefing session (Dillenbourg & Fischer, 2007). In this case, the bureaucratic work of orchestration is off-loaded to the system, which lets the teacher devote more attention to other aspects of orchestration, such as monitoring individual or group activities, adapting deadlines or workload.
2. *Orchestrating scaffolds at different social planes.* Tabak (2004) suggested the term synergistic scaffolding to address the design of integrated sets of coordinated and supporting interventions at different levels. Scaffolding comes from many sources in a regular classroom setting: the teacher, the software, the learning material, peers. These scaffolds might develop synergies when they are part of an effective overall strategy. Conversely, if the scaffolds are not orchestrated appropriately, the potential synergy will not be realized. Even worse, scaffolds on different social planes and from different sources can interact negatively. For example, the scaffolding done by the teacher during whole class sessions might work against group scaffolding by a CSCL script. Approaches to the orchestration of scaffolding on different planes and from different sources in integrated environments are still quite general and have only just begun to stimulate more rigorous empirical research.
3. *Orchestrating self-regulation and external regulation.* Technology-supported learning groups with an appropriate level of instructional guidance are more successful than groups without this guidance (Kirschner, Sweller, & Clark, 2006). Although this statement seems quite agreed upon, it is not clear how to determine the appropriateness of guidance. In their scripting approach, Kollar, Fischer, and Slotta (2007) suggested a distributed cognition framework in which this issue has been framed as the interplay of internal (cognitive) and external (instructional) collaboration scripts. The basic idea is that in any given collaborative learning situation, learning processes and outcomes depend critically on the availability of appropriate regulatory information (see Chapter 10).
4. *Orchestrating individual motivation and social processes.* In Section 1.3, we stressed the need to broaden CSCL research to include affective and motivational issues. Successful engagement in CSCL presumes norms that allow members to feel safe, take risks and share ideas. There is not yet much research how these individual, affective issues interact with the social processes. In a collaborative learning situation, an individual group member can play a leading role in activating motivation regulation (Järvenoja & Järvelä, 2005). Socially shared learning tasks may also stimulate new strategies for motivation regulation (Järvelä, Järvenoja, & Veermans, 2007), as well as collaborative knowledge construction and joint metacognitive regulation (Hurme, Merenluoto, Salonen, & Järvelä, 2007). Theory and practice for CSCL would benefit from a higher synergy between motivation, self-regulated learning and collaborative learning research.

5. *Orchestration requires adaptivity or flexibility.* How to fade the external scaffolding in and out is currently a “hot” research topic (see Pea, 2004; Wecker & Fischer, 2007). If, for example, a script is intended to be internalized, the degree of external scaffolding should progressively decrease until it disappears. Tuning the degree of scaffolding can be done by the teacher or by the CSCL environment. Adaptation by the system requires automatic interaction analysis (Dönmez, Rosé, Stegmann, Weinberger, & Fischer, 2005) to model the current internal scripts of the participants and hence adapt the amount of external guidance. Adaptation by the teacher requires providing him or her both with information on the group process and with functionalities for increasing or decreasing the amount of scaffolding during classroom runs. This means that scripting environments must embed tools for visualizing online interactions or even propose diagnostics and let teachers change the CSCL environment in real time. Dillenbourg and Tchounikine (2007) reviewed the different parameters that teachers should be allowed to modify when they execute scripts.
6. *The teacher conducts the orchestration.* In technology-enhanced learning, the slogan “from the sage on the stage to the guide on the side” became commonplace to stress the evolution of the teacher’s role. This vision was even stronger in CSCL because the idea that students learn from each other in some way weakens the teacher’s role as knowledge provider. However, most CSCL scholars would agree that socioconstructivism does not mean “teacherless” learning, but changes the role of the teacher to be less of a knowledge provider and more of a “conductor” orchestrating a broad range of activities; this role is becoming a central concern in CSCL. It is a key issue for design of CSCL environments, namely with regard to providing teachers with tools to monitor group activities and adapt the environment flexibly. It has become a central issue not only in sociocultural studies but also in the experimental research on CSCL.

Investigating these various forms of orchestration raises several methodological challenges for CSCL research which cannot be elaborated fully here. Among the most important methodological challenges are the following:

1. *How to ensure knowledge accumulation in CSCL orchestration research when concepts and methods become increasingly heterogeneous?* As it is the case for educational research more generally, CSCL research has been suffering from suboptimal knowledge accumulation because researchers do not systematically refer to a set of agreed upon concepts and methods (e.g. Arnseth & Ludvigsen, 2006). Given the call for including rather more heterogeneous concepts from different social planes and potentially from different scientific disciplines, the threat of fostering the problem of low knowledge accumulation is high. Conceptual as well as methodological convergences are among the main desiderata here (Strijbos & Fischer, 2007).
2. *How to conduct basic research given the increasing complexity of interacting factors?* There are different ways to deal with the increased complexity of orchestration research designs. For example, design research approaches typically suggest abandoning the idea of varying one or two variables in a controlled

laboratory or field experiment, given that hundreds of variables still interact uncontrolled in a real classroom setting (e.g. Hoadley, 2004). In contrast, other researchers hold that there are possibilities of disentangling a small number of key variables on different planes (individual, group, class) that might be varied or controlled in multilevel experimental designs (Fischer, Wecker, Schrader, Gerjets, & Hesse, 2005; de Wever, van Keer, Schellens, & Valcke, 2007).

3. *How to create new forms of interaction of CSCL researchers and CSCL practitioners?* Because CSCL research concerns real educational contexts, it increasingly involves teachers as well as other practitioners. Realistically speaking, many forms of practitioner's involvement in the research process and scientists' involvement in the process of learning environment design are impracticable (e.g. Pellegrino & Goldman, 2002). We suggest that a primary task of orchestration research might turn out to be identification, design and implementation of appropriate forms of interactional "scripts" for researchers, designers and/or teachers (Bauer & Fischer, 2007).

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Chapter 2

Developments in Inquiry Learning

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Abstract This chapter presents the current state of the art on technologically supported inquiry learning. The learning processes involved in inquiry learning are briefly presented, as well as an outline of typical inquiry learning environments as consisting of a mission, a source of inquiry and tools for expressing knowledge along with cognitive scaffolds for supporting the inquiry process. The second part of the chapter discusses future technological developments and their consequences. The main foreseeable developments are architectures for component-based development as well as the use of ontologies and repositories of emerging learning objects that are products of learners' inquiry processes.

Keywords Inquiry learning · Ontology · Learning processes · Learning objects

2.1 Introduction

Inquiry-oriented teaching and learning have received attention as part of an effort to bridge the gap between teaching and authentic scientific practices (e.g. Abd-El-Khalick et al., 2004; Anderson, 2002; de Jong, 2006; de Jong & van Joolingen, 1998; Friedler, Nachmias, & Linn, 1990; Klahr & Dunbar, 1988; Krajcik et al., 1998; Kuhn, Black, Keselman, & Kaplan, 2000; Sandoval & Reiser, 2004; White & Frederiksen, 1998). At first glance, inquiry learning seems to have a twofold nature that can be described by “inquiry as means” and “inquiry as ends”, respectively. The first of these would be related to inquiry as an instructional approach or pedagogy whereas the second would see inquiry as a set of instructional outcomes for students that involve abilities to do inquiry and understanding about inquiry (Olson & Loucks-Horsley, 2000; for a detailed discussion, see Abd-El-Khalick et al., 2004). It should be stressed that despite this apparent distinction inquiry learning should not be treated as representing two different modes of learning. One aspect of inquiry always requires the other: without inquiry skills,

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learners will not learn from inquiry and, conversely, inquiry cannot be done in the abstract; a domain is always needed as a practice arena for inquiry skills. Despite some variation in the definition of what actually constitutes inquiry learning (e.g. Anderson, 2002; de Jong & van Joolingen, 1998; Friedler, Nachmias, & Linn, 1990; Klahr & Dunbar, 1988; Kuhn et al., 2000; Sandoval & Reiser, 2004), there is a fair consensus about which processes basically comprise inquiry (de Jong, 2006). Although different classifications of inquiry processes do exist, the differences are mainly in their granularity (de Jong, 2006), ranging from very detailed to rather broad, and not in the processes that are distinguished.

In this chapter we adopt the de Jong (2006) classification which distinguishes the following inquiry processes: *orientation*, in which the learner makes a broad analysis of the domain; *hypothesis generation*, in which specific statements about the domain are chosen for consideration; *experimentation*, in which a test to investigate the validity of this hypothesis or model is designed and performed, predictions are made and outcomes of the experiments are interpreted; and finally *conclusion*, in which a conclusion about the validity of the hypothesis is drawn or new ideas are formed. Although these processes are presented here in a specific and more or less logical sequence, it should be stressed that learners and also experts carry out these processes in different and varying orders and combinations. For instance, a learner can first perform an experiment to get an idea of what the main concepts and relations in the domain are and then proceed with the orientation or hypothesis generation process.

Figure 2.1 displays the decomposition of inquiry processes according to de Jong (2006), as well as a *possible* deeper decomposition. The latter may depend on the context, that is, the actual nature of the domain and the inquiry task. Presenting the decomposition as a hierarchy rather than a cycle emphasises its non-linear nature.

Within the framework of inquiry learning, students are seen as responsible for their own learning, which can take place if they construct new understanding drawing on the data/information they collected through experiments and connections with prior experience. The students are offered the possibility of regulating their own learning by taking initiatives during the actual learning process and by adapting the process to their own experience, along with the necessary scaffolding, as needed.

Inquiry and technology-enhanced learning are a good marriage. In particular, computer technologies have become commonplace in the practice and advancement of science. Being integral to scientific practice, computer technology inevitably has become an integral part of inquiry as a teaching and learning approach (Songer, 1998). As computers have become common in the classrooms, a wide array of technologies has been used for education through an inquiry-based approach, including simulations, virtual labs and microworlds (e.g. de Jong & Pieters, 2006; Papaevripidou, Constantinou, & Zacharia, 2007; van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005; Zacharia, 2007); microcomputer-based laboratories (MBLs) (Friedler, Nachmias, & Linn, 1990; Maor & Fraser, 1996; Settlage, 1995); interactive videodiscs, multimedia and hypermedia (Nesbit & Winne, 2003); and telecommunication technologies, including handhelds, e-mail and Internet interfacing, as well as accessing and using web-based databases (Mistler-Jackson &

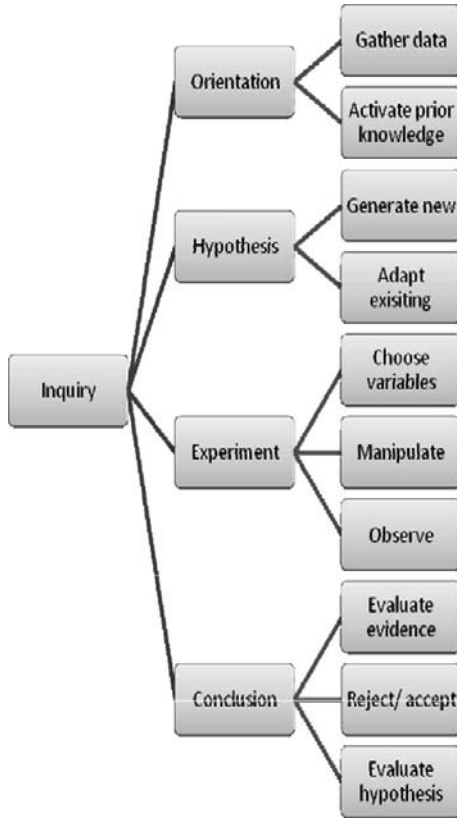


Fig. 2.1 Decomposition of inquiry processes into four main categories, according to de Jong (2006), and subcategories

Songer, 2000; Songer, 1998; Winne, 2001). Recent technology is particularly suited for providing students with state-of-the-art inquiry tasks and at the same time providing them with the necessary support to help them elaborate theories and evidence, as well as with a repository to store intermediate results and knowledge of the domain (Wecker, Kohnle, & Fischer, 2007). Moreover, computer technology can also support and facilitate collaborative approaches to inquiry learning, moving from teacher-centred instruction to student-centred collaborative inquiry (Scardamalia & Bereiter, 1991).

This chapter is organised into two parts. The first part gives an overview of how inquiry learning can be shaped by means of technology. This is done by providing a list of ingredients in a typical inquiry learning environment. The second part discusses the main new developments with respect to computer environments for inquiry learning.

2.2 Ingredients of Inquiry Learning

Rather than focusing on the processes themselves, as has been done elsewhere (de Jong, 2006; de Jong & van Joolingen, 1998), this chapter will focus on the elements in the learning environment that can sustain these processes. These ingredients can be characterised as follows:

- The *mission* of an inquiry activity that defines an incentive and a scenario in order to motivate learners and provide them with a goal for the inquiry activity.
- The *source of information* in an inquiry performance, the possible data resource (e.g. simulations, remote labs, real lab).
- The *tools for expressing knowledge*, to communicate what is learnt (e.g. creating models, writing reports, constructing arguments or explanations).
- The *cognitive and social scaffolds* that enable students to perform processes they would not be able to perform competently without the tools' support.

All four elements are found across inquiry learning practices and can in most cases be considered as necessary ingredients for a meaningful inquiry experience. Each of these ingredients will be discussed below in the context of a full inquiry-based learning environment.

2.2.1 A Mission for Inquiry

The first ingredient that a computer-based inquiry activity draws on is a *mission*, which introduces learners to a domain of knowledge. The purpose of the mission is threefold: (1) it serves as an incentive for the learners to engage in an inquiry activity, (2) it makes learners aware of the parameters (e.g. content, context, variables) of the domain of the inquiry activity and (3) it provides learners with a scenario, making them aware of the goals of the inquiry activity in terms of products to be created and knowledge to be built. The first aspect provides the motivational stimulus that sustains learners' attention and interest, the second aspect provides information about the domain of the inquiry activity and the third provides a framework and an overview of the possible outcomes.

For these aspects to be present and realised, the mission needs to relate productively to the learners' background (e.g. conceptual understanding, skills, culture, language), experience (e.g. prior knowledge, observations from everyday life or laboratory-based experiences) and interests (Sandoval & Reiser, 2004). Failure to associate the mission with the learner's background, experience and interests could lead to deficient engagement or even rejection of the activity by learners (Jonassen & Strobel, 2006). Conversely, in situations where the learners do not identify with the "need" to engage in an inquiry activity, at least one of the above-mentioned aspects (stimulation of interest, awareness of the domain, awareness of the goals) is likely to be missing. A productive option for avoiding disassociation of the mission from the students' background is to involve students in the mission development. This

implies that it is important that the mission be modifiable, that it can be rephrased and even positioned in a new context, while maintaining the original goals.

In terms of learning processes, the mission is mainly associated with orientation, which aims to enable students to explore and analyse the domain at hand. It provides the motivation required for engaging in the orientation process and should provide the links to learners' relevant prior knowledge. Moreover, it establishes an awareness of the parameters of the domain, which are required for several aspects of the orientation process, such as formation of an (initial) idea of the domain, identification of variables and creation of tentative ideas of possible relations between variables (de Jong, 2006). Finally, it makes the learners aware of the goals of the inquiry activity, which is necessary for learners to understand the structure and complexity of the task at hand (e.g. identifying which variable or variables are responsible for an outcome or how a change in the level of one variable causes a change in one or more other variables in the system) (Kuhn et al., 2000).

Examples of computer technologies that build innovative learning environments around this ingredient are STOCHASMOS (Kyza, Michael, & Constantinou, 2007) and WISE (Slotta, 2004). Both of these web-based platforms situate the mission ingredient at the center of any scientifically authentic investigation, thus requiring from learners to pass through the mission stage before engaging in any other inquiry ingredient or process.

2.2.2 A Source of Information for Inquiry

Inquiry can only assume shape if there is something that can serve as the subject of study. This ingredient of a computer-based inquiry activity is a *source of information* that allows learners to extract relevant data that are needed for the process of shaping their growing knowledge. Depending on context there may be many information sources to sustain a single mission.

"Information source" is a very generic description for the multitude of resources that it can represent. It is basically the connection between the inquiry environment and the outside world, or a representation of the outside world. Learners can obtain data from structured, simulated environments through simulations and microworlds, such as those provided by SimQuest (van Joolingen & de Jong, 2003). Learners can collect external data through data collection in the field using handhelds and data loggers. Learners can access data from experimental equipment and sensor networks throughout the world through sensor technologies. Finally, learners can access data from databases of research centres including, for example, data on weather and seismic events.

All information sources have in common that learners can initiate the collection of data by setting parameters, resulting in data in the form of variable values. The way this is done depends strongly on the nature of the information source and can range from entering some values on the computer screen to going outside and collecting data in the field.

The data collected from an information source play a role in two inquiry processes: orientation and experimentation. In the orientation process data are needed to shape one's initial ideas about the domain (Reiser et al., 2001), whereas in the experimentation process, data are needed for testing ideas (hypotheses).

The source of information provides an external input in the course of inquiry that facilitates the transformation from abstract ideas to concrete understanding. Moreover, this information or data are essential for the continuation of the course of inquiry. For example, the learner cannot carry out the conclusion process of inquiry without any information or data because decisions on the validity of the hypotheses cannot be made without evidence.

2.2.3 Tools for Expressing Knowledge

The goal of any inquiry process is knowledge about the domain being investigated and – possibly – about the inquiry endeavour itself. This links inquiry learning to knowledge building approaches (Scardamalia & Bereiter, 1991). This requires that learners, in one way or another, be able to express this knowledge in some external form. The third ingredient of a computer-based inquiry activity is defined as *tools for expressing knowledge*. These tools are related to the hypothesis, experimentation and conclusion processes of inquiry because they provide the means for representing, processing and analysing new data or information. Hypotheses are elements of new knowledge created by learners. Being able to express those using appropriate tools is a valuable support for the knowledge building process. As the information or data gathered through the experimentation process begin to coalesce, learners begin to make connections between their own prior experience and the new information/evidence (conclusion process) and start to synthesise meaning and form knowledge. Finally, learners undertake the creative task of shaping thoughts, ideas and theories and expressing them through tools, in an attempt to communicate with the outside world and to stimulate further inquiry activities. These products can take the shape of a qualitative or quantitative model, a written report, an argument or an explanation.

Research has shown that such tools play a central role in an individual's quest to know and understand the world and to learn, understand and communicate knowledge (de Vries, Lund, & Baker, 2002; van Joolingen et al., 2005; Zacharia, 2005; Zuzovsky & Tamir, 1999). Appropriate tools such as shared workspaces and tools for computer-mediated communication can sustain the idea of shared knowledge building in collaborative settings. In this case knowledge and understanding are co-constructed among peers through complementing and building on each other's ideas (e.g. Wells, 1999). In both collaborative and individual modes, tools offer learners a representation that they can build, modify, exchange and discard as part of a knowledge construction process. Tools can be regarded as a way of constructing and expressing what is learnt from the inquiry process using this representation (tools as means). Systems or phenomena can be presented using these external

representations. Tools and the representations they employ can also be regarded as a way of determining an individual's fundamental understanding of concepts, operational understanding of the nature of science and the ability to employ procedural and reasoning skills (tools as ends) (de Vries et al., 2002; Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 2000; Zacharia, 2005). In this case, understanding is linked to the tools and the representations these tools employ. The final products of these tools can be considered as representational constructs that reflect learners' understanding and skills (Papaevripidou, Constantinou, & Zacharia, 2007).

2.2.4 *Cognitive and Social Scaffolds*

When viewed as a means of learning with a dual goal, learning about a domain and acquiring an inquiry ability, inquiry learning encompasses a paradox in that in order to learn through inquiry, one needs the skills that are acquired through the learning itself. In order to overcome this difficulty, an inquiry environment requires *cognitive and social scaffolds*, which are tools enabling students to perform the inquiry processes they would not be able to perform competently without the tool's support. Cognitive scaffolds may structure a task, take over parts of a task or give hints and supporting information for the task. The ultimate goal is to establish an intellectual partnership between the tool (cognitive scaffold) and the learner (Jonassen, 2000; Salomon, Perkins, & Globerson, 1991). The need for cognitive scaffolds emerged because learners display consistent problems during the processes of inquiry (de Jong, 2006). For example, learners fail to identify the variables involved in a domain or task, generate testable hypotheses, design experiments to test their hypotheses and draw the right conclusion from experiments (van Joolingen et al., 2005). Social scaffolds provide learners with means for coordinating and streamlining collaboration with others, such as tools that map learners' own ideas with those of collaborators or tools that visualise the contribution of each of the collaborators to the knowledge building process. Successful scaffolding requires that participants form shared meanings (Tabak, 2004). This process hinges on issues of authority, expertise, trust and reciprocity engendered through the history of interactions between the participant and the cognitive scaffold. Such dynamics of interaction relate to the participant structures that are at play: the configurations of interactional roles, rights and responsibilities and the conventions of "who can say what, when and how" (e.g. Cazden & Beck, 2003). Therefore, inclusion of more symmetry in learner-cognitive scaffold interactions is key for pedagogical efficacy (Tabak, 2004). For instance, students should assume some of the roles associated with generating and assessing information and with monitoring progress that are typically held by cognitive scaffolds.

Computerised cognitive scaffolding can also be considered as an enabling tool across all of the other inquiry ingredients (mission, sources of information, tools for expressing knowledge). For example, hyperlinks or glossaries were used in several computer technologies (e.g. multimedia, simulations, web-based platforms) to

scaffold the mission of an inquiry activity. In STOCHASMOS (Kyza et al., 2007) a glossary is used to provide further clarification concerning terminology used to describe the mission. The aim is to ensure that the learners are provided with all the information needed to understand the mission in detail.

A number of cognitive scaffolds have also been constructed in order to provide support to a specific inquiry process or a series of inquiry processes (see de Jong, 2006 for an extensive review). For example, the hypothesis scratchpad (van Joolingen & de Jong, 1991) provides scaffolding for the hypothesis generation process. Examples of cognitive scaffolds can be found for every inquiry process: for orientation there are concept maps (Toth, Suthers, & Lesgold, 2002), diagrams (Murray, Woolf, & Marshall, 2004) and models (van Joolingen et al., 2005); for hypothesis generation there is the *hypothesis scratchpad* (van Joolingen & de Jong, 1991); for experimentation there are an *evidence palette* (Lajoie et al., 2001) and *heuristic support including a control of variables strategy* (Veermans, van Joolingen, & de Jong, 2006); for *conclusion*, there are investigation journals (Reiser et al., 2001), *Sensemaker* (Bell & Linn, 2000) and *Explanation Constructor* (Sandoval & Reiser, 2004); and for evaluation there is “*Checking our Understanding*” prompts (Bell & Linn, 2000).

Scaffolds and tools are often related. In the examples listed above many of the scaffolds relate to the production of one or knowledge elements. In such a sense, tool and scaffold are integrated. For instance concept maps can be viewed simultaneously as scaffolds and tools, if the concept map is seen as an expression of knowledge. However, other scaffolds, such as for instance those providing learners with just-in-time information, can be more detached from a tool.

2.2.5 Technological Advances in Inquiry Learning

In the previous section, inquiry learning was characterised as a type of learning in which the processes of scientific inquiry lead to active construction of knowledge by learners, scaffolded by tools that are knowledgeable about these learning processes. So far this has led to a number of landmark systems, such as WISE (Slotta, 2004), ThinkerTools (White, 1993), SimQuest (van Joolingen & de Jong, 2003) and Co-Lab (van Joolingen et al., 2005). These systems and studies that have been performed with them have contributed to the body of knowledge on the implementation and effects of inquiry learning that was described above.

Although many successes have been claimed and published as effects of these systems, there are also drawbacks, both on a conceptual and technological level. The main issue here is that the development and implementation of inquiry learning systems, much like any other technology-enhanced learning (TEL) system, mostly take place within the context of a single research group. As a consequence, the inquiry systems that are currently available each represent a relatively closed world. Typically, an inquiry environment presents learners with the ingredients described above, a *mission*, a *source of inquiry*, *tools for expressing knowledge* and *cognitive*

tools for the inquiry process, all contained within the inquiry environment. The consequence of this situation is that each of the environments approaches the process of inquiry in its own typical way. For instance, WISE provides a strong regulative scaffold in the form of a menu that takes learners through a predefined sequence of activities. Co-Lab offers more freedom as well as access to specific phenomena such as remote laboratories and a modelling tool, but it cannot offer regulative support as strongly as WISE can.

The field is now at a point where the drawbacks of this situation are becoming more and more important. While inquiry learning can be studied within a closed environment from a research point of view, with a major advantage being the full control that the researcher has over this environment, at the level of curriculum implementation technology should be able to support longer term endeavours, moving from inquiry tasks to inquiry-based (science) curricula. After one inquiry experience there should be another, building upon those previous in order to build sustainable inquiry ability for learners.

Questions that require addressing from this viewpoint include the level of inquiry skills that learners need to acquire, the requirements of a modern science curriculum that provides learners with access to actual developments in science and how to integrate inquiry learning with other approaches. The last is important because no curriculum will be “inquiry-only”, just as no modern curriculum will be “lecture-only”. This requires that the products of inquiry learning activities be meaningfully incorporated within the learning environment and be movable from one part or activity to another. Inquiry activities can thus be made an integral and essential part of a science curriculum.

Currently there are no easy ways to integrate inquiry environments such as Co-Lab and WISE smoothly with a curriculum or with each other. For instance, this would mean that when aiming to offer inquiry learning that has some aspects of WISE (such as the strong scaffolding) and some aspects of Co-Lab (such as its modelling tool) integrated into a knowledge building activity (such as supported by KnowledgeForum), nothing can be taken from one environment to the other, and no integrated environment can be created. Data collected or models created in one environment cannot be transferred to the other. This means that there is no natural way to integrate the results of inquiry learning environments into a curriculum. The conceptual approach may also differ between environments. This makes it very hard to support more than one inquiry learning environment within a single curriculum and, at the same time, makes it very hard to integrate inquiry learning with other forms of instruction. In other words, using the existing environments for inquiry learning entails the risk that inquiry will remain an isolated activity within the science curriculum.

The above situation forms the backdrop for the emerging trends in the design of learning environments towards cross-system cooperation and integration. Within this trend we can see two developments: *component-based design* and *learning object ontologies*. Component-based design strives for integration at the system level, meaning that tools or parts of tools can be used and reused in different contexts. Learning object ontologies aim at supporting semantic continuity at the content

level, meaning that the results of inquiry learning will be usable in the context of larger scale curricular contexts, including other learning modes.

2.3 Integration of Multiple Approaches in Component-Based Learning Environments

Component-based design emerged in the 1990s in the field of software design and engineering. Component-based methodologies such as OMT (Rumbaugh, Blaha, Premerlani, Eddy, & Lorensen, 1991) and Catalysis (d'Souza & Wills, 1999) aimed mainly at *reuse* of components. Their main consideration was that in any software development project much of the work went into recreating functionality that already existed in earlier products. The component-based design model allows for the creation of component libraries that offer functionality for specific purposes, ranging from database access and mathematical computations to graphical user interfaces and gaming engines. Component-based design enables the use of such component libraries in multiple contexts, with the advantages that development can proceed faster and that a certain level of consistency is enforced between these contexts. For instance, if a component for displaying graphs is used in different places, the graph will look the same and be operated upon similarly in every context where it is used.

Component-based design evidently has benefits for the design of learning environments in regard to components such as graphs and other user interface components, just as it has for software development in general. An additional advantage within technology-enhanced learning lies in the reuse of educational components. If defined correctly, such reusable components can provide a consistent look and feel as well as a consistent approach to cognitive support throughout multiple learning environments.

A component-based approach to the design of TEL systems can change the role of inquiry learning within the curriculum. Using specific components that allow and/or support inquiry learning processes, such as simulation engines and models, data access tools or modelling tools will enable the integration of inquiry activities within a more comprehensive curriculum. Instead of engaging in a self-enclosed inquiry activity such as offered by WISE, ThinkerTools or Co-Lab, it becomes possible to design environments that combine, for instance, some direct instruction, self-paced online literature study and inquiry activities.

A recent development in component-based design is the Scalable Architecture for Integrated Learning (SAIL) (Slotta & Aleahmad, 2009). SAIL builds on experience from WISE indicating that (1) it became increasingly difficult to maintain or modify WISE as more material was brought into the system and (2) WISE did not allow for the integration of third-party tools or material. SAIL's primary intention is to be able to recreate WISE in a form that allows for flexible maintenance and modification including the integration of new components. SAIL has approached this problem from the bottom up with a design for a complete component-based architecture that consists of the following layers:

- Architecture layer, describing the basic data models and interfaces to which components must conform.
- Framework layer, defining a set of basic components that are necessary in any environment and can be shared, such as data storage, user management and components that arrange the learning settings, such as group or individual work and teacher intervention.
- The environment, which is a coherent collection of framework components to define a coherent working environment for learners.
- The application that runs on top of the environment and is a specific learning activity containing domain-specific elements (images, simulations) to shape the learning process.

For instance, a WISE application on thermodynamics would be a collection of simulations, texts and images that runs within the WISE environment, which is built upon the SAIL framework. Each of the components used conforms to the requirements that are specified in the SAIL architecture.

The strength of this approach is that it allows the building of different environments upon the SAIL framework. For example, it is perfectly possible to build another environment on the same framework. That means that although the environments may differ, a large part of code and approaches will be in common. For instance, both environments may share user management and data models. Exchange of material will also work without problems, so that the same simulation could be used in both Co-Lab and WISE, as long as it conforms to the SAIL specifications.

Such possible approaches change the perspective on inquiry learning. Inquiry learning need no longer be viewed as a self-standing way of learning. Inquiry can rather be regarded as one kind of knowledge creation, along with approaches such as learning by design, learning by collaborative writing and possible others. These various approaches can be linked in various environments and applications, while technical interoperability is ensured by the shared architecture. With respect to the conceptual integration of different approaches, however, we also must consider the semantics of the information that is exchanged between components.

2.3.1 Semantic Interoperability Using Learning Object Ontologies

While component-based design approaches such as SAIL enable the integration of various forms of learning with inquiry, they also have the potential to introduce new problems. Whereas technical integration is ensured by the architecture, opening it up to a multitude of different components, it is by no means guaranteed that there will be any kind of semantic interoperability (Koedinger, Suthers, & Forbus, 1999). Semantic interoperability means that the different tools and other components that are present in an application cooperate in a fluent way. This means that some consistent and sensible set of learning activities are created out of these components, a modelling project including both data gathering activities as well as the use of modelling tools. Semantic interoperability would mean in this case that the results

of one activity (e.g. data gathered) can be used meaningfully within another (e.g. modelling). This would be supported technically by a data interchange interface; semantically, it is also necessary for the meaning of the data to be understood in the same way in both activities.

The key to ensuring semantic interoperability lies in investigating the nature of the activities that is typically combined in creating inquiry-based applications for learning. The common ground of many such approaches is the fact that learning takes place by the creation of knowledge artefacts that represent the developing knowledge of learners, such as the datasets and models that learners create in a modelling application. The meaningful interchange of data between components in a learning application can be supported by accurately describing the kinds of artefacts that learners can create and how they can be interpreted and used.

The Kaleidoscope European Research Team CIEL (collaborative inquiry and experiential learning) has been working on an *ontology of emerging learning objects* (van Joolingen, Bollen, Hoppe, & de Jong, 2007). Such an ontology makes it possible to build semantically interoperable applications for inquiry learning that may include, interoperate with or be part of curricula that include other learning modes as well. Elements of the CIEL ontology currently include concepts such as “hypothesis”, “experiment” and “dataset” for inquiry learning and “argument” and “question” for collaborative learning, along with “plan” and “goal” for describing regulative aspects of the learning process.

Emerging learning objects can support a learning application because they can be passed on from one application component to another. An obvious way to do that is to create a repository that can store these objects and from which they can be retrieved using tools that know how to handle them. Using one tool, learners can collect data and store it in the repository. The data objects can then be searched and retrieved by a dedicated data visualisation tool, for instance. The ontology ensures that the meaning of the objects is maintained over the whole learning process.

2.3.2 Learners Shaping Their Own Learning Environment

The creation of ontologies and repositories for learning objects and processes also allows for a different perspective on the creation of knowledge by learners. Such ontologies’ provision of clear descriptions of the objects learners can create to represent their knowledge allows for indexed storage and exchange of these objects. Repositories of learning objects can then represent the evolving knowledge of individual learners as well as of learner communities. In turn, learning environments can draw upon these repositories in shaping inquiry and other creative activities for learners. In this sense, learners occupy a more prominent role in shaping their own learning environments, by filling them with the results of their own inquiry activities.

This is made possible by the repository of learning objects itself becoming a component in the learning environment. Although the repository itself is a component

like any other, the content of the repository represents knowledge that the learner has created in his or her own learning history. Moreover, the repository can also draw upon learning objects created by other learners. This means that, in contrast to earlier situations, learning environments can base themselves upon an ever increasing body of knowledge, shaped by learners who have interacted with it.

2.3.3 Advanced Forms of Scaffolding with Educational Data Mining

Collecting learner-created objects as well as the traces of the processes leading to their creation also opens options for more advanced ways of scaffolding. Identifying and detecting patterns in learners' actions allow more personalised support. This new development is called educational data mining. Educational data mining gives rise to advanced visualisation of inquiry processes as well as a deeper understanding of the ongoing learning process, leading to fine-tuning of cognitive scaffolds. For instance, Anjewierden, Kollöffel, and Hulshof (2007) demonstrate that by analysing learners' chat messages during a shared inquiry activity, it is possible to automatically distinguish different types of learning processes (regulative versus transformative) and that this classification can be used for providing visual feedback. For the latter they use a drawing of a human figure in which the size of body parts is used as an indicator of the balance between several categories of learning processes.

2.4 Conclusion and Future Outlook

This chapter started out with an introduction into inquiry learning, its processes and ingredients, as well as the technological components that support it. In the second part it became clear that recent technological developments have given rise to the idea that inquiry activities can become part of a form of learning that is based on learners' creation of knowledge artefacts that represent their evolving knowledge. Here the relatively new technology of component-based design and the development of ontologies of emerging learning objects provide the technological driving force towards a changing role of technology-supported inquiry learning in education. This includes changing roles of learners towards being contributors to the learning environment as well as new opportunities for scaffolding the learning process. Data mining and ontology-based repositories are enabling technologies. This entails a number of interesting challenges for future research.

First, the *assessment* of learners becomes a non-trivial problem. As learning environments can grow and the number of pathways learners can take through these environments can be very large, it is a mistake to think that a learner's growing body of knowledge can be assessed by standardised traditional tests. As the learning environment itself also changes under the influence of its use, due to the growing repositories, simple comparison of learners' performance with set norms

is not possible. Instead the quest must be for a means of adaptive testing that not only takes into account a learner's *end state* of knowledge but also considers the starting point of both the learner and the learning environment. Assessment based on portfolio, as well as performance-based assessment, can provide a good starting point. Repositories of learning objects themselves can actually be used to support the creation and maintenance of portfolios.

Second, the emergence of data mining techniques creates an opportunity. As more interesting relations can be found if the amount of data mined is large, a challenge for the research community is to build large corpora of data on inquiry learning processes, consisting of log files and learning objects produced. Open standards for log file storage and learning objects should make this possible.

Finally, the component-based approach is readily suitable as an *open-source* endeavour. SAIL (Slotta & Aleahmad, 2009) stresses the importance of this approach and includes a community concept in its approach, in which participants can exchange material and components. Such a community, in combination with emerging standards, will provide the opportunity for boosting TEL-based inquiry learning in the near future.

Although we started by describing inquiry learning as a self-standing way of learning that can be supported by technology that provides the proper ingredients, the current chapter ends by foreseeing the merging of inquiry learning into modern curricula, where inquiry is only one component, but an important component, of a range of learning modes that can be applied, depending on domain and context. Technical and semantic interoperability will allow for this mix and, more important, for inquiry to become an integral part of curricula rather than a separated occasional activity.

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Chapter 3

Sociocultural Perspectives on Technology-Enhanced Learning and Knowing

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Abstract During the last decades the sociocultural approach to studying learning and knowing has been raised as an alternative to more cognitive approaches to become a vivid research tradition with many branches. Sociocultural theorizing and thinking have played an important part in contemporary educational research and educational psychological research in general and also in the research area of technology-enhanced learning (TEL). This is witnessed by the content of the handbooks in the field (see for example, *Handbook of Educational Psychology* (Alexander & Winne, 2006) and *Handbook of Research on Educational Communications and Technology* (Jonassen, 2004)). This chapter aims to provide an outline of foundational ideas in sociocultural theorizing about human learning and knowing, summarizing some key sociocultural studies on TEL and illustrating key ideas with examples of empirical research.

Keywords Sociocultural · Learning · ICT · Education · Workplace

3.1 Foundational Ideas

The label sociocultural does not stand for a unified theory but rather a framework encompassing a range of theoretical accounts of learning and knowing. This is reflected in the labels that are used: sociocultural, socioconstructive, sociohistorical, cultural–historical, situated cognition and so on. The history of the sociocultural tradition has been documented in depth elsewhere (cf. Martin, 2006). Here we will only point out that sociocultural approaches have academic roots in a number of disciplines (such as psychology, pedagogy, sociology, anthropology and philosophy) and have developed at the crossroad of micro-, meso- and macro-approaches to human conduct.

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The sociocultural perspective is predicated on the view that humans as learning, knowing, reasoning, feeling subjects are *situated in social and cultural practices*. *Participation* in these practices provides the fundamental mechanism for learning and knowing. Furthermore, human conduct, activity and practices must be understood as *products of history*. Also, artefacts and tools are fundamental mediators of this history. This perspective of learning and knowing gained momentum in the 1970s and 1980s partly in reaction to and as an alternative to cognitivist and constructivist theories that assume that humans are autonomous and rational agents, who develop or realize their capabilities in interaction with the environment, but are relatively dissociated from this environment (Martin, 2006).

3.1.1 Learning and Knowing as Situated and Social Activity

The basic assumption that learning and knowing are *situated* in human practices does not only mean that the context or situation has an influence. It also reflects a non-dualist ontology that does not dissociate the human from the world, an ontology that says that the person is constituted in social practice; at the same time social practice is constituted in social interaction. Wertsch (1998) argued that the focus of sociocultural research is “the relationships between human action, on the one hand, and the cultural, institutional, and historical contexts in which this action occurs, on the other” (p. 24).

There is no separation of knowing from the known or the process of knowing from the social, physical and cultural context. Knowledge is constituted in the very activity of knowing, in a process unfolding over the course of time. The unit of analysis then is the process of knowing and learning, the intersection of persons, tools and activity over time.

Sociocultural accounts of learning and knowing take as a premise that humans are social and cultural beings, that we as *persons are social and historical products*. Vygotsky (1962, 1978) argued that “higher psychological functions” originated in society and were developed in social interaction and he also designed a programme to study this empirically (cf. Lurija, Cole, & Cole, 1979). More recently Martin (2006) argued that

complex human phenomena such as mind, self, and agency (all crucially important aspects of personhood) are not given a priori, in advance of worldly experience. Rather, it must be the case that personhood actually requires and is constituted by such experience, both during our collective, cultural history and during our individual, ontogenetic courses of development (p. 598).

Vygotsky discussed this relation between the person and the social context in terms of zone of proximal development (ZPD). In the concept of ZPD general principles of learning and development are encapsulated, centring on the idea that what the child can perform in collaboration or with assistance at one point he or she later can do on their own. Performance comes before competence, and competencies develop through participation in social practices.

Lave and Wenger (1991) proposed the idea of “legitimate peripheral participation” as a mechanism of learning; from being a peripheral member in a *community of practice* performing simple tasks to becoming a full member of the community by mastering its core tasks. Whereas the trajectory of participation is from the periphery to the centre of the community, different people will pursue different trajectories within a specific community of practice; there is not just one route. Learning is a central dimension of such trajectories of participation.

Learning then, in a sociocultural perspective, is the *appropriation* and mastering of symbolic/discursive and cultural *tools* within social practices. This appropriation is a process characterized by increasing coordination between the tools and the user(s) of the tools, from an initial encounter and exploration of the tools to the tools becoming transparent to the user.

3.1.2 Tools, Artefacts and Infrastructure

In sociocultural thinking tools and more generally artefacts are at the centre of human learning and knowing. The development of tools is what distinguishes us from other animals (Luria, 1976; Vygotsky, 1978). Artefacts are reifications of human actions and have both material and conceptual qualities (Cole, 1996). To paraphrase Wartofsky (1979) artefacts are invested with cognitive and affective cultural content. Our collective competences are built into artefacts that mediate human interaction with the environment. Learning is always mediated learning.

Wartofsky distinguishes between three types of artefacts: primary, secondary and tertiary artefacts. Primary artefacts are used in direct production. A hammer, a needle, a pair of scissors are examples of primary artefacts. Primary artefacts are extensions of our bodies, but must also be seen in relation to the practices in which they are used. They have certain affordances (in a Gibsonian sense). Secondary artefacts are symbolic representations; they “are reflexive embodiments of forms of action or praxis, in the sense that they are symbolic externalizations or objectifications of such modes of action” (Wartofsky, 1979, p. 201). A description of how to use a primary artefact is an example of a secondary artefact. Thus, there is a direct coupling between primary and secondary artefacts. Tertiary artefacts are kinds of “higher-order” artefacts – not directly coupled to everyday productive activities. They have a more hypothetical or imaginary nature that can be realized (or not). Computer software, such as a virtual reality, a simulation program, lessonware, a game, a CAD program, pedagogical designs and scientific models are examples of tertiary artefacts. Tertiary artefacts are extremely important in modern society – not only those linked to the use of computer technologies – since the use of such artefacts is not a closed but an open system.

In sociocultural theorizing the mediating function of tools is a core function. Tools mediate between subject and object in concrete human activity through processes of distancing and crystallization. As already emphasized tools also have a culturally and historically mediating function, because they inscribe our

knowledge, experiences and practices. Lave and Wenger (1991) put it this way. “. . . understanding the technology of practice is more than learning to use tools; it is a way to connect with the history of the practice and to participate more directly in its cultural life” (p. 101).

Modern information and communication technologies (ICTs) are important tools for changing practices. They may be designed to make an existing practice more efficient, but the complex and contradictory character of tool use may “transcend” the given and turn traditional practices into innovative ones. These processes of transformation have a logic of their own, since tools are not standing alone. Their use involves the mobilization of a complex sociotechnical infrastructure (other tools, users, institutional contingencies). Thus the study of artefact use should be relational and transformational.

3.2 Empirical Studies of TEL

In this section of the chapter we discuss several TEL studies carried out within a sociocultural perspective – in order to illustrate different aspects of the theoretical ideas raised in the preceding sections. First we discuss results from the InterActive Education project which aimed to expand teachers’ practice and empower them in their uses of technology for teaching and learning. We follow this with an example from physics education that illustrates the importance of micro-analytic studies of TEL that reveal the role of the teacher in inducting students into scientific practices. Finally we present an example from the use of TEL in a workplace setting.

3.2.1 Multi-layered Influences on Classroom Learning

The overall aim of the InterActive Education project (Dale, Robertson, & Shortis, 2004; Matthewman, Blight, & Davies, 2004; Sutherland, Robertson, & John, 2008) was to examine the ways in which ICT can be used in educational settings to enhance teaching and learning. A holistic approach was taken, examining learning with ICT at both the level of the learner and classroom and the learner in outside school settings, also taking into account the institutional and societal factors which structure learning. The project centred around developing research partnerships between teachers, teacher educators and researchers in order to design researchable learning environments. The project focused upon a multi-level set of overlapping communities of practice. At the meso-level, the project was organized around subject design teams (SDTs) in the areas of English, mathematics, science, modern foreign languages, music, history and geography. Within these teams teachers, teacher educators, researchers and research students worked together to develop learning initiatives. Whereas the meso-level was the starting point for designing learning initiatives, much of the working through of the initiative took place at a micro-level where a teacher and researcher worked intensively together on design, realization

and evaluation. Design was informed by theory, research-based evidence on the use of ICT for learning, teacher's craft knowledge, curriculum knowledge and policy and management constraints and possibilities. These classroom-specific, collaboratively designed and progressively adapted initiatives gave the project theoretical and methodological versatility. The aim was to develop understanding and change practice through a long-term shift in conceptions of how ICT can be embedded in classroom practices to enhance learning. At the macro-level the core university team worked together to develop the theoretical and methodological coherence of the project.

From the outset the project drew heavily on sociocultural theories of learning. As discussed already a key aspect of such theory is the claim that all human action is mediated by tools. The idea of "tool" was interpreted broadly to incorporate a wide range of technologies and artefacts (for example, pen, paper, book, computer), semi-otic systems (for example, language, graphs, diagrams), social interaction (for example, group work) and institutional structures (for example, national curriculum).

Within the InterActive Education project it was recognized that learning events in school are situated within a set of overlapping cultures, which relate to both top-down and bottom-up influences. Top-down influences include the school culture, subject cultures (for example, mathematics, history, science), the curriculum and the national assessment structure, which in turn are influenced by more global institutions such as the OECD.¹ Bottom-up influences are more informal and include young people's outside school cultures, their personal histories of learning and the teacher's own personal history of learning. For example, at the time when the InterActive project was being carried out in England, mathematics and English teachers were working within a framework of prescribed National Numeracy and Literacy Strategies.² This framework recommends that teachers organize their teaching around what has been called the three-part lesson: (1) oral work and mental calculation (5–10 minutes); (2) main teaching activity (30–40 minutes); (3) plenary (10–15 minutes). Such a framework can be conceptualized as a mediating tool that can potentially constrain or enhance a teacher's way of working. For example, some teachers worked very creatively to adapt the National Strategy so as to follow a rhythm of whole-class and group work, which enabled them to integrate ICT into their practice so that it supported learning. Other teachers, however, were more constrained by the strategies and were more compliant. As a result, whole-class and individual work became more formulaic and in these situations teachers were not able to respond contingently to student learning opportunities. Interestingly many of the teachers who successfully found ways of using ICT to enhance learning reported that working within the project had enabled them to take risks with their teaching, which would otherwise be difficult, given the prescribed constraints of the

¹ Organisation for Economic Cooperation and Development (<http://www.oecd.org/>).

² For information on the National Numeracy Strategy see <http://www.standards.dfes.gov.uk/numeracy/>; for information on the National Literacy Strategy see <http://www.standards.dfes.gov.uk/literacy/>

National Curriculum, the National Strategies and the National Assessment systems (Sutherland et al., 2008).

When designing new TEL environments, it is also important to take into account the ways in which students bring to the classroom their own histories of learning which relate to their previous experiences of both in-school learning and out-of-school learning. These histories of learning may be at odds with the intended learning. For example, when primary students were using simulation software to learn about the ecology of the sea they treated the ICT simulation as a game and became engaged in winning the game. The language they used as they interacted with the software was about winning – “Don’t die. . .we gotta beat people. . .we need to beat 5 minutes”. In this situation the students were not entering the world of science, as the designers of the simulation had intended. In other situations, young people’s out-of-school uses of ICT can productively feed into the teacher’s intended learning. For example, when 8–9 year olds were learning to use spreadsheets for data handling the teacher became aware that some children in the class had been learning about spreadsheets at home through a process of *peripheral participation*.

Interviewer: Do either of you use Excel at home?

Ray: Sometimes. My Dad uses it for his paper work.

Interviewer: And when you use it what do you use it for?

Ray: Umm, he uses it, ‘cos when he’s got paper calculations and some are hard like for him, he puts it in Excel and then he puts, he circles it and then presses the equal button and it tells him what the sums are.

Both of the above examples draw attention to the fact that schools have been set up to introduce young people to new ways of knowing (for example, mathematics, science) and teachers play a key role in this respect. This point cannot be emphasized enough and emerges strongly from sociocultural studies of TEL in schools. By contrast the early studies of computer-based learning, often influenced by a more cognitivist perspective, tended to assume what has been called the “fingertip effect” (Perkins, 1985), that is, a belief that simply by making a technological system available, people will more or less automatically take advantage of the opportunities that it offers.

One of the distinctive features of the InterActive project was the way in which teachers, teacher educators and researchers worked together to create a multi-layered professional learning and research community. Knowledge was produced by an engagement with and in practice. The results of the project showed that ICTs have the potential to profoundly alter the social relations in the classroom and to impact on learning and knowing in the classroom. The project also showed that there are qualitative shifts when ICTs are introduced into the classroom and that these shifts can tip over into enhancing learning. However, without a teacher carefully crafting and orchestrating learning, the incorporation of ICTs into the classroom can tip over in the other direction, into learning that is at odds with what the school and the teacher intend students to learn. In summary the main findings of the InterActive Education project were the following:

- Teachers remain central to TEL, but exploiting the potential of ICT for learning frequently challenges well-established pedagogies.
- Student learning is more likely to be enhanced when teachers have analysed and understood the potential affordances of the chosen ICTs as they relate to the practices and purposes of their subject teaching and when these tools are deployed appropriately. New digital tools do not necessarily replace more traditional non-digital tools (for example, paper-based map, ruler, book).
- An oversimplified polarization of the teacher's role as either "didactic teller" or "facilitator" is unhelpful in working with ICTs. The teacher's role, at best, involves a complex shifting of perspectives from the "more-knowledgeable-other" to the "co-constructor of knowledge" to the "vicarious participant". Effective teachers orchestrate use of ICT, the interactions around it and their own interventions.
- Allowing learners to be autonomous and exploiting the potential of ICT often produces a high level of student engagement; but this can lead, especially in subjects like mathematics and science, to individually constructed knowledge which is sometimes at-odds with the intended learning. Effective teachers recognize this and find a way to build bridges between idiosyncratic and intended learning.
- Out-of-school practices with ICT impact on in-school learning and teachers often underestimate the extent to which this is the case.

3.2.2 *TEL as a Focus of Intent Participation in School-Based Scientific Activity*

An example of micro-analytic observations of interactions in technology-mediated learning comes from a series of studies of learning physics in a computer-based learning environment called *probeware* or *microcomputer-based labs* (MBL) (Lindwall & Ivarsson, 2004, 2009; Lindwall, Lindström, and Bernhard, 2002; Lindwall & Lymer, 2005, 2008). Although this research is design oriented, the analyses are based on video recordings of educational activities, with the attempt to describe "mechanisms through which participants assemble and employ the social and material resources inherent in their situations for getting their mutual dealings done" (Jordan & Henderson, 1995, p. 42).

The technological setup is a computer with probes measuring scientific phenomena such as force, velocity, light, sound frequencies, radiation and a software that makes it possible to display the measured data in different ways, for example, analogue and digital meters, tables and graphs. Data are displayed in real time and logged over time. Probeware has gained an interest specifically from science educators as a means of overcoming students' conceptual difficulties in science. There are also a number of studies showing that probeware has a positive effect on students' learning and understanding of physics concepts (e.g. Beichner, 1995). Euler and Müller (1999) even claim that probeware is the only computer-based learning environment in physics education that has a proven positive learning effect.

The general *pedagogical design* of the tasks given to the students can be characterized as a *predict–observe–explain* procedure (see for example, Linn & Songer, 1991), where students should state a hypothesis, then observe the results and afterwards discuss discrepancies between the hypothesis and the outcome.

By testing the students' conceptual knowledge in the studies it first of all became clear that the activities led to the anticipated results (cf. Lindwall & Ivarsson, 2004). In scrutinizing the interactional activities some insights in the "mechanisms" of learning and teaching were gained.

Lindwall, Lindström, and Bernhard (2002) showed how the students used the graph as a sequential *script* for their movements in front of the sensor in their attempt to solve the task of reproducing a graph. Through the design of the graphs to be reproduced this scripting made it necessary for the student to *make specific and critical conceptual distinctions*, relating both to the construction of the graph and movements in the real world. Thus, the design of the graphs also involved a pedagogical or didactical "dimension".

The last point is further illustrated by an analysis presented by Lindwall and Lymer (2008). They conducted in-depth analyses and description of an interactional sequence where a group of students, supported by a teacher, tried to come to grips with the task of "seeing a linear relationship" in a messy set of data. This was part of a set of labs on Newton's second law ($F = m \times a$). The students worked with a cart that runs on a track. Motions of the cart can be represented as plotted relationships between any of the relevant variables (velocity, acceleration, position and time). The cart is also coupled to a force sensor that measures the force imposed on the cart if pushed or pulled along the track. This adds force as one available variable to display on the screen, which makes it possible to show how force is coupled to acceleration, velocity, position and time.

The analysis demonstrates how learning to see a linear relationship is a process in which the students struggle with giving meaning to the graph and where the graph gradually acquires the status of representing a linear relationship (between force and acceleration). An important aspect of this "seeing" is a holistic quality. To learn to perceive a set of data as a linear relationship in terms of the practices of a scientific discipline amounts to developing a "professional vision" to use Goodwin's (1994) wording. The analyses also show *the important role played by the teacher* in the learning activity and its highly interactive nature. The teacher has the scientific knowledge, the professional vision as it were, and is continuously interacting with the students pointing out what it means to "see" in this specific setting. The teacher is in interaction with the students, reacting to their actions. He is not just giving feedback about right or wrong, he is not "instructing" them, but tries to "show" what it means to see the linear relationship as a holistic quality given the concrete circumstances. Through this "scaffolding" by the teacher, in response to the students' difficulties, the students progressively gain access not only to a set of concepts but also to a disciplined "scientific" way of perceiving the world. In this respect it could be argued that the students are engaging in legitimate peripheral participation of scientific activity, and the technological artefact (i.e. the probeware) is being used as a focus for "intent participation" (Rogoff, Paradise, Mejía Arauz,

Correa-Chávez, & Angelillo, 2003). This quality of “intent participation” would be hard to build into any media, text-based or computer-based artefact.

The dynamics of this interaction or “intent participation” is not only constituted by the student–teacher dialogue, even though “talking” about the task and the difficulties the students’ articulate is crucially important. The interaction also has an indexical nature, the teacher and the students relating to the graphs and the actions by gesturing, pointing and indexical wording. The dialogue is situated in an activity, where the technological tools play an important role. The technology affords graphing, based on recordings of physical/material action. This graphing is based on using scientific categories and principles built into the technology, which creates (necessary, but not sufficient) conditions for development of scientific knowledge. Put another way, using the tools of science in “the making of science” thus becomes an important condition for the students. Learning for the students involved the appropriation of the graphing tool, a process in which the graphing tool gradually (and with the support of the teacher) became transparent to the user.

We argue that micro-analytic studies, such as the one described above, are key to developing understanding of the ways in which ICTs can be used in schools to enhance learning. Within such studies what is visible and analysed is a process of interaction. This process is a process of learning, but at the same time it is a process of “teaching”. It is also a process that (most often) extends over time. Whereas we often see what the teacher is doing, we can observe the professional vision of the teacher, the learning process (trajectory) of the students is not that visible. It is less clear what the students bring into this arena – and how the institutional context shapes what is going on. These issues – on the interchange between formal and non-formal learning processes and the coupling of analytical levels – represent critical methodological and theoretical challenges for the sociocultural tradition. From a methodological point of view, it is often not easy to localize instances of learning even though moments of “insight” sometimes show up in the many hours of video recordings. Instead we may get an understanding of how students’ struggle to figure out the affordances of a particular technology.

3.2.3 TEL in a Workplace Context

The sociocultural literature has always been interested in learning that takes place outside schools – and more specifically in the workplace. Seminal studies have been carried out of expertise in professional and “unskilled” work (Hutchins & Klausen, 1996; Scribner & Sachs, 1991), and its influence on the field of computer-supported collaborative work (CSCW) has been considerable (Nardi, 1996; Suchman, 1987).

Workplace learning is said to be “informal”, taking place in complex, dynamic environments. More fundamentally any development of human expertise is subjected to the needs of economic production. In the era of “re-engineering” and knowledge-intensive systems these dynamic patterns should be a central concern

of TEL research. Cultural–historical activity theory has proven to be a promising approach in understanding the contradictory development of work-integrated learning and in framing a research agenda that includes several analytical levels (micro–meso–macro) and different time scales (Engeström, 2008). These methodological and theoretical points came out clearly in Norwegian studies of TEL in working life.

The project NEMLIG (net and multimedia-based learning in graphic industries) was an interdisciplinary attempt in Norway to develop a sociocultural model of e-learning in workplaces (see Lahn, 2004). It was initiated by the trade union for graphical workers, but included cases from other industries such as the media, engineering companies, public service providers and a train repair workshop. Some of the design ideas were inspired by activity theory. This project demonstrated that the development of TEL in working life is a complex process where learning takes place at different levels, for example, involving individual skill acquisition, reorganization of workplaces and the transformation of expert fields such as graphic design and project management. Technological maturity and readiness differed considerably between the settings. As a consequence the implementation of TEL environments did not proceed in a smooth linear way and the research process was continuously redesigned in the course of the project.

Another study of e-learning in working life largely “replicates” the findings above. It is taken from Telenor, the largest telecom company in Norway, that in 2001 relocated 6000 employees to new headquarters (Netteland, Wasson, & Mørch, 2007). These were constructed as open-office areas, and the new organization represented an advance in IT-mediated work practices. A short e-learning program was aimed at enabling the employees to be operative in the restructured work environments. When evaluating this implementation the researchers used concepts from activity theory as analytical resources “in order to understand the tension-riddled network of interacting activity systems” (p. 393) that frame the changing learning contexts of individuals and collectivities.

The researchers observed that the e-learning program was not “tailored” to the needs and expectancies of specific groups. As in the previous case a complexity of processes was set in motion during the project – most of them unanticipated in the design phase and resulting in a series of delays. In a rationalistic evaluation model these effects would easily be interpreted as failures of implementation since outcomes did not match the expected. If we frame this process in activity-theoretical terms and focus on the contradictory evolution of innovative practices, delays and deviations could be understood as temporary setbacks. Only a longitudinal study of the implementation process would provide the necessary evidence.

These cases from TEL in working life illustrate a set of issues that are critical in the discussion of TEL. Usually we consider tools that provide more information, easier access to information and better communication of information. They are likely to support and widen the workers’ horizontal understanding of tasks, that is, so that they know more about what is going on outside their local context. However an activity-theoretical framework would also be concerned with the tool-mediated development of vertical skills – that is, how TEL enables workers to get a systematic

understanding of their own situation and ways it can be changed. This dimension which has some resemblance to Argyris and Schon's (1974) notion of "double-loop learning" is not addressed in reviews that are made of the general literature on TEL and work (Lain & Aston, 2004).

The following points could summarize this section on sociocultural perspectives on TEL in working life:

- TEL tools are not stand alone, but integrated with resources for work processing and information systems, as illustrated in the cases above. They serve as "boundary objects" defined by Star and Griesemer (1989) as objects or infrastructures that keep different communities together, but at the same time allow for different interpretations and uses of these entities. TEL environments may both connect different parts of the workplace and preserve some tensions in their development.
- Innovations, also TEL innovations, in the workplace are often part of more comprehensive processes of "re-engineering". Many parties are involved, and great attention has to be given to the (project) organization of participative design.
- In line with the former points the design and implementation of TEL tools in working life is moving along different time scales – at different levels.

3.3 Concluding Remarks

Within this chapter we have shown how studies influenced by a sociocultural research perspective are contributing to our knowledge in the field of technology-enhanced learning.

The research from the InterActive Education project demonstrates the complexities involved in bringing about changes in school-based learning practices through integrating ICT into classroom-based teaching and learning. We argue that such complexities need to be understood if the vision of TEL in schools is ever to be realized.

The studies of the probeware labs illustrate how detailed micro-analytic studies of school-based TEL learning give an insight into mechanisms that are important (or even critical and necessary) for TEL design to be successful. They also highlight how meaning is made in highly interactive and multi-leveled processes, where the participating subjects and the technological artefacts and tools are intertwined. At the core of these interactive processes is the emergent object of knowledge (the subject matter), which the students are discursively oriented towards.

Naturalistic studies of ICT use in classrooms show more ambiguous results than what is identified in experimental and quasi-experimental studies (Arnseth & Ludvigsen, 2006). We argue that the explanation of this mismatch relates to a set of institutional factors, as illustrated by the results of the InterActive project discussed earlier. Different types of ICT tools do not in and by themselves create better learning processes and outcomes. The findings show that it is not ICT in and of itself, but rather a number of other factors working together with ICT that are decisive for the quality of the learning process and for learning results. Such factors can include

- A teacher's understanding of the particular ICTs chosen to enhance the intended learning;
- The students' out-of-school learning with ICT;
- The quality of the learning resources that are developed.

This picture also includes the quality of the interaction between the teacher and the students, and between the students. The last relationship that should be noted is how the pedagogic and academic use of ICT is based on what can be called an institutional or collective dimension. In this perspective all the factors above are part of an activity system that influences the ICT-supported learning trajectories of students (and teachers). In these processes meaning and knowledge are communicated, negotiated and transformed through the use of emergent technologies.

In the workplace example the learning agenda and its infrastructure are continuously challenged by innovations in the production systems. There is no well-defined curriculum (or intended learning) and the content to be learned is subject to transformations when individuals and group of workers are asked to update themselves and adopt new work routines. In the sociocultural literature the notion of "learning trajectories" has been introduced to highlight the complexity of temporal order and multi-level changes – and at the same time to focus on the "leading edge" of development (Beach, 1999).

The notion of "learning trajectories" also sets focuses on learning as a complex developmental process, extended over time. On a general level, whether in educational institutions or in the workplace, individual and collective learning trajectories are characterized by the progressive appropriation of the tools of a "scientific" community or other symbolic artefacts, and the trajectory is also a trajectory of enhanced community membership by virtue of increasing competencies. The probeware example also makes very clear that its success relies on the pedagogical design, a design that not only creates the conditions for the interactive learning work but also is one with a substantial degree of indeterminacy. The results of the InterActive Education project suggest that as well as paying attention to micro-level design attention has also to be paid to the meso and macro-level institutional structures and systems.

In working life contexts it is more difficult to disentangle successful results, and such assessments can only be done through follow-up studies of systemic changes over extended periods of time. When the focus is on TEL tools as participants in the transformations of activity systems, the spatial dimension is expanded, and artefacts cannot be analysed in isolation. They are part of changing infrastructures for work and learning (Guribye, 2005; Jones, Dirckinck-Holmfeld, & Lindström, 2005). Often TEL environments can function as boundary objects or boundary crossing devices, mediating between practices. From this perspective, the analyses of the probeware labs show a meeting of pedagogical and professional practices, where tasks and tools function as boundary objects, and the intervention by the teacher makes it a boundary practice.

Sociocultural research represents both descriptive and developmental strategies. It does not only study a moving target, often researchers are working with other

experts and practitioners in the design of TEL tools and environments. The introduction of TEL is to a large extent motivated by changing demands on education or work to meet new challenges. The inclusion of new technological tools in an environment is sometimes a part of a redesign and redefinition of both content and method. Thus researchers working in this tradition need to develop models and instruments that allow them to understand the effect of their own intervention and work closely with practitioners as co-researchers.

In this chapter we have brought to the fore some of the merits of sociocultural thinking in studies of TEL. At the same time it should be evident that there is a need to address some issues in a more concerted way: longitudinal studies of learning trajectories within and across different institutional settings, micro-analyses of the interaction between formal and informal processes in learning and the design of multi-level studies that include a dynamic dimension.³ We have also argued that a number of theoretical approaches can be subsumed under the heading sociocultural – begging for some tolerance and multi-voicedness in the “socialization” of experts in this community.

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³ Within the scope of the Kaleidoscope Network of Excellence these problems have been the topic of doctoral schools and other activities.

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Chapter 4

Narrative Learning in Technology-Enhanced Environments

An Introduction to Narrative Learning Environments

Giuliana Dettori and Ana Paiva

Abstract Narrative is recognized as a valid support for learning because it helps make sense of experience, organize knowledge and increase motivation. Narrative learning environments (NLEs) aim to exploit its educational potential by engaging the learner in technology-mediated activity where stories related to the learning task play a central role. This chapter illustrates the variety of NLEs currently available and suggests a classification of them based on the technology used. It also points out what issues need to be tackled to advance the field.

Keywords Narrative learning environments · Story · Narration · Sense making · Motivation · Storytelling · Story creation · Collaboration · Interactive environments · Multimedia editors · Educational design · Web 2.0

4.1 Introduction

Narrative, in the form of stories and narrations, is increasingly used in education. Not only is it a natural expressive form for people of any age and culture (Bruner, 1990), but it is also recognized as a privileged way to help develop cognitive abilities and organize knowledge (Schank, 2000), as well as to work out a coherent meaning for our experience (Bruner, 1990, 2003). As a consequence, stories are being increasingly used in a variety of subjects, not only intuitively related ones such as history, literature and language but also in the scientific domain (Burton, 1996, 1999; Bruner, 2004).

Stories can be used in the educational field for different purposes, that is, to support learning, teaching and research (McEwan & Egan, 1995). In a narrative approach to learning, the focus is on finding meaningful ways for the students to

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make use of stories related to their learning tasks, with the aim of facilitating and improving learning. In a narrative approach to teaching, on the other hand, the attention is on creating and using suitable stories to convey content knowledge incisively and to motivate people to learn, both in school (Jackson, 1995) and in organizational contexts (James & Minnis, 2004). Finally, the use of narrative for research purposes, which is usually called “narrative research”, consists in using narrative as a way to collect data; it entails, therefore, the development of procedures to extract and interpret data from narrations (Lieblich, Tuval-Mashiach, & Zilber, 1998). While there is clearly a relation between the study of narrative to support learning and teaching, narrative research differs both in its aim and operation and is actually an independent research field.

This chapter is focused on narrative learning, in particular within technology-enhanced learning environments. Studying the synergy between narrative and technology for the creation of effective learning environments is of interest because ICT offers a variety of tools and techniques – from 3D graphics and animation to intelligent agents, from communication means to augmented reality – able to exploit and amplify the learning potential of narrative in different ways and for different purposes. This gave rise, in the last few decades, to the research and application field of narrative learning environments (NLEs).

In the next sections we highlight why narrative can support learning, drawing from the literature. Then we discuss NLEs’ main features and learning potential and mention a few examples. Finally, we point out some issues to be tackled in advancing the field.

4.2 Why Narrative Can Support Learning

4.2.1 What Is Narrative

Even though the concept of narrative might seem rather intuitive, defining it precisely is not trivial. This term is often improperly used in everyday speech to mean a wide range of expression types, thus voiding it of its meaning and possible usefulness in relation to learning (Thomas & Young, 2007). Relying on a loose characterization may generate confusion and does not help understanding of what determines the learning potential of narrative. For this reason, we need to start our analysis with a meaningful definition, drawing from the large number of characterizations given in the literature. Let us therefore compare the points of view of four scientists with different orientations working in non-literary fields.

Bruner (1990), whose work on cultural psychology represented a milestone for the development of many subsequent studies on the educational impact of narrative, defines it as follows:

a unique sequence of events, mental states, happenings [...] But these constituents do not have a life or meaning of their own. Their meaning is given by their place in the overall configuration of the sequence as a whole – its plot or *fabula* (p. 43).

Wertsch (1998), who analyses narrative as a cultural artefact in his studies on mediated action, points out its components:

Narrative is organized around temporality, it has a central subject, a plot with a beginning, middle and end, and an identifiable narrative voice; it makes connections between events; it achieves a closure, a conclusion, a resolution (p. 80).

and then adds

The cognitive function of narrative form is not just to relate a succession of events but to body forth an ensemble of relationships of many different kinds as a single whole (p. 81).

Ricoeur (2005), considering narrative in his studies on hermeneutics and the human sciences, explains it as follows:

The activity of narrating does not consist simply in adding episodes to one another; it constructs meaningful totalities out of scattered events. The art of narrating, as well as the corresponding art of following a story, therefore requires that we are able to extract a configuration from a sequence (p. 278).

Herman (2003), in relation to cognitive science, claims

One of the hallmarks of narrative is its linking of phenomena into causal-chronological wholes (p. 176).

It is clear that behind the different phrasings, these characterizations of narrative are in agreement with each other. This is very important, because it indicates that the word narrative is used in a consistent way across different scholarly fields, so that, when working on the use of narrative to support learning, we can rely on theoretical studies of different origins.

All of the cited definitions highlight the presence of connections and relationships among the elements of a story that build a configuration out of them, that is, a whole giving meaning to all single parts. Therefore, loose definitions of narrative that acknowledge the presence of a sequence of events but miss highlighting the configuration created by the relationships end up inadequate, because the presence of relationships among narrative elements is a key point for provoking active thinking and supporting meaning construction. Annals and chronicles are not narratives, because they do not build a complete configuration from a list of events (Wertsch, 1998, p. 79). Analogously, lectures and scientific reports are not narratives just by being discursive, unless they consist of stories with a relational structure, a narrating voice (which suggests that there is a point of view in reporting the facts) and a conclusion. Nor can reflections and explanations be considered narratives, because they do not consist of sequences of related events but rather of descriptions, argumentations, generalizations and abstractions.

On the other hand, the given definitions do not limit the nature of the content or the language employed. Hence, narrative includes both invented and true stories, as well as narrations of personal experiences. It can be expressed in a variety of different languages, such as spoken words, written texts, sequences of static or moving pictures and even body language and shadows, or a combination of all of them.

4.2.2 Learning Potential of Narrative

The presence of logical relationships among the elements of a narrative allows its users to infer more than is explicitly reported (Bruner, 2003) and hence leads people – both receivers and producers – to engage in a meaningful construction process. This makes narrative a powerful sense-making device and cognitive tool.

Starting from this essential characterization, many authors have deepened the analysis of narrative properties, identifying roles which are relevant for learning, such as *external knowledge representation* (Porter Abbott, 2002), *cognitive process* (Luckin et al., 2001; Scalise Sugiyama, 2001), *context setting element* (Aylett, 2006), *organizational principle* (Polkinghorne, 1988), *way to structure human experience* (Aylett, 2006) and *mediator of human action* (Wertsch, 1998).

Moreover, the literature highlights that narrative can support not only cognition but also motivation and emotion, which are equally important components of learning. As Bruner (2003) points out, “narrative in all its forms is a dialectic between what was expected and what came to pass” (p. 15), as well as “an invitation to problem finding, not a lesson in problem solving” (p. 20). For this reason, the use of narrative in learning can result in challenging and stimulating curiosity and fantasy, which are the major components of intrinsic motivation according to the taxonomy proposed by Malone and Leppers (Rowe, Mcquiggan, Mott, & Lester, 2007).

The support for emotion arises from the fact that “stories are based on an interplay between characters and causation” (Aylett, 2006), which leads the user to highlight aspects of personality, emotional state and social standing, as well as the motives and intentions underlying characters’ actions.

4.3 What are NLEs

The expression *Narrative Learning Environments* was created in the 1990s within the field of artificial intelligence (AI) to indicate learning environments where stories, interactively created by user and system, had a central role in facilitating learning. In recent years, however, due to the widespread interest aroused by the educational potential of narrative, this expression started to be used in connection with learning environments that originated within other contexts and were developed with different technology. Such environments share with the original NLEs the characteristic of being based on ICT-mediated learning activities in which narratives related to the task at hand play a central role. They differ, however, in a meaningful way.

AI-based NLEs are *technological* constructions, with all the necessary components packaged in them. That is, they include the assignment of relevant narrative activities, a pedagogical approach to guide them and a selection of suitable technological tools. NLEs created in other research fields, on the contrary, are *conceptual* constructions, making use of some technological tools that facilitate a relevant narrative activity; they require some human labour to set up narrative tasks and

define a pedagogical approach apt to favour task completion and the achievement of the expected learning. Moreover, technological NLEs allow joint story construction by user and system, thanks to AI technology, as will be explained in Section 4.5. For this reason, they are called *interactive NLEs*. Conceptual NLEs allow only the level of interactivity usually provided by currently available software, such as hypermedia navigation and communication with networked users; therefore, they are not usually considered interactive, even though the learner interacts with a story and with other learners.

The Special Interest Group on Narrative Learning Environments¹ of the Kaleidoscope Network of Excellence played an important role in recognizing the wide similarity between technological and conceptual NLEs by comparing different points of view and similar outcomes of people working with narrative learning. This activity led to the spotting of similarities and differences, thereby providing the basis for the NLE classification presented in this chapter.

Even though meaningful narrative learning activities can be realized with traditional educational means (e.g. drawing, dramatization, books), NLEs usually make use of some form of ICT tool. This allows easier and faster management of multimedia narratives, hence leading the learners to become familiar with multiple representational modes, within an activity – the interaction with stories – which is naturally appealing and not too difficult. Non-verbal narratives can also be constructed easily, allowing people with language-related disabilities to exploit the learning potential of narrative (e.g. Faux, 2006).

Among the variety of technological means that are used in NLEs, some influence the appearance of the environment and interaction mode, while others determine its structure and the experience afforded. The first group includes 2D and 3D graphics, animations, sound and tactile interfaces. Intelligent agents, natural language processing, multimedia editors, web 2.0 technology and general purpose tools belong to the second group.

Besides AI, the fields that most influence the creation of NLEs are multimedia and educational design. The increasing diffusion of web 2.0 technology is also providing technological tools that can properly be used to set up NLEs centred on role playing. Hence, at present, we can identify four main groups, which resort to different kinds of technology and require varying amounts of human labour to set up stimulating tasks and control the development of the narrative activity. Table 4.1 summarizes them, highlighting what kind of technology is used in each group. The four groups are described in Section 4.5, together with some examples.

It is important to note that not just any learning environment including a story can properly be considered narrative. There are environments where a story is given as an appealing background to problem solving, without a conceptual integration between the given narrative and the assigned tasks. In this case, the back-story simply aims to provide a generic, extrinsic motivation to work in the environment. This may work well in disciplines (such as mathematics) that are scarcely appealing for

¹ <http://nle.noe-kaleidoscope.org> or <http://gaips.inesc-id.pt/nle/en/context.html>

Table 4.1 Classification of NLE types according to the technology used

	Focus on creating a story	Focus on receiving a story
<i>Interactive NLEs based on AI technology</i> (control of the activity is largely embedded in the environment; limited teacher intervention is necessary)	Stories emerge from collaboration among users and environments. Parts of narrative are automatically created by means of intelligent agents, e.g. Teatrix	Interactive environments where users are given a narrative that can help them understand a problem situation. The narrative is mainly produced by the environment, but the users influence it. New stories are produced at each use, e.g. FearNot!, Crystal Island
Equal space to story telling and listening, e.g. SAM		
<i>NLEs based on multimedia technology</i> (technology provides features to facilitate story creation, but organization and control of the activity relies on users)	Environments based on narrative editors, i.e. multimedia editors oriented to the creation of stories in the form of cartoon strips or animations, e.g. StoryMakerII, MediaStage, Kart2ouche, ZimmerTwins	Multimedia environments where the user is given a narrative to help them understand a problem situation. The narrative is pre-defined, the user has only navigation freedom, e.g. Ecolandia
<i>NLEs based on web 2.0 technology</i> (story creation facilities, pedagogical planning and activity control are necessary)	Intrinsically collaborative, mainly based on role playing. Users participate in story creation, receiving part of a narrative from the other participants and contribute to it complying with constraints and adjusting to the story's global development, e.g. Revolution	
<i>NLEs based on general purpose technology and on educational design and theories</i> (the narrative activity is completely decided by the humans involved in the environment)	1) Environments where some relevant narrative activity is assigned within an articulated learning task, e.g. Dolk & Den Hertog (2006), de Vries (2006), Makrì (2006), Walker (2006a, b) 2) POGO, a virtual story world, accessible through a number of physical interactive tools	This falls under Narrative Teaching

many students, as a way to sweeten an unpleasant pill (Aylett, 2006), but it does not characterize such environments as NLEs.

4.4 Learning with NLEs

NLEs may be devoted to developing narrative competence, which is a relevant cognitive task, especially for children and teenagers. They can also aim to support learning in a variety of subjects, such as linguistic expression in a mother or foreign

language, history, science or to develop social competence and soft skills, such as relational behaviour in critical conditions, decision making. These two possibilities are not alternatives to each other but in fact intertwined and always take place together: using narrative to foster learning in a given field is a way of practicing with narrative as well, while reinforcing narrative competence necessarily involves also other skills, such as the use of language or of some other expressive code. This is not surprising, because narrative is a cultural artefact used in NLEs to mediate learners' action, and it is typical of mediated action to have multiple simultaneous goals (Wertsch, 1998, p. 25).

Learners can interact with narrative in different ways, that is, by receiving a narrative, by producing a new one or by telling a known one, no matter whether the environment's learning aim is to build competence in narrative, a subject or a soft skill. Each of these activities can be performed individually or by interacting with peers or software. In all cases, a number of cognitive abilities are brought into play, favouring the acquisition of several basic skills, as shown in Table 4.2, which add to the environment's learning aims.

Story creation fosters creativity and understanding of logical consistency, while storytelling stimulates recognition of main elements and memory. Receiving a story, on the other hand, entails building a mental picture of the narrated events. This turns out to be very useful in problem solving, because it helps to highlight the elements in play and to relate them with each other, giving rise to a meaning-creation process that supports the construction of a solution. This data-highlighting role is neither trivial nor irrelevant: a number of research studies have underlined that problem solving is more often hindered by an incomplete or inaccurate analysis of the data involved than by the lack of a suitable solution strategy (Sutherland, 2002).

Table 4.2 Basic abilities and skills supported by user's roles and working modes in NLEs

	Individual work	Interaction with peers	Interaction with software
Story creation	Creativity Learning to narrate Respect for logical constraints Communication skills	Same as in individual work Negotiating story plot with peers	Same as in individual work Adjusting individual plans to story
Story telling	Understanding story Detection of plot's main elements Memory Personalization Communication skills	Same as in individual work Negotiating story representation with peers	Same as in individual work Matching mental plot with actions made by the software
Story use	Mental picture of narrated events Understanding meaning and relations of story elements and data	Discussing configuration with peers Negotiating meanings with peers	Same as in individual work, with the possibility of asking personal questions to clarify the situation

4.5 A Classification of NLEs

4.5.1 *Interactive NLEs*

The group of NLEs originating from AI research consists of *interactive* NLEs, that is, technological environments where the users interact in non-trivial ways with the system to generate consistent narrative, thanks to *intelligent agents* and other AI procedures. It includes primarily environments produced within research projects; they are, hence, well documented by research reports but not commercially available.

Implementing this kind of environment entails working out a solution to a number of technological and conceptual issues. A major issue concerns making computers automatically generate consistent and believable narrative. To this end, researchers derive formalisms for story generation by drawing from narrative theories formulated within narratology studies (Cavazza & Pizzi, 2006). Another important issue concerns realizing interactivity between human and computer in narrative construction. This entails addressing a number of complex questions balancing the user's freedom and the system's intended aims. Research in this field has given rise to several different approaches (Paiva, 2005), leading to a variety of solutions for the creation of *emergent narrative*, that is, consistent stories collaboratively created by human-computer interaction (Aylett, 1999).

Though always involving the user to some extent as a participant in story creation, interactive NLEs may be more focused on narrative construction or on narrative use. An environment focused on story construction is Teatrix,² a virtual stage where pupils can build and play stories in collaboration with other networked users and with artificial characters. Moreover, some AI functions help the users check the consistency of their stories and of characters' behaviour.

An example of interactive NLEs where a story is mostly given is FearNot!³ This environment aims to help pupils understand what is bullying and cope with it. It offers stories generated by following the suggestions given by the user to the environment's main character, a child who is being bullied in school. The implemented learning approach consists in raising empathy in the users so as to make them become aware of the negative side of bullying.

Crystal Island (Rowe et al., 2007), an environment for middle-school students supporting inquiry-based learning in microbiology and genetics, also proposes a story to the learner, who is invited to identify with one of the characters. He/she takes the role of a member of a scientific expedition who needs to solve a genetic problem to stop an epidemic disease that is afflicting the research group. The student navigates the environment and, interacting with the story characters, gets information on the object of study and suggestions for working out a solution. The characters are animated by semi-autonomous agents, which means that (partially) new dialogues are generated each time one of them interacts with the user.

² <http://gaips.inesc-id.pt/teatrix/>

³ <http://info.nicve.salford.ac.uk/victec/> and <http://www.e-circus.org/>

SAM,⁴ which both encourages and carries out storytelling, lies across the two groups. In this environment, which aims to help children become fluent in storytelling, a virtual child, projected on a wall, invites the user to engage in a game of telling stories to each other, taking turns. In this case, story creation is done individually by the real and the virtual child, but the system selects some keywords in the user's stories to guide the generation of the next story told by the virtual child, so as to give the impression of a kind of dialogic activity.

4.5.2 NLEs Based on Multimedia Technology

The second group of NLEs, which sprang from research in multimedia, also includes hypermedia environments where some narrative is given, as well as environments that facilitate the creation of stories.

Ecolandia, a nice example of a multimedia environment presenting a narrative (Dettori & Giannetti, 2006), aims to foster reasoning on environmental issues, showing that it is necessary to integrate information from different sources and that complex problems may have more than one possible solution. Here the student plays the role of an expert who is sent to solve the garbage disposal problem of three neighbouring cities and gathers the data necessary to tackle the task by going to the library and listening to public administrators, citizens and experts.

Multimedia NLEs for story creation can be set up with the use of narrative editors, that is, multimedia editors explicitly oriented to the creation of narratives in the form of cartoon strips or animations (Earp & Giannetti, 2006). Both commercial software, such as Kar2ouche Composer,⁵ MediaStage,⁶ StoryMaker II, and freeware, such as Zimmer Twins,⁷ are currently available. These differ from each other as far as the graphics used (2D or 3D), the kind of animation allowed, the complexity of scene and dialogue supported. Plain multimedia editors (such as Textease)⁸ can also be used (Faux, 2006), as well as programmes for movie editing (e.g. Kynigos, Kazazis, & Makrì (2006) use Camtasia Studio;⁹ Arnedillo-Sanchez (Chapter 14) uses Microsoft MovieMaker with images and sounds collected with mobile devices). Multimedia editors usually offer facilities for multimedia composition analogous to narrative editors, and often even better ones, but do not provide choices of characters and story-like backgrounds, as is the case with narrative editors.

Both narrative and multimedia editors offer facilities for story construction but do not provide functions for checking story consistency or built-in tasks or learning approaches to guide the narrative activity; they require therefore some attention from the users (teachers or mentors or the learners themselves) to shaping the narrative

⁴ <http://www.media.mit.edu/gnl/projects/castlemate/>

⁵ <http://www.mediastage.net/kar2ouche/>

⁶ <http://www.mediastage.net/mediastage/>

⁷ <http://www.zimmertwins.com>

⁸ <http://www.softease.com/textease.htm>

⁹ <http://www.techsmith.com/camtasia.asp>

learning activity, checking the consistency of the stories constructed and reasoning about logical constraints.

4.5.3 NLEs Based on Web 2.0 Technology

The multimedia communication technology of web 2.0 gives rise only to collaborative environments where the users participate in story creation.

The educational game Revolution¹⁰ is a web 2.0 environment that was expressly designed for learning. It is a multi-user role-playing game on the American revolution designed to be played by a group of learners in a networked environment, in 45-minute sessions. During the game, narrative action unfolds and the users become part of it by taking one of seven different social perspectives, hence experiencing the social, economic and cultural life of the period. The given historical context constrains the participants' actions, turning the game into a learning activity where knowledge is built by interacting and discussing with peers. As with all role playing, however, suitable preparation is essential for generating consistent narrative and giving educational meaning to the experience. A debriefing phase to acquire awareness of the learning achieved is also advisable.

Moreover, online multi-player games with a narrative background, such as World of Warcraft¹¹ (WoW), or even role-playing environments without pre-defined backstory, such as Second Life,¹² are also arousing interest in the educational field and could be used as technological engines for setting up NLEs. Usually a kind of story arises from the interaction among participants, and some learning is involved, at least as concerns the creation and application of strategies. Mass multi-player games, however, cannot be considered NLEs as such, in that a learning approach is missing and the variety of participants' possible behaviours and motivations does not favour the creation of really consistent stories. In order to build NLEs by means of such online games, therefore, it is necessary to design meaningful narrative activities, specifying the learning aims and their relation with the created narrative.

4.5.4 NLEs Based on General Purpose Technological Tools

The literature reports on a number of learning environments based on general purpose technology, that is, not strictly oriented to the production of stories, that can be considered NLEs. They are strongly human-centred and envisage some narrative task within the overall design of a learning activity. For instance, de Vries (2006) has pupils create narrations of science classes by e-mail, with the aim of stimulating the learners to reflect on what they are learning. Dolk and Den Hertog (2006)

¹⁰ <http://www.educationarcade.org/revolution>

¹¹ <http://www.worldofwarcraft.com/index.xml>

¹² <http://secondlife.com/>

challenge trainee teachers to collaboratively develop narratives of classroom situations, with the aim of improving their ability to observe and detect learning difficulties. Makrì (2006) has trainee teachers exchange narrations of learning experiences by means of blogs, with the aim of helping them reflect on the teaching profession. Walker supports the creation of narrative trails in museums (2006a) and in botanical gardens (2006b) by means of mobile technology, with the aim of stimulating and facilitating reflection on experience. In all cases, the use of some technological tools amplifies the impact of the narrative activity.

Such environments are shaped by educational design. They are characterized by a stronger human component than the other NLE groups, because the technology they rely on is neutral with respect to narrative, so that organizing narrative activities completely relies on human intervention. Because they are not supported by narrative-oriented technology, setting them up requires knowledge of narrative learning and educational theories, in order to plan meaningful and consistent narrative tasks. It also requires controlling that the learners' activity be actually narrative, because relying on other types of discourse would obviously influence learning in a different way.

We can also place within this group of NLEs POGO (Fusai, Saudelli, Marti, Decortis, & Rizzo, 2003), an environment very different from all of those mentioned previously. POGO, which aims to facilitate children's collaborative creation of stories, is a virtual world, accessible through a number of interactive tools that are distributed in the physical environment and allow children to create and manipulate the story elements. This leads them to mix the physical (scanned drawings and objects, videos of themselves performing) and the virtual (digital elaborations) in story creation. Unlike the other NLEs in this group, POGO has a technological core. The technology used, however, even though developed specifically to appeal to children, is suitable for a wide range of operations. Moreover, good use of it requires pedagogical planning, which makes POGO more similar to the environments in this group than to those in the others.

4.5.5 Appreciating Differences

NLEs classified in different groups often appear to be similar. This similarity, however, is only superficial.

Let us compare, for instance, the interactive NLE Teatrix and an environment based on the narrative editor StoryMaker II. Both of them support story construction and stimulate creativity, but the experience of story creation is structured and developed in different ways. In Teatrix, the number of character types available is limited, but the characters are completed by a description constraining their behaviour. The environment also includes a function that detects inconsistencies, thus encouraging awareness of characters' intentions. This strongly fosters the development of narrative competence, particularly for causal reasoning. Using StoryMaker II, on the other hand, orients the user's activity towards developing communication

skills, because this editor provides multimedia facilities such as recording speech or producing spoken sentences by means of a text-to-speech tool. It offers a library of backgrounds, props and characters much richer than that provided by Teatrix, with more complex animations and more refined graphics. These features not only support the creation of more articulated and fancier stories, but also favour the acquisition of technological literacy in relation to multimedia expressive capabilities.

Crystal Island and Ecolandia also have similar aims and tasks, but differ in their functioning. Being interactive, Crystal Island does not propose pre-determined stories, but generates new variants every time, taking into account the user's behaviour and questions. Ecolandia, on the other hand, is based only on multimedia technology, so that the learners are free to move in the environment, but their possible interactions with the characters are all pre-defined. The user can only try to find answers to his/her questions by browsing through the environment's material.

It is clear from these examples that the technology used is a meaningful parameter for the classification of NLEs, because it actually influences the cognitive activities afforded and the expected learning.

4.6 Research Directions and Open Issues

The field of NLEs can be considered to be an emerging one, because its taxonomy is still an object of study, its dissemination limited and many conceptual and practical issues need to be addressed. Attention to the use of narrative to support learning is rapidly increasing, however, and we can expect a rapid development of the research in this field and dissemination of its applications.

In order to advance the field, work should be done in (at least) the following three directions:

1. *Enrichment.* Different cases of NLEs should be explored, as concerns both their structure and the topic addressed, leading to a better understanding of the field. The educational potential of NLEs should be analysed in depth, in relation to different subjects and skills. More effective and interactive environments should be researched, for example, by suitably exploiting the interaction engines developed for narrative applications without educational aims, such as narrative games and virtual storytelling systems.
2. *Evaluation.* Suitable approaches for evaluating NLEs should be worked out. This is a complex task which involves many different aspects: technical features and ease of use; activities carried out in the environment, as concerns both process and outcomes; support for improving user's learning ability; enjoyment of the experience, because this supports learning by producing a positive impact on emotion and motivation.
3. *Dissemination.* In order to make NLEs a real educational option, teachers and educators should be prepared for informed and conscious use of them, especially as concerns conceptual NLEs, which require knowledge of narrative learning and pedagogical planning. It would also be necessary to develop quantitative studies

to provide evidence of outcomes, as well as to share reports of experiences and analyses of case studies within the scientific and educational communities, so as to inspire and guide the use of NLEs in formal and informal learning.

4.7 Concluding Remarks

Narrative is a form of thought which is innate in human beings (Bruner, 1990), not simply an activity or a learning approach. As a consequence, it can support learning and skill formation with regard to cognition, motivation and emotion in the most diverse fields. Narrative learning is not an alternative to other learning approaches, but rather a possible way to complement them and improve their effectiveness. The interactive environment Crystal Island offers an example in this respect, providing an inquiry learning activity in a narrative context likely to support learner's engagement and motivation and to guide problem solving.

Another example is provided by online learning activities, which can be supported by taking place in narrative learning environments, as exemplified by NLEs based on web 2.0 and by the narrative blog mentioned in Section 4.5.4. A positive synergy between narrative and online learning is also observed in the literature by Arnold, Smith, & Trayner (2006), who point out how narrative can foster the creation and cohesion of online learning communities. This is not surprising, because narrating is essentially a social activity and hence particularly suited to a mode of learning which relies heavily on social practices. Wider dissemination of NLEs could therefore help address the issue, pointed out by Dillenbourg, Järvelä, and Fischer (Chapter 1), of supporting motivational and emotional aspects in online learning.

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Part II
Learning in Specific Domains

Chapter 5

Building European Collaboration in Technology-Enhanced Learning in Mathematics

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Abstract This chapter is concerned with the work that Kaleidoscope Network of Excellence made possible on technology-enhanced learning in mathematics. It presents some findings from two complementary initiatives that were carried out in this field: TELMA European Research Team and the Special Interest Group on Learning and Technology at Work. TELMA initiative, starting from the acknowledgement of the difficulties generated in mathematics education by the diversity and fragmentation of existing theoretical frameworks and methodological approaches, worked towards the collaboration and integration of European research teams involved in the use of digital technologies in mathematics education. Some common concepts and a methodology based on the cross-experimentation of ICT-based tools for school mathematics were elaborated and tested in real classroom settings, with the aim of analysing the intertwined influence played, both implicitly and explicitly, by the different contextual characteristics and theoretical frames assumed as reference by the diverse teams participating in TELMA. The work developed by the Learning and Technology at Work group gave the possibility to enlarge the usual perspective on mathematics learning since it allowed considering not only indications coming from school education, but also needs coming from the world outside the school and, in particular, from the workspace, where novel kinds of mathematical knowledge, techno-mathematical literacies, have become of critical importance.

Keywords Technology-enhanced mathematics education · Learning environments · Theoretical frameworks · Cross-experiments · Techno-mathematical literacy

5.1 Introduction

The advent of the microcomputer in the early 1980s brought with it high expectations regarding the potential of technology to drive change and innovation in schools. Notwithstanding the positive results produced in experimental settings

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by a number of research projects and the considerable budget invested by many governments for equipping schools with hardware and software tools, it is nevertheless true that these expectations appear to have remained unfulfilled at the level of wide school practice (Pelgrum, 1996; Sutherland, 2004; Venezky & Davis, 2002). This is true in particular for mathematics, even if, from the beginning, a wide number of researchers have been concerned with the study of the opportunities brought about by new technologies to the teaching and learning of this discipline (Cornu & Ralston, 1992; Lagrange, Artigue, Laborde, & Trouche, 2003).

Many reasons can be considered for this outcome, from those related to the traditional resistance of both the school system and teachers themselves to change to reasons more deeply related to the fact that technology has often been introduced as an addition to an existing, unchanged classroom setting (de Corte, 1996; Grasha & Yangarber-Hicks, 2000).

If one considers the character of the recommendations frequently adopted at the beginning to promote the integration of ICT in school practice, many of them seem to assume (often implicitly) that the character of ICT “use” in teaching and learning is relatively independent from the specific context of application and unproblematic (Jones, 2005). The problem was that software tools for education were often evaluated on the basis of very general, ill-defined expectations, resulting in a lack of understanding about the theoretical frameworks and the conditions under which the educational use of such tools could have been meaningful and productive (Noss, 1995).

A more critical perspective was adopted at the research level, where digital technologies have been seen as vehicles to promote change in education and to implement didactical strategies in line with the different theoretical frameworks and principles that, in the course of time, have typified the evolution of didactical research.

The tension between theory and practice has deeply characterized the educational use of digital technology and, in particular, the use of technology in mathematics education.

Moreover, mathematics education in the last decades had to confront not only the problem of how ICT might be used to improve teaching and learning processes to achieve existing curricular goals, but also the problem of the changing nature of the knowledge required in workplaces or in everyday life: what Papert calls the “what” as opposed to the “how” of learning (Papert, 2006).

One of the most acute issues in this regard, arising from recent research in workplaces (Kent, Hoyles, Noss, Guile, & Bakker, 2007), is the finding that, over the last two decades, the nature of mathematical knowledge required in workplaces has been influenced by two significant changes. The first change has been a dramatic increase in the deployment of information technologies within workplace practices. The second change is the shift to customer focus and greater transparency of processes. Taken together, these two changes have impacted on the nature of the skills (and particularly, the mathematical skills) required in modern workplaces.

New work practices increasingly involve quantitative or symbolic data processed by information technology, as part of the interactions between employees, and

between employees and customers. “Techno-mathematical literacies” are needed to reason with this kind of information and integrate it into decision-making and communication (see, for example, Noss, Bakker, Hoyles, & Kent, 2007). This change in what is required in the world beyond school is a critical issue for the “what” of school and college curricula and presents a significant challenge for those who are concerned with the analysis of how the use of ICT in classroom activities can produce significant changes both in the nature of the knowledge imparted and in the processes involved in acquiring it.

Within the frame outlined above, in this chapter two complementary perspectives, coming from the work that Kaleidoscope Network of Excellence made possible on mathematical learning with digital technologies, are considered. Both perspectives address crucial issues and needs that, up to now, have been underestimated in the research field of mathematics education. The first perspective, which is examined more in detail, is concerned with the work performed by the Kaleidoscope European Research Team in the area of technology-enhanced learning in mathematics (TELMA). The second perspective has to do with the work performed by the Kaleidoscope Special Interest Group on Learning and Technology at Work.

On the one hand, the TELMA initiative, starting from the acknowledgement of the difficulties generated in mathematics education by the diversity and fragmentation of existing theoretical frameworks and methodological approaches, worked towards the collaboration and integration of European research teams that, within different contexts and cultures, are all involved in the use of digital technologies for mathematics education in school.

On the other hand, the work developed by the Learning and Technology at Work group gave the possibility to enlarge the usual perspective on mathematics learning since it allowed considering not only indications coming from school education, but also needs coming from the world outside the school and, in particular, from the workspace, where novel kinds of mathematical knowledge, techno-mathematical literacies, have become of critical importance.

5.2 Technology-Enhanced Learning in Mathematics: The TELMA Joint Research Activity

Among the different joint research activities in Kaleidoscope, TELMA initiative has been established to focus on the improvements and changes that technology can bring to teaching and learning processes in mathematics. It includes six European teams with a strong tradition in the field.¹ TELMA’s main aim is to promote

¹ TELMA teams (whose acronyms are indicated in brackets) belong to the following institutions: Consiglio Nazionale delle Ricerche, Istituto Tecnologie Didattiche, Italy (CNR-ITD); Università di Siena, Dipartimento di Scienze Matematiche ed Informatiche, Italy (UNISI); University of Paris 7 Denis Diderot, France (DIDIREM); Grenoble University and CNRS, Leibniz Laboratory, Metah, France (LIG); University of London, Institute of Education, United Kingdom (UNILON); National Kapodistrian University of Athens, Educational Technology Laboratory, Greece (ETL-NKUA).

networking and integration among such teams and to favour the development of shared projects, common methodologies and research priorities.²

Each team has brought to the project particular focuses and theoretical frameworks, adopted and developed over a period of time. Most of these teams have also designed, implemented and experimented, in different classroom settings, computer-based systems for supporting teaching and learning processes in mathematics. Since it was clear from the beginning that, to connect the work of groups that have different traditions and frameworks, it was necessary to find some common perspectives from which to look at the different approaches adopted by each team, to find similarities and to clarify differences, it was decided to concentrate the analysis on three interrelated topics: the theoretical frameworks within which the different research teams face research in mathematics education with technology, the role assigned to representations provided by technological tools and the way in which each team plans and analyses the educational context in which the technology is employed.

As a first step towards this analysis, an investigation on current technological tools in mathematics education with a specific attention on those designed and/or used by each TELMA team was made together with the definition of a common notion able to facilitate the comparison and the interpretation of the different research projects. Then a more operative phase followed aimed at designing and testing a new methodological approach for networking research teams: the cross-experiments methodology.

In the following we briefly examine these two phases and provide some findings and observations that we have derived from such work.

5.2.1 Evolution of Perspectives in ICT-Based Systems for Mathematics Education

Research on technology-enhanced teaching and learning has undergone a deep transformation in the course of time, due to the opportunities offered by the extraordinarily rapid progress of technology and by the evolution of educational, pedagogical and cognitive science theories (Bottino, 2004; European Commission, 2004). TELMA teams have a long tradition in working in this field and, even if in the course of time their work evolved in different directions and along with different theoretical references, it is possible to single out some common perspectives and considerations.

A first consideration regards the theoretical frameworks that TELMA teams refer to. They reflect the general trends and major evolutions of the field. Even with different interpretations and focuses, the prevailing orientation is on socioconstructivist and sociocultural perspectives with an interest for tools such as microworlds [see Hoyles (1993) and Balacheff & Sutherland (1994) for an historical overview of the

² TELMA web site: <http://telma.noe-kaleidoscope.org/>

term and meaningful examples]. Microworlds are environments characterized by some primitives (objects and functions) that can be combined in order to produce a desired effect (computational, graphical, etc.). Examples of microworlds developed and used by TELMA teams are the Fraction Slider microworld developed by the ETL-NKUA team or the microworlds incorporated in the ARI-LAB-2 system developed by CNR-ITD team to support the development of arithmetic problem-solving abilities. Microworlds are built up around a given knowledge domain which has to be explored by the students interacting with the program (often in a direct manipulation modality). The Fraction Slider, for instance, provides immediate visual feedback following student manipulation of either symbolic (Logo) or dynamic (slider) representations, indicating the relative sizes of fractions by the relative positions of slider cursors. ARI-LAB-2 microworlds have been designed to model common situations in everyday life such as “purchase and sales” or “time measure” problems or to model different arithmetic fields and tools for solving problems (graphs, spreadsheets, etc.). For example, to solve a problem involving a money transaction the student can enter the “Euro” microworld where s/he can generate Euros, move them on the screen to represent a given amount, change them with other Euro coins or banknotes of an equivalent value, and so on.

In a socioconstructivist/constructionist framework, students interact with and manipulate the representations provided by the microworlds, making sense of their behaviours taking into account both the interaction and the feedback provided by the tool and the social context of the classroom.

TELMA researchers share a common sensitiveness on the fact that learning processes cannot be understood just by looking at the learners and their inner cognitive processes in interaction with the tool, but that this understanding requires to take into consideration the context in its situational, institutional and cultural dimension. The underestimation of the role played by these contextual characteristics has certainly contributed to the difficulties met in fulfilling the expectations of ICT in education. Consequently, one of the crucial areas to be investigated by TELMA teams was that related to the study of the role played by contextual issues with the aim of understanding how different backgrounds, technologies and content-related educational objectives and cultures can shape different learning environments.

The concept itself of learning environment is understood in a broader perspective, considering not only the relationship of the learner with a digital technology but the teaching and learning situation as a whole (that is, considering not only the tool but also the tasks proposed, the settings, the role played by the different actors). This is in line with current research approaches in educational computing where progressive consideration has been given to the definition of meaningful practices through which technology can be used effectively. Focus has moved to the teachers and to their needs, to the social context in which technology is used, to the ways in which teaching and learning activities integrating technology are organized, etc. (Griffiths & Blat, 2005; Monaghan, 2004).

The analysis of the social dimension of the learning process has been faced in a variety of ways that depend on the different theories assumed as frameworks. Such frameworks answer to different needs even if they share a common sensitivity to the

social and cultural dimensions of the teaching and learning processes. Some of these frameworks are strictly related to the mathematics education area as the Theory of Didactic Situations (Brousseau, 1997), deeply used by the TELMA French teams, while others, as activity theory (Cole & Engeström, 1991) referred to by CNR-ITD team or the theory of semiotic mediation (Vygotsky, 1978) referred to, for example, by the UNISI team, are more general and not specifically developed for educational purposes.

Moreover, French researchers pay a specific attention to the instrumental dimension of teaching and learning processes mediated by technology, considering, from one side, Chevallard's anthropological approach (Chevallard, 1992) and, on the other side, the views developed by Rabardel in cognitive ergonomics (Rabardel, 1995). A specific attention is thus paid to institutional values and norms and to the development of instrumented techniques, avoiding reducing them to mere skills. A fundamental role is attributed to instrumental genesis (Artigue, 2002; Lagrange et al., 2003), that is, to the process that produces in the learner the transformation of artefacts into instruments. As an example of tools produced under such framework, Aplusix, an algebra-learning assistant, developed by the LIG team can be mentioned. Aplusix has been implemented with the aim to be fully integrated into the regular work of secondary school classes and it is centred on the feedback provided by the system to students' calculations, thus helping them to verify step by step the acquisition of algebraic rules.

The brief excursus made above suggests that to understand, at a not superficial way, how the different frameworks adopted as reference by the various TELMA teams have been concretely applied to the design, practical implementation and analysis of learning environments integrating technology, it was necessary to go beyond the simple reading of papers and reports made by each team and to move towards a more concrete phase where comparison and integration among teams could be promoted in an operative way. As the matter of fact, in the research papers provided by each team, theoretical references were explicitly mentioned but it was very difficult to infer from what was written the exact role these had played in the design and management of the research projects, and thus in the analysis of the data collected and in the identification of the results obtained. The same was true for the impact of contextual characteristics, making it difficult to figure out up to what point the experience and knowledge gained in one team could be useful for the others and on what basis collaboration and integration could be undertaken.

A first level of integration was then pursued through the elaboration of the notion of *didactical functionalities of an ICT-based tool* (Cerulli, Pedemonte, & Robotti, 2007). This notion was developed as a means to link theoretical reflections to the concrete pedagogical plans that one has to face when designing or analysing effective uses of digital technologies. It individuates three main dimensions to be analysed when considering a learning environment where an ICT-based tool is integrated:

1. A set of features/characteristics of the considered ICT-based tool.
2. An educational goal.

3. The modalities of use of the tool in the teaching and learning activity enacted to reach such goal.

These three dimensions are interrelated: although characteristics and features of an ICT-based tool can be identified through an a priori inspection, these features only become functionally meaningful when understood in relation to the educational goal for which the tool is used and to the modalities of its use. Moreover, it is worthwhile to point out that when designing an educational ICT-based tool, designers necessarily have in mind some specific didactical functionalities, but these are not necessarily those which emerge when the tool is used, especially when it is used outside the control of its designers or in contexts different from those initially envisaged.

A new approach was then implemented by the TELMA group: the cross-experiments methodology (Artigue et al., 2007) where the notion of didactical functionalities has been operatively used to implement guidelines of experiments and to analyse the results obtained.

5.2.2 The Cross-Experiments Methodology

The key idea around which this methodology was built was the design and the implementation by each TELMA team of an experiment in a real classroom setting making use of an ICT-based tool developed by another team. Such experiments were constructed in order to provide a systematic way of gaining insight into theoretical and methodological similarities and differences in the work of the various TELMA teams. This is a new approach to collaboration that seeks to facilitate common understanding across teams with diverse practices and cultures and to elaborate integrated views that transcend individual team cultures. There are two principal characteristics of the cross-experiments methodology elaborated by TELMA that distinguish it from other forms of collaborative research:

1. The design and implementation by each research team of a field experiment making use of an ICT-based tool developed by another team.
2. The joint construction of a common set of questions to be answered by each team in order to frame the process of cross-team communication.

In the development of cross-experiments, an important role was given to TELMA young researchers and doctoral students. This choice was coherent with the general philosophy of Kaleidoscope and was suggested also by the wish to have “fresh” eyes looking at teams’ approaches, theoretical frameworks and consolidated practice, in order to better make explicit those factors that often remain implicit in the choices made by more experienced researchers.

Each team was asked to select an ICT tool among those developed by the other teams, as shown in Table 5.1. This decision was expected to induce exchanges between the teams and to make more visible the influence of theoretical frames through comparison of the didactical functionalities developed by the designers of

Table 5.1 The ICT-based tools employed by TELMA teams in the cross-experiments

ICT tool	Developed by	Experimented by
Aplusix ¹	LIG (France)	CNR-ITD (Italy), UNISI (Italy)
E-Slate ²	ETL-NKUA (Greece)	UNILON (UK)
ARI-LAB-2 ³	ITD (Italy)	LIG (France), DIDIREM (France), ETL-NKUA (Greece)

¹<http://aplusix.imag.fr>

²<http://etl.ppp.uoa.gr>

³http://www.itd.ge.cnr.it/arilab_english/index.html

the tool and those implemented by the team developing a field experiment using such tool. Moreover, in order to facilitate the comparison between the different experimental settings, it was also agreed to address common mathematical knowledge domains (arithmetic and introduction to algebra), to carry out the experiments with students between the fifth and eighth grades and to perform them for about the same amount of time (1 month).

Cross-experiments were developed with the aim of acquiring a better understanding of what happens when an ICT-based learning environment is implemented using a tool that has been designed under theoretical frameworks and in a context different from that of the experimenting team. This approach allowed making some step further in the analysis of the complexities involved in designing and implementing learning environments integrating technology. Each experiment had its specific goals but was also an object of collective research for TELMA, and the following issues have been particularly considered:

- What does it mean to “tune” the use of a tool to the specific pedagogical aims and research objectives of a team that has not developed it?
- What are the similarities and differences in the educational settings set up by each team to develop a teaching experiment involving the use of an ICT-based tool?
- Is it possible to unpack some of the implicit aspects embedded in tools?
- Is it possible to understand implicit theoretical assumptions that characterize the design and the development of a learning environment involving the use of an ICT-based tool?

Experiments’ guidelines were collectively built for monitoring the whole process: from the design and the a priori analysis of the experiments to their implementation, the collection of data and the a posteriori analysis. Guidelines contained all the research questions to be addressed and the experimental plans developed by each team. These plans included information on the experimental settings, on the modalities of employment of the tool and on the methods used to collect and analyse data. The research questions included in the guidelines were both questions to be addressed before the experiments and questions to be addressed after them.

At the end of the experiments, reflective interviews based on stimulated recall were organized in order to make clear the exact role theoretical frames and contextual characteristics had played in the different phases of experimental work, explicitly or in a more naturalized and implicit way.

It was hypothesized that introducing an “alien” technology would be problematic, and thus can better contribute to make visible design decisions and practices that generally remain implicit when one uses tools developed within his/her research and educational culture, and that this visibility would be increased by making explicit the requirements of the guidelines. Cross-experiments made also possible the comparison of the designs and analyses produced for the experiments with those already produced by the teams having developed the tools. Moreover, since most tools were experimented with by two different teams, it was also possible to compare their designs, implementations and analysis. All these comparisons were expected to contribute to the visibility of the role played by theoretical frames and contexts and help understand their respective influence.

For supporting such understanding, TELMA teams introduced a second basic notion: that of “key concerns” (Artigue, 2005). Concerns are issues considered functionally important as far as a specific aspect or characteristic. Behind this choice lies the hypothesis that the level of concerns is a good level for establishing useful connections between theoretical frameworks, as concerns approach these in terms of functionality, focusing on the needs they respond to. A set of key concerns was thus a priori attached to each of the dimensions of the didactical functionality construct. For instance, as regards the characteristics of a given tool, key concerns considered are related to the mathematical objects implemented and their relationships, to the actions available on these objects, to the possible interaction with other agents, to the support provided to the professional work of the teacher and to the distance with institutional and/or cultural habits and values. Similarly, as regards educational goals, it seemed interesting to investigate key concerns of epistemological nature referring to mathematics as a domain of knowledge or as a field of practice, to concerns of a cognitive nature focusing on the student in his/her relationship with mathematical knowledge, to concerns focusing on the social dimension of learning processes, and so on.

5.2.3 Some Findings from the Cross-Experiments

The first evidence provided by the cross-experiments project was that theoretical frameworks, while influencing design and analysis, were far from playing the role they are usually given in the literature. They mainly acted in the design as implicit and naturalized frames, and more in terms of general principles than of operational constructs. Even if some interesting variations can be noticed, all the teams pointed out the gap they experienced between the support offered by theoretical frames and the decisions to be taken in the design process. Theoretical frames were in general much more explicitly active in the analysis and interpretation of collected data.

This does not mean that theoretical frames did not have a serious influence on the identification of didactical functionalities and thus on the design. For instance, the influence of the theory of didactical situations (Brousseau, 1997) and of the anthropological theory of didactics (Chevallard, 1992) was evident in the choices made by the French teams. It was clear that they were expecting the tools to provide

a “milieu” for the students’ work with a strong potential in terms of a-didactic³ adaptation. This led them to pay particular attention to the feedback that tools offer to students’ actions. They were also very sensitive to the necessity of maintaining a reasonable distance between the mathematics implemented in the tool and the French institutional one, and to limit the instrumental needs. This sensitivity was increased in that specific case by the limited duration of the experiment. Such factors influenced the selection of the tools to be used, the specific educational goals attached to them and the pedagogical plans built. The other teams did not impose to their constructions the same constraints and were more open to exploratory activities. They did not feel so obliged to anticipate the possible mathematical outcomes of the student’s interaction with the tool and were less concerned with the way in which responsibilities were shared between the students and the teacher and to what could be institutionalized and how from the students’ activity.

Conversely, they were more sensitive to other key concerns. For instance, the Italian teams, relying on theories of activity, were especially concerned by the way the representations provided by the tools could act as semiotic mediators of mathematical knowledge. Their scenarios tried to maximize the learning effect of such semiotic mediations to be orchestrated by the teacher (Bartolini Bussi & Mariotti, 2008).

The cross-experiments also confirmed that the differences observed were not just resulting from differences in theoretical approaches. What was at stake was more an intertwined influence of theoretical and contextual characteristics. Some of these contextual characteristics are situated at a rather global level. For instance, the institutional pressure was stronger in France than in Italy and Greece, reducing the space of freedom of the researchers and teachers involved in the experiments. Some are more local. They contribute to explain why teams sharing the same culture (as was the case for the two Italian teams), and using the same tool (Aplusix), developed quite different pedagogical plans.

Another point that is worth mentioning is that it was useful to compare not only the experimental designs but also the way the different teams analysed the data they had collected, and how they invested in this analysis their theoretical constructs. This comparison showed the TELMA teams how their respective tools for design analysis could complement each other to provide a better understanding of the learning phenomena at stake and, in some cases, challenge the interpretations made by one team providing it with alternative ways of thinking, or make unexpected events highly predictable. From this point of view, the results of the a posteriori interviews (Artigue, 2006) were especially valuable.

Finally, thanks to cross-experiments and to the constructs developed for planning and evaluating them, the assumptions lying behind the design of the tools considered

³ The notion of a-didactic adaptation is attached to the notion of a-didactic situation, a core concept in the theory of didactical situations. This notion denotes a situation where students behave “mathematically”, forgetting for a while that the situation has been built with a precise educational goal, freeing themselves from the pressure of the didactic contract. For an elementary introduction to the theory of didactical situations, see Warfield (2006).

were made clearer and teams got a clearer vision of the kind of theoretical integration they could achieve. Moreover, developers were provided with new ways of employing their tool and, thus, new perspectives to the design process itself were offered. Teams also gained the conviction that theoretical networking or integration cannot be achieved just by reading and discussing. Knowledge in this domain, as in any other, can only result from collective practice, organizing the communication between different cultures in appropriate ways. In TELMA this is done with the cross-experiments methodology and with the didactical functionality construct and the meta-language of key concerns.

As shown by the research on communities of practices, communication can be also supported by the identification of some boundary objects (Lee, 2007). In the TELMA cross-experiments, two different notions have apparently played such a role: the notion of instrument and that of a priori analysis, which as expressed in Artigue (2007)

has become progressively shared, not, of course, for each of us with the meaning given to it in the theory of didactical situations, where it originated, but filled with what our different approaches found reasonable to try to anticipate and control (p. 79).

Such notions are to be more widely tested to investigate their potential for supporting comparison as well as the development of connections and complementarities among teams.

5.3 Technology-Enhanced Learning in Mathematics: Considering Techno-mathematical Literacies Outside School

The analysis of ICT evolution in education indicates that there is a widely assumed appreciation that in the design of ICT-based learning environments the whole learning situation should be considered, that is, not only the tool, but the teachers who will be using the software, the ways in which it will be used, the curriculum objectives, the social context and way in which learning is organized. TELMA work shows up to what point such systemic views are also necessary following collaboration and integration between research teams working in different contexts and cultures about the educational use of digital technology.

However, at this point, we reinstate our earlier remarks concerning the novel kinds of mathematical knowledge – techno-mathematical literacies – that have become necessary as a result of the ubiquitous but largely invisible mathematical relationships built into ICT systems in workplaces, and elsewhere. In recent workplace-based studies⁴ focusing on mathematical knowledge (see, for example,

⁴ The work referred to was performed both within the Learning and Technology at Work Kaleidoscope Special Interest Group and in the Techno-mathematics in the Workplace project (funded by the Teaching and Learning Research Programme of the Economic and Social Research Council – 2004–2007) by the group composed of Richard Noss, Celia Hoyles, Phillip Kent, Arthur Bakker, Chand Bhinder and David Guile.

Noss et al., 2007), the techno-mathematical literacies (TmL) needed by a wide variety of employees in four manufacturing and service sectors in the UK were investigated. From the point of view of this chapter, the relevant findings emerged from a series of iterative design-based experiments undertaken with employer-partners, to design learning opportunities to develop the TmL identified in the first phase. Learning opportunities incorporated technologically enhanced “boundary objects” that modelled elements of the work process or were reconstructions of symbolic artefacts from workplace practice (Lee, 2007). The learning opportunities were embedded in activity sequences largely derived from authentic episodes recorded in the ethnographic studies or reported by employer-partners and aimed to allow exploration and discussion of the interconnections between the different inputs and outputs within the (normally invisible) models.

The researchers isolated three aspects of workplace learning that were consistently successful across the workplace sectors, namely

- Authenticity, in which situations derived from actual workplace events can be the subject of discussion and reflection.
- Visibility, in which hitherto invisible relationships become visible and manipulable.
- Complexity, in which relationships are represented in non-trivial ways that reflect real situations, but alternative representations are used which avoid conventional and usually problematic algebraic symbolism.

While these principles concern workplace learning, they do, we think, have lessons for broader learning contexts (including schools); moreover, they illustrate the reciprocal relationship between knowledge and pedagogy – how, for example, an engagement with new kinds of knowledge can catalyse new approaches to learning (and vice versa). The promise of digital technologies, particularly, in allowing authentic and complex models to be probed, manipulated and modified, offers genuinely novel epistemological as well as didactical opportunities to introduce modelling as mathematical knowledge in new and hardly tested ways (see, for example, Wilensky, 2003).

Moreover, the increasing necessity to pay attention to a knowledge characterized by significant new attributes such as accelerated production, continuous change, distribution in terms of geography and community through a variety of media and tools brings with it that an increasing importance has to be given to contextual aspects and to skills such as, for example, logical and strategic reasoning. Since problems posed in social and work settings are currently subject to constant change and do not lend themselves to pre-determined solution schemes, critical thinking, under an increasing mass of stimuli, is to be systematically cultivated as a key factor for growth. Further, the increasing need to wade through vast amounts of distributed information emphasizes the importance of capacities related to information problem-solving (Vakkari, 1999), especially the capacity to select, re-organize and integrate information and to be able, as mentioned before, to deal with quantitative information presented in different visual and iconic representations.

The workplace and societal perspectives thus add new epistemological and concrete indications to school mathematics, especially for the provision of a basic knowledge that takes into account the new needs posed by the digital revolution. Techno-mathematical literacies are required to be developed in order to provide all students with skills and abilities that can support them in becoming effective members of a flexible, adaptable and competitive workforce and to engage in lifelong learning.

5.4 Conclusion

In conclusion, we are acutely aware of the importance of coordinating different perspectives and methodologies for throwing light on problems of technology-enhanced learning. This is a general issue, transcending the school disciplines, but each of these disciplines raises specific problems. Regarding the particular case of mathematics, the Kaleidoscope Network of Excellence allowed European researchers involved in mathematics education to approach this issue from a diversity of facets, both in its transversal and specific dimensions. We have tried to reflect these characteristics in this chapter by presenting the complementary advances made possible through the ERT TELMA and the SIG Learning and Technology at Work. The interrelationships between the various teams participating in TELMA allowed a productive investigation of contexts, settings and methodologies, which would have been difficult – if not impossible – without the involvement of a network like Kaleidoscope, allowing us to use differences between groups to assess what really might be invariant among them. TELMA allowed the joint development of a methodology, the cross-experimentation methodology, and of specific constructs, such as didactical functionality and key concerns. The initiative showed the effectiveness of these developments for promoting communication and coordination among different theoretical perspectives and contexts in research studies concerning technology-enhanced learning in mathematics. Even if nested in a specific discipline, mathematics, these results have certainly a more general value.

In a complementary way, the advances of the Learning and Technology at Work group (and its national “TmL” project) allowed to expand the approach on technology-enhanced learning in mathematics beyond the sole school perspective so common in research studies in this area. The work performed opened up the possibility of bringing perspectives from the workplace where, thanks to a reflection carried out in a different and more global context, novel kinds of mathematical knowledge, techno-mathematical literacies, have assumed a critical importance.

This cross-fertilization – of school and workplace settings – is a pointer, perhaps, to a more interesting issue which merits further investigation. Mathematics in school is a rather special kind of entity, an (almost) arbitrary “sliver” (as Papert has called it) of mathematical thought, and one which is most often divorced from any contextual reality (except, of course, the artificial reality of mathematical “problems”). Workplaces are, on the contrary, rich in contextual knowledge, and in so far as they

deal with abstractions at all, these are always embedded within situations and – most crucially – technologies. By bringing these two settings together, we hardly solve the problem of making mathematics more meaningful for learners, but we can, at least, delineate some of the roles for technology in both contexts.

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Chapter 6

Integrated Digital Language Learning

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Abstract While the field of technology-enhanced language learning (TELL) is undeniably thriving, most technology-enhanced language tools are still relatively crude. One reason for this is that the field is disconnected from research in natural language processing (NLP) and corpus linguistics (CL), two fields which could greatly improve the effectiveness of most pedagogical tools. The research carried out within the framework of the Kaleidoscope Network of Excellence aimed to demonstrate that it is both possible and desirable to integrate insights from NLP and CL into TELL to produce more powerful and effective tools. In the article we give a general outline of NLP and CL techniques and highlight their relevance for TELL. We also describe two types of integration that were implemented within the framework of Kaleidoscope: (1) integration of NLP processing into the glossary of the *Moodle* Learning Management System; (2) integration of error-tagged learner corpus data into *Exxelant*, a web-based error interface for teachers and researchers. The chapter also argues the case for optimising the role of language in all technology-enhanced learning applications, whether language focused or not.

Keywords Natural language processing (NLP) · Language learning · Computer-assisted language learning (CALL) · Technology-enhanced language learning (TELL) · Corpus · Learner corpus · Learning Management System · *Moodle* · Glossary · Error · Error tagging · Error feedback · Error interface

6.1 Introduction

Technologies have never been as much in the forefront of language learning as they are now. They have admittedly played an ever increasing role ever since the introduction of audiolingual methods, but today we are truly witnessing a technological explosion in the field, with a host of new developments such as web-based

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learning platforms, computer-mediated communication, blogs, wikis, whiteboards and the use of mobile devices such as iPods, PDAs and mobile phones. In this technology-rich environment, one would expect close links with two highly relevant language-related fields, namely natural language processing (NLP) and corpus linguistics (CL). Both are clearly of high relevance for language learning and teaching. NLP provides tools capable of automating language analysis and providing feedback on learner productions. CL offers large quantities of text in electronic format and tools to explore them quickly and efficiently. However, the impact of NLP and CL on technology-enhanced language learning (TELL) is still very limited, as attested by the very small number of articles dealing with these issues in major scientific journals. It is symptomatic, for example, that Chun's (2007) survey of major topics tackled in the latest issues of CALICO does not contain a line on those research strands. Most TELL specialists are still not aware of the relevance of NLP and CL. The three scientific communities remain quite separate, each with their own paradigms, terminology, scientific journals and conferences. Although some special interest groups are very active,¹ integration is still minimal. There are several reasons for this. One major factor is that NLP techniques are not foolproof and language practitioners do not want to have to deal with errors due to the software used. The fact that corpus linguistics is still a very young field also plays a role. As demonstrated by Mukherjee's (2004) survey among English-language teachers in Germany, the majority of language teachers show little familiarity with corpus tools and methods.

In this chapter we focus on these two neglected but highly promising aspects and report on a small-scale project carried out within Kaleidoscope to demonstrate the contribution that they can make to TELL. Sections 6.2 and 6.3 of this chapter give a brief overview of NLP techniques and corpus linguistics methods and tools and highlight their respective relevance for language learning and teaching. In Section 6.4 we describe the obstacles to the integration of NLP and corpus techniques into TELL and suggest ways of circumventing them. In Section 6.5 we demonstrate the feasibility of integration by describing two prototypes designed within the framework of Kaleidoscope: an intelligent glossary and a web-based error interface. In Section 6.6 we widen the perspective and highlight the potential impact of this type of research on the general field of technology-enhanced learning.

6.2 Natural Language Processing

Natural language processing is a multidisciplinary research field, at the crossroads of linguistics, computer science and artificial intelligence. It deals with the problems of understanding and generating natural human languages. Among the many NLP techniques, the following are particularly relevant for TELL: tokenisation,

¹ For example, EUROCALL's NLP Special Interest Group and CALICO's Intelligent Computer-Assisted Language Instruction group.

morphological processing, syntactic processing, speech recognition and synthesis and concordancing.² Here is a quick review of these techniques, starting from the simplest ones:

- *Tokenisation* is the very first operation of text processing: it consists of segmenting a text, that is, a sequence of characters, to get a sequence of lexical units, or tokens (e.g. punctuation marks, numbers, words). This simple operation leads, for example, to spell checking, by comparing the resulting tokens with recorded lists of inflected forms.
- *Morphological analysis* aims at analysing the morphemes that compose lexemes, in order to determine their morphological category (part-of-speech or POS), features (inflections), components (affixes) and canonical form (lemma). In many languages, state-of-the-art tools allow automatic POS-tagging and lemmatising with a very good accuracy (over 95% precision). Such analysis allows for many interesting applications: error diagnosis, as when the learner uses a correct form with an erroneous inflection (Kraif and Ponton, 2007), or glossing inflected terms in a text, as in the intelligent glossary described in Section 6.5.1.
- *Syntactic parsing*, usually taking POS-tagged and lemmatised texts as an input, aims at extracting dependency relations between lexemes, or hierarchical relations between phrases (constituents). Parsing is required, for example, to detect the erroneous verbal inflection in the following utterance: *The inhabitants of this country *suffers from malnutrition*, where the head of the noun phrase bearing subject function is *inhabitants* and not *country*. Because of syntactic ambiguities and computational complexity limitations, this analysis remains a tricky problem for unconstrained utterances. The best parsers hardly get fewer than 25% errors for standard written language, without full coverage of the sentences. Improved parsing would be a huge step forward for error detection and analysis.
- *Speech recognition* aims at discriminating through an acoustic signal the sequence of phonemes – and then lexemes – that composes the oral message. It is a particular problem of form recognition: discrete structures must be extracted from a continuous signal where many variations occur (tempo, pitch, accent, voice, intensity) without being relevant. Although considerable progress has been achieved with probabilistic models of language, these techniques are highly problematic and get low results for unexpected messages in a noisy environment.
- *Speech synthesis* is the reciprocal process to recognition. Text-to-speech systems are designed to convert written utterances (sometimes with phonetic and prosodic indications) into their oral form, using various parameters such as pitch, tempo and voice tone. It is an easier problem than recognition and many everyday life devices, such as GPS and phones, already implement this technology. The final quality depends closely on prosodic processing, which is an essential component for communication.

² Other major NLP techniques, such as machine translation, will not be described here as they are arguably less relevant for TELL. See Mitkov (2003) for a comprehensive overview of the field.

- *Concordancing* is dedicated to the extraction of examples from a corpus, searching for a given expression and its surrounding context. Concordances are often presented in KWIC (keyword in context) format, where left context, key expressions and right context appear in aligned columns. Modern concordancers allow searching not only for character strings but also for lemmas, compound units and morphosyntactic features, including NLP formalisms such as finite state automata or regular expressions. By sorting the data in various ways, users have easy access to the typical use of words or phrases. For example, a search for the verb “argue” in a corpus of native English academic writing instantly brings out the typically passive use of this verb in patterns like *it can/could/might be argued that. . . or it has been argued that. . .*

Because it is as old as modern computer science, NLP has yielded many mature technological outcomes in various fields such as machine translation, dialog generation, spell and grammar checking, information retrieval, speech recognition and speech synthesis. Applications for language learning appear to be a natural extension of these technologies. As stated by Nerbonne (2003),

NLP focuses on how computers can best process language, analyze, store, sort and search it. It seems natural that NLP should be applied to the task of helping people learn language (p. 678).

NLP techniques are indeed numerous and cover a wide range of needs in language engineering. More than 20 years after the beginning of the rapprochement between NLP and computer-assisted language learning (CALL), many prototypes or experimental systems have been developed. For instance, some systems make use of POS-tagged and lemmatised texts to generate gap-fill exercises where the gaps are selected on the basis of morphosyntactic and/or semantic criteria (e.g. only personal pronouns or only time adverbs are gapped) (Antoniadis et al., 2004; Selva, 2002). Other systems, such as the Exills platform (Brun, Parmentier, Sandor, & Segond, 2002), give the learner access to NLP-enhanced linguistic tools (conjugators, disambiguated dictionaries, tagging, language identification, etc.) as an aid to producing and understanding utterances in a virtual environment.

Surprisingly, however, commercial systems are extremely rare and research developments remain at the stage of prototypes. This is due to the following three factors:

- The lack of reliability of NLP technologies.
- The high cost of NLP research and development and the lack of system modularity.
- The lack of interdisciplinary communication (didactic/linguistic/NLP).

Concerning the last two points, the NLP community is currently striving towards standardisation and one sees more and more “generic” resources with free software development (concordancers, taggers, lemmatisers, etc.). Generally, these programs do not require any modification other than the adaptation of the input/output formats and of the basic parameters. In view of the current state of the art, using the simplest tools is likely to bring major improvements, which more than compensate for the

modest investment made (see Section 6.5). As for collaboration between language practitioners and NLP specialists, various projects or networks such as Kaleidoscope demonstrate that it is clearly underway even if there is still scope for greater synergy.

6.3 Corpus Linguistics

Corpus linguistics can be defined as a linguistic methodology that is founded on the use of large electronic collections of naturally occurring texts, namely corpora. There are many different types of corpus: spoken and written, monolingual and multilingual, diachronic and synchronic, etc. Some corpora are meant to be representative of a language as a whole and therefore contain texts from a wide range of written and spoken sources (fiction, journalese, academic writing, informal conversation, political speeches, etc.). A good example of this type of corpus is the *British National Corpus*³ (Aston & Burnard, 1998). Others, like the *Micase* corpus of academic spoken English,⁴ are more limited in scope and cover only one text type. One relatively new corpus type that is particularly relevant for language learning and teaching is the learner corpus containing written or spoken data produced by foreign-language learners (for a survey of learner corpus research, see Granger, 2008a,b). For example, the *International Corpus of Learner English* (ICLE) CD-ROM contains writing produced by learners from 11 different mother tongue backgrounds (Granger, Dagneaux, & Meunier, 2002).

The fact that corpus data are in electronic format makes it possible to automate the analysis of a large amount of data. First, the data can easily be quantified; second, it is easy to get accurate information on the preferred environment of linguistic items; and third, it is possible to enrich the data with a wide range of linguistic annotations, notably by means of NLP techniques such as lemmatisation or POS-tagging.

In the following, we illustrate the power of corpus techniques with reference to learner corpora.

1. *Frequency*. Text retrieval software tools such as *WordSmith Tools* (WST) (Scott, 2004) are language-independent programs that enable researchers to count and sort words in text samples automatically. Using these tools, researchers have immediate access to frequency lists of all of the single words or sequences of words in their corpora. Lists derived from learner corpora can be automatically compared to lists based on comparable native speaker corpora, thereby revealing the words or phrases that learners tend to over- or underuse. By way of illustration, Table 6.1 lists the 10 most underused verb forms in the ICLE corpus as

³ A simple search service for the BNC is offered at <http://www.natcorp.ox.ac.uk/index.xml>.

⁴ The online, searchable part of the Micase corpus is available at <http://quod.lib.umich.edu/m/micase/>.

Table 6.1 Top 10 underused verb forms in the ICLE corpus

	Verb form	Keyness
1	described_VVN	554,7
2	seen_VVN	423,8
3	suggests_VVZ	363,1
4	argues_VVZ	332,9
5	required_VVN	330,0
6	remained_VVD	287,2
7	obtained_VVN	249,4
8	shown_VVN	242,9
9	appears_VVZ	233,7
10	held_VVN	231,9

compared to a comparable native academic corpus ordered in decreasing order of keyness.

2. *Patterning*. Corpus tools included in packages like WST, in particular phrase (or chunk) extraction and concordancing, are very powerful heuristic devices for uncovering recurrent patterns of use, or to put it another way, words' preferred lexical and grammatical company. Applying the phrase extraction method to a corpus of EFL speech and a comparable native speaker corpus, de Cock (2004) shows that EFL learners significantly underuse discourse markers such as *you know* or *I mean* and vagueness markers such as *sort of* or *and things* and therefore prove to be lacking routinised ways of interacting and building rapport with their interlocutors and of weaving in the right amount of imprecision and vagueness, both typical features of informal interactions. On the other hand, concordancers make it possible to extract all occurrences of a given lexical item (single word or phrase) in a corpus and sort them in a variety of ways, thereby allowing typical patterns to emerge. The concordance of the verb *argue* in learner writing highlights a preference for active structures such as *people argue* or *some people may argue*, which differ from the typical passive pattern brought out by the native concordance.
3. *Annotation*. In corpus linguistics terms, the term "annotation" refers to "the practice of adding interpretative (especially linguistic) information to an existing corpus of spoken and/or written language by some kind of coding attached to, or interspersed with, the electronic representation of the language material" (Leech, 1993, p. 275). In learner corpus terms, this means that any information about the learner samples that the researcher wants to code can be inserted in the text. Although there is no limit in principle to the type of annotation that can be used to enrich a learner corpus, two are by far the most commonly used: morphosyntactic annotation and error annotation. While the first type of annotation is an NLP technique (see Section 6.2), the latter is still largely manual. It consists of marking each error in learner corpora with a standardised system of error codes together with the error correction. For example, the above-mentioned error *The inhabitants of this country *suffers* will be coded as a grammatical error affecting a lexical verb and belonging to the category of concord errors. The correct form

suffer is also included with the appropriate mark-up. Error-tagging is a highly complex and time-consuming process, but it is a necessary step for automatic error detection.

6.4 NLP, Corpora and TELL

Both NLP and corpus research have a major role to play in TELL. NLP makes it possible to analyse language in much more sophisticated ways and several widely available NLP tools could easily be integrated into TELL applications. This said, NLP technologies are not 100% foolproof and their relative unreliability is a major obstacle, as the didactic context precludes the integration of erroneous input or feedback. For this reason, learner production analysis remains a problematic task. The more promising attempts concern very constrained contexts, where production variability is finite. Heift and Nicholson (2001) describe “German Tutor”, a tutoring system that involves syntactic parsing of learner answers, with a high accuracy. Kraif and Ponton (2007) give a global framework for short answer analysis and error diagnosis and present an experiment that shows how very simple NLP techniques may yield high accuracy when comparing the learner’s answer with an expected one. As suggested by the latter authors, it is advisable to favour such modest integration of NLP tools.

More realistic NLP applications in TELL concern the use and processing of native and learner corpora. Corpora give language teachers a practically inexhaustible source of examples of “real” native language, the type of language that the students will have to use in communicative situations. NLP makes it possible to search not only for character strings, but also for linguistic forms, namely lemmas, morphemes, morphosyntactic features, functional relations or complex patterns. This vastly extends the potential of corpus analysis and enhances searching functionalities in monolingual or multilingual corpora (Kraif & Tutin, in press).

Native corpora can be conceived of as large repositories of examples that illustrate specific linguistic phenomena, ranging from lexicon to morphology, syntax, phraseology, terminology and even translation (in the case of a multilingual corpus). NLP techniques are useful for adding comprehension aids to these texts: lemmatisation allows linking of inflected forms with entries in a dictionary (Antoniadis et al., 2004), and the results of automatic annotation may be directly displayed to the learner in order to help him understand the lexicon and grammar structure (Dokter & Nerbonne, 1998; Dokter, Nerbonne, Schurcks-Grozeva, & Smit, 1998).

Another promising development is the possibility of searching for new examples at each query (by a random selection of the parsed texts). By dynamic retrieval of examples, new activities can be generated every time the system is accessed. This is the case for Alfalex (Selva, 2002), where gap-fill exercises allow practicing of French inflectional and derivational morphology, conjugations, prepositions, collocations, etc., with sentences that are extracted on-the-fly from a corpus. The data-driven learning approach has given rise to a large amount of work, resources

and systems (Tribble & Barlow, 2001), which could be greatly enhanced by the addition of simple NLP techniques.

In their error-tagged format especially, *learner corpora* constitute an unparalleled resource that provides a very accurate profile of learners' degree of accuracy, complexity and fluency in the target language. They lend themselves to two types of pedagogical uses: direct and indirect (Römer, 2008):

- *Direct use.* Learners can compare data extracted from learner corpora and compare them with similar data from native corpora to discover differences between the two. Data-driven learning activities of this type may contribute to raising learners' awareness of their own difficulties and promoting learner autonomy (Bernardini, 2004).
- *Indirect use.* Materials designers can use learner corpora to draw up catalogues of learners' attested difficulties and thereby ensure that the pedagogical materials meet learners' needs. Learner corpus insights can be integrated into TELL in two different ways:
 - Non-NLP based: production of remedial TELL resources that tackle recurring errors (cf. Granger, 2003: CALL exercises targeting attested errors produced by learners of French as a Foreign Language; Chuang & Nesi, 2006: web-based resource called *GrammarTalk* which tackles recurring errors made by Chinese students).
 - NLP based: use of NLP techniques to design automatic error detection and feedback systems (cf. Izumi, Uchimoto, & Isahara, 2004; L'haire, 2004; Vandevanter, 2001). The main weaknesses of these techniques are their low precision and recall rates: results are disappointing for a wide range of error types and more corpus analyses are needed to improve the overall success rate. Learner corpora can be used as a benchmark to assess the efficiency of various NLP techniques. As demonstrated by Metcalf and Meurers (2006), different types of word order errors call for different processing: those involving phrasal verbs (e.g. *they give up it*) can be handled successfully by means of instance-based regular expression matching, while errors involving adverbs (e.g. *it brings rarely such connotations*) require more sophisticated parsing algorithms. A corpus containing learner errors is useful in determining which errors fall within the scope of which technique.

6.5 NLP-Enhanced TELL Applications

Two prototypes have been designed within the framework of Kaleidoscope⁵ with a view to demonstrating how simple NLP techniques and learner corpus insights can be used to enhance TELL:

⁵ The prototypes have been developed in the framework of the Integrated Digital Language Learning (IDILL) project, funded within the framework of the Kaleidoscope Network of Excellence. <http://www.noie-kaleidoscope.org/group/idill/Home/>.

- Integration of a POS-tagger into the *Moodle* glossary function.
- Design of a web-based error interface, *Exxelant*.

6.5.1 Intelligent Glossary

Glossing consists of providing additional information on words (definition, translation, additional examples, grammatical information, etc.). Several studies have demonstrated that computerised reading with full glossing may promote vocabulary acquisition. Constantinescu (2007) studies the benefits of CALL for vocabulary acquisition and reading comprehension and comes to the conclusion that “one great way to increase vocabulary acquisition and retention is the use of computerised reading passages enhanced with various types of glosses”. The use of electronic glossing is supported by other studies such as Lomicka (1998), Al-Seghayer (2001) and Yoshii (2006).

According to these studies, glossing of difficult terms would seem like an essential tool for language learners’ vocabulary acquisition. Some programs have been designed for this purpose, for instance the *Glosser* system which involves advanced morphological analysis (Dokter et al., 1998; Dokter & Nerbonne, 1998; Nerbonne, Dokter, & Smit, 1998). However, these tools tend to be stand-alone platforms and many – like *Glosser* – have been discontinued. In today’s educational institutions, the adoption of one Learning Management System (LMS) for the whole institution is often recommended. The concurrent use of another learning environment is difficult to manage for both teachers and learners. The best solution is therefore to adapt existing LMSs and/or create tools that are portable to other platforms. Preference should be given to well-disseminated open source platforms such as *Moodle* for at least two main reasons. First, they can be run with limited resources and support and can therefore contribute to reducing the digital divide globally. Second, these platforms have a very large user base and being part of a lively community of users worldwide is a real boost for both teachers and learners.⁶

Despite their usefulness, glossaries are rarely present in Learning Management Systems. Botturi’s (2004) survey of nine LMSs shows that only five of those tested have a glossary. In addition, existing glossaries tend to be quite rudimentary and user unfriendly. *Moodle*, the top LMS today and arguably the best (cf. Graf and List, 2005), is an exception. Its glossary is more sophisticated, as it includes an auto-linking functionality. As soon as a word or phrase is entered in the glossary, it will automatically show up in each new text where the word or phrase appears. This is clearly an improvement which allows for “economies of scale” for the teacher. However, the glossary has two major flaws. First, it is linguistically crude, as it relies on simplistic pattern-matching techniques: to be recognised, a word needs to have

⁶ *Moodle* has over 400,000 registered users in 193 countries and several discussion groups, including a special “*Moodle* for Language Teaching” forum. More information can be found on the *Moodle* website: <http://moodle.org/>.

exactly the same form as the word entered in the glossary.⁷ For instance, the forms *went* and *go* are not recognised as forms of one and the same lemma GO. Even if the basic form *go* is already in the glossary, the form *went* will not be automatically linked to the glossary entry. The glossary is not “intelligent”, that is, it does not rest on any linguistic analysis. Second, the interface makes it difficult for teachers to correct any erroneous link. As part of the Kaleidoscope project, we have remedied these two flaws by (1) integrating a POS-tagger into the *Moodle* glossary tool and (2) improving *Moodle*’s text view interface.

For the first operation, we opted for the *TreeTagger*, an open source POS-tagger developed by the University of Stuttgart⁸ which has the advantage of being available for several languages. We integrated the English version of the tagger into *Moodle*. The entire text goes through the tagger, which outputs the grammatical categories and basic word forms of each word. As a result, the form *provides*, for example, is analysed as an inflected form of *provide* and automatically linked to the glossary entry *provide*.

The second stage, namely the improvement of the teacher interface, is all the more necessary as the POS-tagging is not 100% error-free. For instance, depending on the context, *leaves* can be considered as the plural of the noun *leaf* or as the third person singular of the verb *to leave*. This is not straightforward for a computer program, which often generates the wrong analysis. Therefore, we needed to be able to provide teachers with ways to correct these mistakes, as it is not acceptable to provide learners with resources that contain errors. It was therefore necessary to give teachers quick and easy control over the glossary links. In the new interface, when a teacher is logged in and enters a new text, all of the words in the text are clickable and open a pop-up window, in which there is either the glossary entry for this word if it is already in the glossary or an empty entry if it is not. A box was added in the pop-up window that could be ticked if the teacher wanted to remove a link and another box if the teacher wanted to correct an erroneous link (e.g. if *leaves*, plural of *leaf*, is in the text but it is automatically linked to the verb *leave*). Providing user-friendly interfaces is essential for all technology-enhanced tools, as it can boost acceptance among teachers who often – and at times quite rightly – view them as disruptive rather than sustaining innovations.

6.5.2 Error Interface

As part of the Kaleidoscope project, we have designed a web-based error interface, called *Exxelant*⁹ (Granger, Kraif, Ponton, Antoniadis, & Zampa, 2007), that can give researchers, teachers and learners easy and versatile access to authentic learner

⁷ It is possible to add variants to the glossary but this is cumbersome for teachers, especially in the case of languages with extended morphology.

⁸ <http://www.ims.uni-stuttgart.de/projekte/corplex/TreeTagger/DecisionTreeTagger.html>.

⁹ *Exxelant* stands for EXample eXtractor Engine for LANguage Teaching.

The screenshot shows the EXXELANT v.1.0 interface. At the top, there are logos for Université Stendhal and kaleidoscope. The main title is 'EXXELANT v.1.0 (Exemple eXtractor Engine for LANGUAGE Teaching)'. Below this, there are three dropdown menus for 'Sélection du corpus': 'Provenance' (toutes), 'Densité d'erreurs' (toutes : 0 à 60), and 'Longueur des textes (nombre de mots)' (tous : 29 à 3003). The 'Recherche d'expression' section is divided into three columns: 'Contexte gauche', 'Terme', and 'Contexte droit'. The 'Contexte gauche' column has fields for 'Forme', 'Lemme', 'Catégorie' (nom), and 'Intervalle (nb mots)'. The 'Terme' column has a 'Recherche dans une erreur?' dropdown (oui), a 'Si erreur' dropdown (domaines d'erreur: Tous les domaines), and a 'Termes / terme erroné' section with fields for 'Forme' (qui), 'Lemme', 'Catégorie' (toutes les cat), and 'Trait'. Below this is a 'Correction' section with fields for 'Forme' (que), 'Lemme', 'Catégorie' (toutes les cat), and 'Trait'. The 'Contexte droit' column has fields for 'Forme', 'Lemme', 'Catégorie' (toutes les cat), and 'Intervalle (nb mots)'. At the bottom, there are two buttons: 'Ok pour ces valeurs' and 'Nouvelle interrogation'.

Fig. 6.1 Search for errors concerning the confusion between “qui” and “que” as a relative pronoun

errors and their corrections. Taking as input an XML formatted corpus, which contains error annotations and morphosyntactic tags, this tool allows extraction of examples using a query system that combines various kinds of criteria: error category, part-of-speech, corrected forms, error-prone forms, learners’ mother tongue and level. As part of the project, the tool has been tested on a POS-tagged version of a corpus of learner French, the FRIDA corpus.¹⁰

To illustrate how *Exxelant* works, we take the example of teachers wanting to investigate learners’ errors affecting relative pronouns, and more particularly cases where the subject pronoun *qui* is used instead of the object pronoun *que* in environments where the pronoun has a noun as a left-hand context. As shown in Fig. 6.1, the interface is divided into two main parts. The first (*sélection du corpus*) allows users to select the corpus: source (whole corpus or only part of it), error density (numbers of errors per 100 words) and text length. The second part (*Recherche d’expression*) allows users to specify their query on the basis of the left-hand context, the term (errors and/or correction) and the right-hand context. In our example, we are searching for an erroneous term (i.e. “forme=qui” and “erreur=oui”) for which the corrected form is “que” (i.e. “forme=que”). This term must be preceded by a noun (“catégorie=nom”). Such a query outputs sentences such as “*Les étudiants qui [que] j’ai rencontré pendant le cours m’ont aidé à m’intégrer sans problème*”. Users can access the complete learner production for each sentence.

¹⁰ The FRIDA learner corpus (FRench Interlanguage DAtabase) is a corpus of French as a Foreign Language compiled within the framework of the EU-funded FreeText project (Granger, Vandeventer, & Hamel, 2001, Granger, 2003).

Although *Exxelant* was initially designed for teachers, it has many features in common with Hegelheimer and Fisher's (2006) *iWRITE* system which was designed to be used directly by learners in activities of noticing and collaborative error solving. As pointed out by the authors, the tool "can be used to raise learners' grammatical awareness, encourage learner autonomy, and help learners prepare for editing or peer editing" (p. 270). *Exxelant* could easily be adapted to perform similar functions.

The expansion of the Internet makes it possible to share and disseminate these resources and systems, which could greatly contribute to the expansion of corpus use in language learning. Several CALL systems now use and exploit raw or annotated corpora; the care taken in compiling and annotating these corpora contributes greatly to the overall quality of the programs.

6.6 Conclusion: From TELL to TEL

This study has pleaded for greater integration of natural language processing and corpus insights into TELL. Things are clearly moving as regards corpora, as evidenced by the fact that one of the latest issues of *ReCALL* journal is entirely devoted to "Integrating corpora in language learning and teaching" (Chambers, 2007), but as pointed out by the editor, the articles in the volume "represent only part of the potential of this developing area" (ibid: 250). In particular, learner corpora deserve more attention than they have received so far. As for NLP, one of the main factors that account for the current lack of integration was pointed out by Holland over 10 years ago and is still valid today:

The most important reason for this failure is that NLP (Natural Language Processing) programs which underlie the development of ICALL cannot account for the full complexity of natural human languages (Holland, 1995, p. viii).

However, we claim that there is no need to wait until NLP can account for the "full complexity" of language to bring NLP and TELL closer together. The research carried out within the Kaleidoscope network has demonstrated that it is possible and indeed desirable to integrate NLP technologies, provided certain conditions are met: (1) only technologies that have a high degree of reliability are used; (2) the techniques are used in carefully selected contexts; and (3) teachers are given full control over the output to facilitate correction in case of error. In other words, what we need is a judicious combination of audacity and caution. Combined use of NLP and CL techniques can lead to a great leap forward in automatic error feedback and automatic rating, two fields where Milton (2002) suggests "it is particularly worth investing in research" (p. 24).

In this project, we have focused on web-based environments, and more particularly on Learning Management Systems. Our study confirms that LMSs need to be adapted to meet the needs of the different fields as suggested by Graf and List (2005) and Kukulska-Hulme and Shield (2004). Future research should focus on fuller adaptation of LMSs to the discipline of language learning, and the components of the ideal LLMS, that is, Language Learning Management System, should be

identified and implemented. At this stage, it is still debatable whether a totally new type of platform should be built or whether existing platforms such as *Moodle* can be expanded with discipline-specific interoperable modules. Another avenue for future research lies in the rapid development of mobile language learning environments (Chinnery, 2006; Gilgen, 2005; Kiernan & Aizawa, 2004; Kukulska-Hulme, 2007). The migration of NLP and corpus technologies to these new environments is one of the major challenges for the TELL agenda.

But integration should go further than that. Natural language is ubiquitous in technology-enhanced learning (TEL): it is present in both the input (texts, instructions, scripts) and the output (answers to exercises, collaborative writing, etc.) of the learning process and is the main channel of interactive communication between the tutor and the learner and between the learners. Sophisticated automatic analysis should therefore be a major feature of all TEL applications, in both hard and soft sciences, not only in language learning. It can help develop new types of scaffolding tools which will foster independent inquiry by learners. Intelligent glossaries, for example, have a role to play in all disciplines. Medical TEL applications, for example, would clearly benefit from an intelligent glossary of medical terms automatically linked to multimedia files and hyperlinked to domain-specific corpora for additional examples. On the other hand, learner output that consists of language – be it in the form of answers to questions or interactions via email, forum, blog or chat – is a particularly rich type of “trail” left behind by learners in TEL environments (cf. Chapter 12). These language trails can be submitted to a wide range of linguistic analyses, some of which, such as automatic discourse analysis (cf. Hilbert, Lobin, Bärenfänger, Lungen, & Puskás, 2006), are particularly relevant. The applications seem limitless and constitute a near virgin territory waiting to be explored.

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Chapter 7

Novel Technology for Learning in Medicine

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Abstract In this chapter we will present some medical educational approaches together with their links to different learning objectives and learning situations. We will also present various forms of computer-based technology, which aim to enhance the teaching and learning capabilities of doctors, mostly in the form of 3D visualisation, simulation and haptic technology. We will focus on research conducted in the areas of spinal anaesthesia, surgery and emergency. Finally, we will emphasise some challenges of our domain which are related to the interaction between medical education, technological and computer factors.

Keywords Technology-enhanced learning · Simulation · Medical education · spinal anaesthesia · Surgery and emergency

7.1 Introduction

The nature of postgraduate medical training in Europe is changing greatly. The main determinants of this change are the European Working Time Directive (fewer teaching and learning hours available), the increase in transnational mobility of doctors (trainees and independent practitioners), altered patient expectations, the Bologna Accord and new forms of governance of training and practice. The implication of these changes is that doctors have a reduction in training opportunities. Traditionally medical education was based on an experience-based model (apprenticeship), where junior doctors and medical students learn the procedures on real patients (thereby exposing patients to inexperienced practitioners). As this training procedure becomes less and less acceptable or appropriate, young doctors will acquire less “hands-on” training during everyday work situations, in particular in psychomotor skills.

With respect to medical skills, the aim is for trainees to practice skills in a safe environment, before refining them in the real world. These “paradigm shifts” in

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medical education, where the focus is on expertise rather than experience (Aggarwal & Darzi, 2006), require new tools, educational theories, teaching techniques and curricula. Different types of technology-enriched learning environments are presented in this chapter as examples of innovative instructional approaches that can speak to these training needs. Technology-enhanced learning (TEL) provides a safe, standardised way to practice complex skills (Lajoie & Azevedo, 2006).

The educational approaches for medical education that are presented in this chapter explicitly take into account the different learning objects and pedagogical settings that are at stake. Moreover, this chapter also presents various forms of computer-based technology which aim to enhance the teaching and learning capabilities of doctors, mostly in the form of 3D visualisation, simulation and haptic technology. We will focus on research conducted in the areas of spinal anaesthesia, surgery and emergency.

Finally, we will challenge the relationship between medical education, technological and computer factors.

7.2 General Framework of the Presented Studies

A largely accepted model of the development of expertise considers that expertise emerges through the concomitant development of a cognitive model and an operative model of the activity (see, for example, Samurçay, 1995). Theory is necessary to practice, and practicing allows the reorganisation and operationalisation of theory. The more the subject has been confronted with a variety of situations, the more efficient he is, which means that he can easily adapt his action to a new situation. In this context the appeal of TEL environments is obviously in allowing the learner to be confronted with situations he could not have met, or dealt with, in real settings. Particularly in hospitals, and for evident reasons, learners are never left “alone” to solve a problematic situation. Taking a constructivist point of view which assumes a personal construction of knowledge through interaction with a situation, we aim to design environments that will complement the traditional model of learning in medicine.

In this context, this text will describe different TEL environments involved in problem-based and problem-solving situations. These situations are either integrated in the “operating under supervision” phase or constitute an additional phase, aiming at enhancing the articulation between theory and practice (Vadcard & Luengo, 2005). The related technologies constitute a very important and relevant category of TEL environment for medical training, that is, simulations. Within this wide category we will distinguish different kinds of simulators according to their technological characteristics and accuracy (Romero, Ventura, Gibaja, Hervás, & Romero, 2006):

- *Screen-based simulators* are the most classic type; typically the user indicates the sequence of action using the presented interface and the system shows the state result of this manipulation. It can provide customised feedback. If this

kind of simulator is executed remotely over the Internet it is called a Web-based simulator.

- *Virtual reality* is a technology allowing a user to interact with computer-generated space and objects which are presented in a three-dimensional format and sometimes with sensory information (sound, tactile, etc.). Uses range from anatomy instruction to surgery simulation (particularly in laparoscopy). Utilisation of virtual reality in the medical fields is thought to incorporate the latest research.
- *Training devices and part-task trainers* are of intermediate fidelity and allow users to acquire the skills for a specific task prior to patient contact.
- *Realistic simulators* are realistic human simulators, including an organ or a life-mannequin which simulates a real patient. Special sensors allow detection of the face mask and tracheal tube. Several pre-programmed events, including patient bucking, cardiac arrest and changes in blood pressure, can be activated.

In the next sections we develop some examples of learning situations using these kinds of TEL environments, developed by Kaleidoscope Network of Excellence teams.

7.3 Operating Under Expert Supervision: The Case of New Training Devices

In Europe, learning to be a surgeon is a 13-year-long process. The seven final years are dedicated to practical education. In most European hospitals, every operation is performed by both a surgeon and a resident. The latter is given increasing responsibilities during the operation, under the supervision of the expert, according to his/her degree of acquired expertise. This is the “professional hands-on training” phase. This phase has proven its efficiency in the training process, particularly in the development of practical skills and procedural knowledge. However, it has some limitations.

The fact that professional hands-on training is not safe for the patient is one classically described aspect. Let us also point out some other aspects which are more related to an epistemic point of view of this training process.

First of all, it is important to note that the surgeon must assume two roles during real operations. He must be both the expert, thus performing the operation well, and the teacher, providing the resident with the essentials that allow him to understand the whole activity (actions performed, controls required, organisational constraints, etc.). But, as it is now well known, experts know much more than they can express (Schön 1983) Empirical knowledge, built during their years of practice, is encapsulated in the action and cannot be verbalised by the expert. This means that part of the knowledge at play during the operation cannot be grasped by the resident.

Another important aspect of professional hands-on training is that the surgeon is first an expert. This means that he will take charge of the operation as soon as he considers that the resident is not able to perform it correctly. In educational terms this means that the resident often cannot solve a problem by himself/herself.

The surgeon shows him the solution. This last point illustrates the perspective that technology-enhanced learning can offer to complete professional hands-on training with problem-solving environments. Added to the fact that residents' training is refined by the cases on which they assist during these 7 years, the further value of TEL for medical education becomes evident.

Some other aspects of learning/operating under expert supervision might include the nature of the trainer (expert)/trainee interaction (relationship) as an important determinant of learning procedural skills (we will develop here an example based on some original data related to using a procedure).

Important aspects of this relationship include the physical location of each relative to the other, perceived conflict between service delivery and education, multiple roles for trainer/expert and trainee (e.g. for the expert: custodian of patient safety, teacher, future decision-maker regarding trainee's career, health service provider), implicit and explicit expectations and definition of roles within a formal structured training programme.

The transition from the "command performance" (i.e. under expert supervision) to independent practice is also a specific aspect of professional hands-on training. For procedural skills, some evidence exists that proficiency demonstrated in a simulated setting can be reliably translated into performance in a clinical setting (Gallagher & Satava, 2002). The implication is that the value of "expert supervision" can be captured in the form of a very detailed curriculum and results in clinical error rates which are lower than those associated with clinical apprenticeship training.

7.3.1 A Case Study Analysis of Usage of Training Devices for Minimally Invasive Surgery

Minimally invasive surgery presents new obstacles for surgeons attempting to acquire laparoscopic skills. This surgical technique is performed with the help of a camera and long instruments introduced through small incisions into the body. Laparoscopic surgery brings a lot of advantages, particularly for the patient (very small incisions, smaller risks of infections, etc.). For all these reasons, minimally invasive techniques are now ubiquitous and indispensable in the management of surgical disease. However, despite the clinical benefits, significant challenges have been noted: the view of the surgical site is indirect and restricted, the surgeon must observe and manipulate tissues and organs through very small incisions with long and rigid instruments, tactile perception is lost, the feedback of the action is principally visual with a 2D image and finally, the degree of freedom for the instruments' movements (DOF) is restricted at 4. All of these drawbacks are responsible for the long learning curve observed in the training of residents (Forbes, DeRose, Kribs, & Harris, 2004; Sidhu et al., 2004). A new robotic system has been designed in order to suppress the main drawbacks of classical laparoscopy: it permits 3D visualisation of the operative field and the DOF lost in classical laparoscopy.

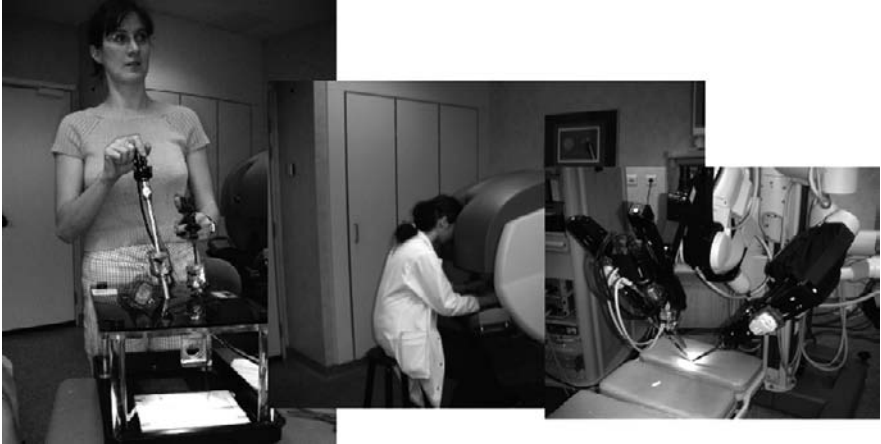


Fig. 7.1 Example of training devices in classical laparoscopy (photo on the *left*) and with the robotic system (*centre and right* photos)

In this context of new technology introduction, the University of Liège evaluated the training of medical students and residents in these two techniques (classical and robotic laparoscopy) using bench model inanimate trainers (see Fig. 7.1). Bench model tasks consisted of a “pick and place” task, checkerboard, rings route, circular pattern cutting and suture and knot. All of these tasks were validated by previous studies. We measured speed and accuracy for each task and we asked subjects to answer a questionnaire on their subjective impressions about their performance (satisfaction, self-confidence and difficulty). Data showed that training with these two techniques improved the performance and gesture accuracy of participants differently (Blavier, Gaudissart, Cadière, & Nyssen, 2007). Classical laparoscopy that is performed with a 2D view and low dexterity required more practice than the robotic system that is more intuitive in the view mode and gestures. A 2D view is less natural and requires more controlled cognitive processes and thus entails specific training in order to act in a 2D world (as shown in cognitive psychology, Marotta & Goodale, 1998). Furthermore, training with one technique did not lead to mastery of the other technique: the transfer of skills from one technique to the other was very difficult (Blavier, Gaudissart, Cadière, & Nyssen, 2007). In conclusion, training with both techniques out of the operating room must be differentiated and the training must be more intensive in classical laparoscopy.

Furthermore, these studies showed that using bench models allows us to understand better the nature of the cognitive and motor processes involved in the execution and control of laparoscopic gestures (Blavier, Gaudissart, Cadière, & Nyssen, 2007). This allows us to improve the quality of the training devices. Moreover, if bench models improve surgical performance out of the operating room, several studies have also shown that the skills acquired on bench models transfer to the operating room (Hamilton et al., 2002). In contrast to animals or cadavers, the principal advantages of bench models are their low cost and the possibility of

repeating the same task several times at any time and thus evaluating the training or assessing a performance (Gallagher & Satava, 2002; Stone & McCloy, 2004). Finally, studies show a benefit of the training in the improvement of performance but also in the feelings of mastery, familiarity, satisfaction, self-confidence and facility, which are essential factors of well-being, motivation, accurate performance and new technology acceptance in the operating room (Blavier, Gaudissart, Cadière, & Nyssen, 2007; Hamilton et al., 2002; Issenberg et al., 1999). Based on all of these characteristics, most studies encourage the use of bench models in parallel to traditional learning in the training of surgical skills.

7.3.2 Using Haptic Technology to Enhance Spinal Anaesthesia Training

Performance of spinal anaesthesia comprises cognitive knowledge, psychomotor, social and affective skills (judgements, confidence, etc.). Typically, cognitive knowledge of anatomy and pharmacology is achieved before fine psychomotor skills (procedural knowledge) of needle insertion are practiced in the operating room. Medical trainees are currently taught this technique using an apprenticeship approach, that is, watching an experienced anaesthetist and subsequently performing the procedure under supervision.

There is a concerted effort to improve medical training through the use of state-of-the-art technology. However, an aspect that has been overlooked in the design of this technology is the fine psychomotor dimension of learning. As a collaborative effort, the Department of Anaesthesia at Cork University Hospital and Interaction Design Centre, University of Limerick, investigated the feasibility of designing novel learning technology to assist the training of hospital doctors in performing a spinal anaesthesia (DBMT).¹ The team consists of a multidisciplinary group of researchers: medical doctors, system developers and a psychologist. All researchers were involved in all the phases of the design process, however, to a greater or lesser extent. The case studies that were conducted in order to identify key determinants of learning and teaching a spinal gesture were designed and conducted by the medical experts with methodological support from the psychologist. The system developers designed and re-designed the haptic device in close collaboration with the medical doctors and the psychologist. The testing of the final prototype was conducted in Cork University Hospital with all parties involved.

The case studies involved 66 subjects including patients, anaesthetists-in-training, consultant anaesthetists, surgeons and nurses. The results identified a variety of different determinants, including affective factors such as “time or schedule pressure” and “interpersonal dynamics of trainer and trainee” and cognitive factors such as background knowledge (Kulcsár, Aboulafia, Hall, Sabova, & Shorten, 2008).

¹ The project, named Design-Based Medical Training (DBMT), was funded by the Health Service Executive, Ireland, 2006 (<http://www.dbmt.eu/>).

The first prototype development of the simulator focused on the psychomotor skill of haptic perception. The identification of the correct placement of a spinal needle was argued to be the most difficult task to perform and also to explain to trainees. The doctor must place a needle in the thin layer of fluid that surrounds the spinal cord. As there are no visual clues, the doctor “feels” the resistive forces as the needle passes through the different layers (skin, subcutaneous tissue and ligaments). Verbal explanation of these sensations to trainees is obviously very difficult, and as mentioned by trainers, recognition and identification of the different (haptic) sensations can only be learned through experience, although the importance of having a mental representation of the anatomy and the procedure was also emphasised.

Among many contributions to understanding mechanisms of senses, Weber at the University of Leipzig (1818–1871) made important discoveries concerning the sense of touch in skill development (Ross & Murray, 1996). He argued that touch becomes more sensitive with practice. Since Weber, haptic perception has received much less scientific attention than vision and hearing.

Derived from the case studies, and supported by Weber, we hypothesised that, through practice, doctors learn the haptic sensation of each layer of tissue and consequently are able to recognise the correct location for injection of anaesthesia.

7.3.2.1 Prototype Development and Initial Evaluation

Before attempting to construct a simulator, a trial was proposed to test the above hypothesis using virtual reality technology and a PHANTOM haptic device (from Sensable Technologies Inc.), which supplies mechanical force feedback to the user. Based on a single expert anaesthetist, a model was proposed with a parameter space of simulated tissue sensations. A comparative study involving 25 anaesthetists (experts and novices) was later conducted, which indicated that expert anaesthetists are able to recognise the “correct” haptic or force feedback for each layer of tissue, although it was not clear if they also have acquired a more “sensitive touch” as suggested by Weber. The study did however provide the basis for developing a simulator that is able to capture the haptic sensations involved in spinal anaesthesia.

The interface is a model of a spine and includes visual feedback. Figure 7.2 shows the setup of the system that is being tested by an anaesthetist using 3D glasses. A spinal needle was attached to the PHANTOM’s mechanical arm in order to create a more realistic “hands-on” sensation.

The spine can be rotated, which enables the user to see where the needle has been inserted. From a training point of view this feature was important. Next to being able to “feel” the way through the different layers, visualising the process was also identified by trainees and trainers as critical to learning this technique.

A number of evaluations of the simulator have been conducted with expert and novice anaesthetists. The results are promising, as the haptic sensations were perceived as very similar to those encountered during the real procedure. However,

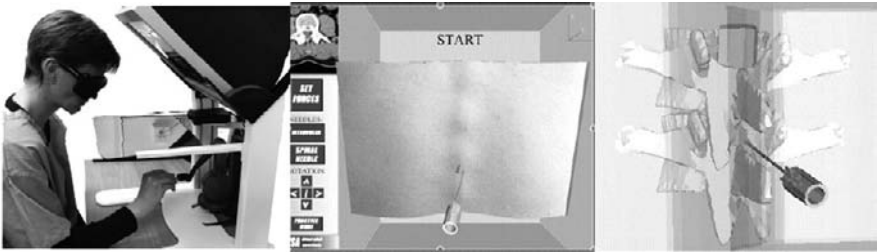


Fig. 7.2 The haptic device setup and screen shots of the interface

besides an accurate simulation of psychomotor procedures such as haptic sensations, a successful training tool will require curriculum, functionality that allows rehearsal and practice, links to educational information and testing capabilities (Shaffer et al., 2001). The development and design of such a complete training tool for spinal anaesthesia, including a valid and reliable competence assessment procedure for cognitive, affective and psychomotor skills of medical trainees, is currently ongoing.²

7.4 Problem-Based Learning and Simulation of Clinical Material

In problem-based learning (PBL), problems are used as a focus for integrated learning of basic science and clinical knowledge along with clinical reasoning skills. In short, the main goals of PBL are to guide students to become experts in a field of study and to facilitate the acquisition and the application of knowledge. According to a model by Barrows (1996), there are six core characteristics of PBL: (1) student centred, (2) small groups under tutorial guidance, (3) the tutor as facilitator/guide, (4) starting with authentic problems, (5) problems as a tool to achieve knowledge and (6) acquisition of new information through self-directed learning. A seventh point was later added: students learn by analysing and solving representative problems. PBL students are asked to put their knowledge to use and be reflective and self-directed learners. Conventional instruction, in contrast, is marked by large group lectures and instructor-provided objectives and assignments (Albanese & Mitchell, 1993). However, PBL obviously means different things to different people, so its applications vary considerably. The range of meanings and connotations makes it difficult to come to a universal definition (see Gijbels, Dochy, van den Bossche, & Segers, 2005).

² The research project “MedCap” is a 2-year project (November 2007 to November 2009) funded by Lifelong Learning Programme Leonardo da Vinci. It involves five partners in four countries (<http://www.medcap.eu/partners.html>).

7.4.1 Implementing a PBL-Based Curriculum for Medical Students

Implementation of a PBL-based curriculum requires increased staffing and greater access to learning resources. Selection and design of the scenarios to be used depend on clear definition of a core curriculum which is integrated with clinical elements. The success of PBL tutorials depends largely on the effort invested in writing and presenting and refining scenarios and on the performance of the tutor. Well-designed scenarios and suitable “trigger material” will prompt the students to formulate specific learning objectives which lie within the scope of the module. Each group (8–10 students) will appoint a “scribe” and a “chair” and, with the facilitation of a tutor, will apply itself to the problem presented. One widely used process follows the so-called Maastricht “seven jumps”. These are: definition of terms and problems; “brainstorming”; review/restructuring of explanations; definition of learning objectives; private study; results shared and assessment.

7.4.2 Empirical Evidence

In addressing the efficacy of PBL within medical education, it is necessary to define the outcome of interest. The medical knowledge acquired by students who complete PBL-based and traditional curricula appears to be similar (although knowledge retention may be superior in the former). These curricula also do not differ in the resulting clinical performance measures of their graduates (Colliver, 2000). Perhaps the apparent lack of benefit in PBL-based curricula may be due to the selection of outcome measure applied. Lycke, Grottum, and Stromso (2006) demonstrated that students in a PBL-based programme practiced more self-regulated learning and made use of a broader range of resources than those in a traditional programme.

In a meta-analysis of 43 quasi-experimental empirical studies, Dochy, Segers, van den Bossche, and Gijbels (2003) addressed the main effects of PBL on knowledge and skills. They were also able to identify several moderators of these effects (type of assessment, for example). This analysis as well as earlier literature reviews (see Gijbels et al., 2005, for an overview of six systematic reviews on PBL) concludes there is a robust effect of PBL on skills, while results for knowledge are inconclusive, but tend to be negative. While Gijbels and colleagues (2005) did not limit their literature search to the domain of medical education, all of the 40 studies meeting the selection criteria (e.g. empirical studies, course or curriculum comparison) for their meta-analysis on the effects of PBL came from that domain except one study from the field of economics. In contrast to the fact that PBL has been widely adopted, claims about its effects seem to rely almost exclusively on literature in medical education.

7.4.3 PBL and the Role of Technology-Enhanced Learning

The logistic and organisational limitations to making PBL “work” in the real world may be addressed using technology as a vehicle, enabler or facilitator. Some of core characteristics of PBL present by Barrows (1996) are considered in turn:

Student centred. Students learn what they are ready to learn. The personalised learning environment (PLE) is an ICT resource which enables an individual to access learning tools or services. The personal elements (e.g. personal hosting, portfolio) are blended with formal shared or community elements so that the learner identifies his/her own learning profile and learning path.

Tutor/facilitator. The high-fidelity simulator centres used for training in medicine and healthcare tend to offer learning sessions to small groups facilitated by one or two experienced trainers. Each scenario will be designed to achieve well-defined objectives. The format usually entails a briefing (familiarisation), simulation and debriefing sessions.

Authentic problems. The authenticity of the simulated environment will depend on both the scenario design (by experts) and the degree of immersion achieved by the simulation. Although unproven, it is likely that both of these sets of factors determine the extent to which learning benefits are transferred into the clinical setting (Ahlberg et al., 2007).

Problems as a tool. The subject matter for simulated scenarios is frequently a “critical event” (Gaba et al., 1998). Benefits include the learning related to events which occur infrequently during an “apprenticeship” and the absence of risk to patients during the “learning by doing”. The opportunities to address human factors, communication and “crew resource management” may be less obvious.

7.4.4 Collaborative Learning and PBL in Simulation-Based Learning

The socio-cognitive activities of collaborating individuals can initiate various cognitive and meta-cognitive processes, for example explaining a situation, asking thought-provoking questions, elaborating together, exchanging arguments in a discussion, resolving cognitive divergences or modelling cognitive strategies (see King, 2007). However, these activities usually do not emerge spontaneously from a collaborative learning situation. In fact, group losses are more often observed than group benefits (Hertel, 2000). With respect to collaborative learning this means that at least some of the learners might learn less in the collaborative situation than they would when learning on their own.

Empirical research from various domains has shown that so-called external collaboration scripts are a promising approach to compensate for the problems described above (King, 2007). In short, a collaboration script is a directive that distributes roles and activities among learners and can also include content-specific

support for the completion of a task (for a more detailed description of the collaboration script approach see Chapter 10).

In a recent study, Zottmann, Dieckmann, Rall, Fischer, and Taraszow (2006) investigated the effects of a collaboration script in the observational learning phases of a full-scale simulator course with video-assisted debriefing in anaesthesia. Their aim was to foster the individual and collaborative learning processes of the participating students for more focused and active participation, as well as the individual learning outcome of the ability or skill of applying heuristics to cope with a medical crisis situation (see Rall & Gaba, 2005). While the intervention was rather short, the expected positive effect of the script was found with regard to the learning processes, suggesting that further research should be conducted on the implementation of collaboration scripts in medical training situations.

7.5 Problem Solving: A Case Study of Screen-Based and Web-Based Simulations Design

The problem-solving educational approach is slightly different than the previous one, taking much more account of the knowledge involved in the problem resolution process. It is also a less often adopted approach in medical education than problem-based learning.

Within this educational approach the intent is thus to build problems which will allow the targeted knowledge to be developed by the subject during the problem-solving process. The authenticity of problems in this approach is not material but rather consists in an epistemic validity related to real work situations. It thus requires the design of training-oriented situations from work situations.

Relevant components of the situations are identified by analysis of the real activity, both from an expert point of view and from a training point of view. These components are then used to design problem situations that will be specific for the learning of this particular domain.

The “interaction” that we assume between the learner and the situation during the learning process implies that the situation itself can react, according to the learner’s actions (Brousseau 1997). This so-called feedback must be relevant for the learning perspective and the targeted knowledge. The feedback accompanies the subject in the learning process, by provoking reinforcements, destabilisations, hints and scaffolding, for example.

The TELEOS (Technology Enhanced Learning Environment for Orthopaedic Surgery) project assumes that a TEL device can produce relevant feedback for apprenticeship if it reacts according to an internal validation of the learner’s solution process.

The screen shots (Fig. 7.3) of the TELEOS system show how the simulator allows the trainee to position a pin in a pelvis, with appropriate visual feedback (X-rays during the process and transparency of tissues after the user’s confirmation). The aim is to train learners to place a pin which will be a guide for the placement of an

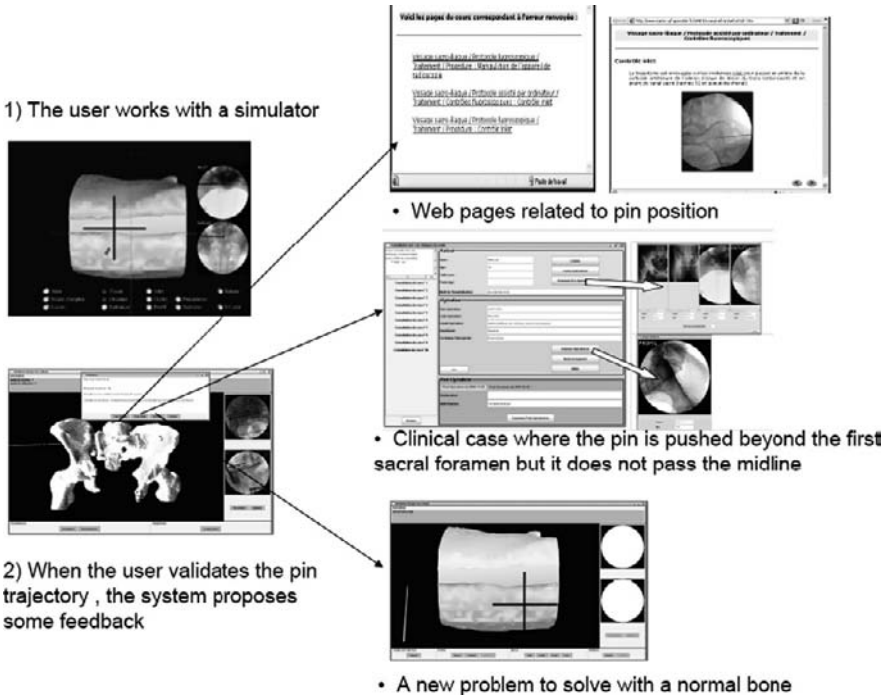


Fig. 7.3 TELEOS feedback examples

ilio-sacral screw. This operation is percutaneous; this means that the validation of the pin’s position is made through obtained X-rays.

The learning objectives of TELEOS are as follows: first, training in the correspondence between the two phenomenological domains of the 2D X-rays and the 3D body of the patient; second, learning the range of applicability of declarative pieces of knowledge according to the characteristics of the situation (age of the patient, type of lesion, etc.). TELEOS bases the system feedback on consistency checks of learner’s actions rather than on a priori solutions. The user solves a problem using web simulation software. Tracks of the user’s actions are analysed by the system in terms of their possible relationship to identified conceptions. A conception is an organised set of problems and pieces of knowledge. This cognitive diagnosis allows the system to make a didactic decision which determines the feedback to be given to the user.

As the declarative knowledge, gathered in an online course, indicates the validation criteria of a pin’s trajectory for a general case, thanks to real situations cognitive analysis we have identified that each particular situation leads the surgeon to adapt this declarative knowledge. In some cases, the surgeon even seems to violate the prescription. We have called these adaptations of knowledge in a situation, “empirical knowledge”, to emphasise their links to the reality of encountered situations. The different kinds of feedback proposed in TELEOS are calculated according

to the cognitive diagnosis: as declarative knowledge is related to the redirection to a precise part of the online course, empirical knowledge is related to clinical cases to consult (playing the role of illustrations or counterexamples of the actions performed) and to the simulator (other problems are proposed, according to those previous and their treatments) (Luengo & Vadcard, 2005).

Let us take the example of a problem to solve, involving a patient who has a particularly dense bone (Fig. 7.3). The user's solution (the pin's trajectory) takes into account the particularities of this situation (in this case the pin can be stopped earlier than prescribed). As the trajectory is considered to be correct in this case, but only in this case, the system's learning objective will be to ensure that the domain of validity of this empirical knowledge is well known. It will thus calculate the appropriate set of feedback: the first feedback is related to the declarative knowledge, that is, the system proposes a set of Web pages related to the pin position; the second feedback is related to the empirical aspect, in that the system proposes another problem to be solved where in this case the bone is a normal one, not particularly dense; the third kind of feedback is an example or counter example, so that in this case the system proposes consulting a clinical case that shows the possible consequences of this solution applied to a normal bone (the pin will not be well enough anchored and has a good likelihood of getting out of the bone within a few days).

The challenge of this problem-solving environment is the adequacy of the system's reactions – feedback – with the user's knowledge. This adequacy relies on the calculation of a cognitive diagnosis based on the user's actions (Luengo & Vadcard, 2005).

7.6 Challenges

Modern simulation (3D, haptic, full scale, etc.) in medicine allows the performance of professional gestures of surgeons or doctors in a quite realistic environment. However, these environments have limited capacity to efficiently support training because of the difficulty of providing learners with the relevant feedback in the relevant form (Blavier et al., 2007; Issenberg et al., 1999).

This issue is related to a problem known from TEL research for two decades: the representation of expert knowledge (Clancey, 1983) or full-scale realistic simulations are not sufficient to provide reliable and efficient learning environments. The problem has specific complexity because the knowledge concerned is not explicit enough.

Hence, a critical issue in the design of TEL for medical training is the relationship between technology and training effectiveness. In the minimal invasive surgery case, we showed that new learning situations for novel technology are needed. In other cases, novel technology is necessary in order to improve the learning of particular skills, as we showed in the spinal anaesthesia case.

There are promising potential applications for simulation-assisted learning in the field of medical procedural skills because of its ability to provide hands-on

learning in a risk-free, realistic environment. However, much of the research to date has focused on reproducing the physical and sensory environment and only thereafter evaluated it as an educational method. It is of course important to evaluate the simulator as an educational method, but designing simulators for training also implies designing educational activities and context. The argument here is thus that the principles listed below, including pedagogical questions, should be incorporated into the design process from the beginning:

- Learning outcomes, including core competencies, should be defined and be integral to the development and implementation of the learning systems.
- A multidisciplinary approach should be applied to the design and evaluation of technology, through an iterative design process.
- The applications of such systems should include not just training, but selection for specialty training, credentialing (and re-credentialing) and competency-based assessment.
- The role of human–human and human–machine interaction should be factored into the development of training programmes at the design stage.

The case studies we have presented show that sometimes the training device must be as realistic as possible, as in the spinal anaesthesia example, and at other times the device does not need to recreate this level of “realism”, as in the case of the bench models for the minimal invasive surgery. We have also shown that on the one hand TEL environments need an appropriate learning situation (e.g. the collaboration script for PBL example), but in some cases, the learning situations must use specific tools (e.g. the orthopaedic surgery case).

For us the main challenge is to put forward computer tools, based on educational and cognitive science theories (Lillehaug & Lajoie, 1998), to re-think the TEL system in order to achieve adequate apprenticeship realism and to organise the feedback, which is linked to an interpretation of the user’s actions in terms of knowledge used.

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Chapter 8

Technology-Enhanced Learning in Science

Eleni A. Kyza, Sibel Erduran and Andrée Tiberghien

Abstract This chapter investigates the supportive role of new technologies in science learning. The first part presents the theoretical underpinnings of technology-enhanced learning (TEL) in science, framing TEL in the context of current socio-cultural view of science learning as inquiry. The second part discusses the potential of TEL, which is organized around the potential of learning technologies to make science learning authentic and to provide the tools to sustain engaged participation in making sense of the physical and the natural world. Examples of learning technologies are presented and discussed.

Keywords Learning technologies · Science education · Inquiry

8.1 Introduction

As new technologies are increasingly being portrayed as pivotal to reform initiatives, the Kaleidoscope Network of Excellence was formed with the explicit goal of exploring the future of technology-enhanced learning (TEL). In this chapter, we discuss the supportive role of TEL in science education. The argument is unpacked by discussing the theoretical underpinnings of technology-enhanced science learning and the potential of new technologies for learning in science education.

We begin our discussion with a theoretical framing of technology-enhanced learning in science. The first issue concerns the relation between cognitive, epistemological, and sociocultural accounts of knowledge growth in science learning. Substantial amount of research has investigated children's cognitive development (e.g., Carey, 1985), theory change in science (e.g., Giere, 1991), and the sociocultural foundations of learning (e.g., Anderson, 2007). An important implication is that cognitive, epistemological, and sociocultural criteria and conditions that drive scientific theory change might be useful for supporting students' science learning in

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the classroom and can guide the design of technology-enhanced learning environments. We then turn our attention to the potential of new technologies to support learning in science, and we contextualize our discussion with respect to the learning goals related to scientific inquiry. We conclude by discussing the contribution of technology-enhanced environments to promote science learning.

8.2 Theoretical Framing of Technology-Enhanced Learning in Science

There is worldwide dissatisfaction with the quality of science education (Bransford, Brown, & Cocking, 1999; Osborne & Dillon, 2008). Among others, Bransford and colleagues point to the incongruence between the state of knowledge about science learning and the expectations on learning goals in the current education system in the United States, while Osborne and Dillon emphasize that there are problems with both the nature and the structure of science education efforts in Europe. These authors argue that the state of science teaching today is far behind current societal expectations and needs of a scientifically literate citizenry.

A fundamental tenet of modern learning theories is that different kinds of learning goals require different approaches to instruction and that new goals for education require changes in opportunities to learn. Reform proponents call for a socio-constructivist, learner-centered approach to science education, one that places emphasis on inquiry learning as the means to learn scientific content and acquire life-long skills to enable them to reason scientifically (also see Chapter 2). Scientific literacy has been defined as “the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities” (National Research Council, 1996, Chapter 2). In this chapter we argue that scientific literacy, which includes understanding of the scientific concepts and skills and understanding the nature of science, has to be a primary goal for inquiry-based science learning and teaching today and that new technologies have the capacity to support the attainment of this goal.

One’s theoretical perspective about how science learning happens influences the design and implementation of technology-enhanced learning. The question of the relation between learning theories and the design of technology-enhanced learning is complex. There are many theoretical perspectives in science learning while some components of the design of specific learning software, or of an effective teaching sequence, may be compatible with different aspects of the theoretical components (Design-Based Research Collective, 2003).

Recently several review papers have appeared on general orientations of research in science education (Anderson, 2007), on science learning (Scott, Asoko, & Leach, 2007), and on a historical perspective of an important research stream of science learning, conceptual change (diSessa, 2006). It appears that several traditions or perspectives emerge from these reviews, each one of them having the capacity of

changing the design and role of learning technologies in the classroom, and thus affecting science learning. Leach and Scott (2003) discuss individual and sociocultural views as the two main theoretical strands in science learning. The individual strand, which has its main roots in Piagetian constructivism, has been described using such terms as “conceptual change tradition” (Anderson, 2007) and “cognitive approaches” (Scott et al., 2007). A distinctive approach of this current is its focus on the role of the *individual* students’ prior knowledge which is frequently in conflict with the conceptual knowledge to be acquired. This conflict is often referred to in the history and philosophy of science in terms of scientific revolution proposed by Kuhn (1970). A seminal paper by Posner, Strike, Hewson, and Gertzog (1982) proposed that

the conditions needed for a major change in thinking with a scientific field (such as the shift from an Earth-centered to a Sun-centered model of the solar system) were considered analogous to the conditions needed to bring about accommodation or conceptual change in individual learners can occur. These conditions are that a learner must first be dissatisfied, with existing ideas and then that the new ideas must be seen as intelligible, plausible, and fruitful (pp. 35–36).

Similarly, Anderson (2007) has emphasized that this current on conceptual change explains “the failure of students to learn the science that they are taught in schools in terms of hidden conflicts – conflicts between scientific conceptual frameworks and their own experience” (p. 14).

The second theoretical strand is the *sociocultural* one, which has its roots in Vygotsky’s work. As Sutherland, Lindström, and Lahn (Chapter 3) discuss, the sociocultural perspective situates learning in human practice and views this activity as mediated by tools and actions. The social context plays a major role in learning, without neglecting the role of individual with the process of internalization. The view of scientific knowledge in the sociocultural perspective is different from that of the conceptual change perspective: “in contrast to conceptual change researchers’ emphasis on scientists’ dialogues with nature, sociocultural researchers focus primarily on scientists’ dialogues with people” (Anderson, 2007, p. 18). The sociocultural theory of learning has been pivotal in developing research on computer-supported collaborative learning environments, as well as on focusing the research on the interacting agents in any learning situation which, according to this perspective, can facilitate or hinder learning. The idea here is that tools are objects to think with and that they inevitably and fundamentally shape human thoughts, discourse, actions, and interactions; the latter is the perspective that we adopt in this chapter, as we examine the role of technology-enhanced learning in science.

The case of visual model is particularly illustrative of this gap between grand theories and design of learning technologies to be used in classrooms. The multimodality, not only of communication between people but also of science, involves multiple semiotic systems. The hypothesis on the role of this multiplicity of semiotic systems in learning has been emphasized by tenants of “science concept learning as participation” (Lemke, 1990) and by those of cognitive approaches (Duval, 1995). Then, this hypothesis leads the designer to take into account the different representations of concepts like force, acceleration, or models like particulate model of

matter, which have several components: natural language, geometric and algebraic, drawings, and then constrains the design of environment (Tiberghien, Gaidioz, & Vince, 2007). Thus, the theoretical framing of the designer shapes the final design, which in turn mediates and can modify the learning process and outcomes.

8.3 The Role of New Technologies in Science Learning

In the last few decades, new technologies have gradually claimed a significant role in supporting the goals of science learning, as they are described in key science education documents worldwide (American Association for the Advancement of Science, 1993; National Research Council, 1996; Organisation for Economic Co-operation and Development, 2004). Moving beyond technological tools that support factual learning and memorization and the reinforcement of basic skills, this chapter focuses on learning technologies which give students the tools to engage in meaningful science learning. TEL environments can support the gradual development of higher-order skills, such as critical thinking and problem-solving in inquiry-based learning, alongside the development of domain-based reasoning. To this end, new technologies become cognitive tools, which are tailored specifically to meet the needs and learning goals of science learners (Songer, 2007). Songer makes a distinction between digital tools, such as scientific data available on the web, and cognitive tools, which she defines as “computer-available information . . . presenting focused information specifically tailored for particular learning goals on a particular topic of interest for learning by a particular target audience” (p. 476). Agreeing with the definition given by Songer, we also use the term “learning technologies” to describe those new technologies that become cognitive tools in the hands of the learners to facilitate learning in science.

Learning technologies can extend what the learner can do on their own (Hutchins, 1995) and enable them to engage in observing, manipulating, and examining the natural world around them in a way that would be otherwise extremely challenging, time consuming, or plain unattainable. In this context, learning technologies serve multiple goals: first, they support the acculturation of the learner into the practices of science, by giving them access to tools that can help them engage in scientific inquiry processes that resemble the ones used by practicing scientists. Second, acknowledging that the development of expertise takes time and that learners are novices in the scientific practices they are asked to engage with, scaffolds in the learning technologies can help learners more easily engage in higher-order reasoning. Thus, learning technologies can be seen as contributing to making science learning authentic and supporting the development of scientific literacy. Together, these efforts can contribute to students’ appreciation and understanding of the nature of science.

In the next section we present some representative examples of learning technologies to support inquiry-based learning in science. This section is not meant to be a comprehensive overview, but rather it can be seen as an illustration of the

breadth of tools currently available in science education. The section discusses four areas of technology's contribution: tools to support meaningful science learning, tools for reflection, argumentation, and communication of ideas, tools to support communities of learners, and tools to support teaching and learning.

8.3.1 Tools to Support Meaningful Science Learning

Many researchers argue that science learning should consist of authentic learning activities which resemble the practices of the scientific community (Bransford et al., 1999; Brown, Collins, & Duguid, 1989; Chinn & Malhotra, 2002; Edelson, 1997; Lee & Songer, 2003) and allows students to experience scientific inquiry. This often means that students are asked to solve problems that are complex and which do not have an easily perceivable solution. Perhaps the primary goal of science curricula today ought to be the creation of the conditions for what Chinn and Malhotra (2002) call "epistemologically authentic inquiry", in which students engage in targeted scientific inquiry practices that enable the development of reasoning that resembles that of scientists. Some of these practices (as also discussed in Chapter 2) are solving meaningful and open-ended problems, interpreting and analyzing primary data, modeling ideas and phenomena, and creating evidence-based arguments and explanations.

New technologies are an indispensable commodity to modern science. As such, they are essential to learning science as they extend students' capacity to engage in theory testing and the construction of evidence-based explanations. Almost all scientific domains have been tremendously supported by the presence of such tools, the geosciences and biology being just two examples. According to Edelson (1997) the scientific practice consists of three key categories of features: attitudes, tools and techniques, and social interaction. In Edelson's categorization the environments that afford the development of authentic scientific attitudes are those in which students experience the uncertainty of the scientific knowledge and in which students are committed to systematically pursuing their research questions. By providing learners with open-ended technological tools they are encouraged to engage in practices resembling those of scientists, having at their disposal a variety of tools and techniques which they can use to test their developing theories.

Furthermore, the use of scaffolding, an idea borrowed from Vygotsky's (1978, 1986) work and present in the design of learning technologies, can support the gradual acculturation into the terminology, concepts, and practices of science. As part of this effort to make school science more authentic, and since scientific practice and technology are dynamically linked, researchers have created scaffolded technological tools to enable students to engage in practices similar to the ones of scientists, by adapting the technology to serve the needs of the novice learners. With their multimodal, interactive, and dynamic representations, new technologies have the capacity to motivate learning by helping create situations in which the learners undertake the solution of authentic science problems and use tools that enable

them to take responsibility over their own learning. This motivating aspect of new technologies is crucial considering the declining interest of young students in the sciences (Sjøberg & Schreiner, 2006). Scaffolded environments can help bridge the learner's current state of understanding and the scientific mode of thinking, helping learners grow within their zone of proximal development (Vygotsky, 1978). In addition, technology can foster inquiry learning in science by serving as a metacognitive tool, helping structure the students' task, facilitating the articulation and externalization of students' understanding, and scaffolding the development of the learner as a self-regulated inquirer (Linn, Davis, & Eylon, 2004). Finally, technological tools can support the development of scientifically resonant attitudes and facilitate the communication among peers and between learners and teachers.

We next present an overview of such scaffolded tools, organized in the following five categories: scientific visualization tools, databases, data collection and analysis tools, computer-based simulations, and modeling tools.

- a) *Scientific visualization tools.* This category reflects the adaptation of expert tools used by practicing scientists so that young learners can engage in the analysis of complex, real-world data sets. For example, *MyWorld GIS* (Edelson & Russell, 2006) is a scaffolded interface for a database that automatically represents geographic data in visual modes. The possibility to have multiple representations on-demand with a click of the mouse, along with the other analytical tools, can support students' experimentation with important ideas about science.
- b) *Databases.* Oftentimes in science learning a teacher may choose to focus on particular aspects of science practices, in order to foster deep understanding about those practices. This is the case of working with existing data sets, usually collected in digital databases either on a stand-alone computer or off the Internet (Chinn & Malhotra, 2002). In some domains, inquiry cannot be conducted without access to such databases, as is the case with historic data that need to be compared and contrasted over large periods of time in order to discern patterns and reach valid conclusions. Natural selection is one such important concept, which can be facilitated by accessing scaffolded databases such as the one in the *Galapagos Finches* environment (Reiser et al., 2001). It is important to note that such environments not only give access to data but also structure the learning environment so that the learner is subtly guided and constrained in the choices they can make. This is an important role of scaffolding, which can thus be seen as facilitating the sense-making process (Quintana et al., 2004).
- c) *Data collection and analysis tools.* Learning technologies can also facilitate the data-gathering and analysis aspect of scientific practice. Examples of such technologies are probes, sensors, or handheld computers which make the collection of real-time data from the local environment possible – these data can then be used to answer a multitude of research questions. (For instance, sensors usually found in many high school classrooms today can facilitate the collection of data on temperature, salinity, motion paths, voltage, etc.) These data are then automatically and dynamically represented in graphical or numerical form, can be digitally stored for further analysis, and can contribute to conceptual understanding. The

Kids as Global Scientists (Songer, 1996) environment is one such example of a technology that allows the mining of online data from the Internet, which are then available to students for comparisons and analysis. Furthermore, such tools can help students answer problems of local importance, such as the quality of the water in the river near them, and can thus enhance students' motivation and meaningful engagement with science.

- d) *Computer-based simulations*. Computer-based simulations are powerful tools that can support conceptual understanding (de Jong, 2006; Zacharia, 2007) by allowing experimentation to answer "what if" questions. A main affordance of computer-based simulations, as compared to other simulation activities, is that they allow manipulation of ideas overcoming issues such as safety, access to physical resources, and temporal constraints (Hofstein & Lunetta, 2003). In science education, simulations are based on scientific models and provide learners with the tools to systematically observe and manipulate central parameters of the phenomenon under examination (van Joolingen & de Jong, 1991). Examples of research-informed computer-based simulations environment include *SimQuest* (van Joolingen & de Jong, 2003), *Co-Lab* (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005), and *BioWorld* (Lajoie, Lavigne, Guerrero, & Munsie, 2001). Currently, there are many simulation environments to help teach a multitude of topics in disciplines such as physics, chemistry, biology, as well as environments that adopt an approach of integrated learning. For instance, *SimQuest* includes several simulations that can support learning about biology concepts and processes, such as bacteria growth, physics concepts such as Newtonian mechanics, and learning about socio-scientific topics such as waste water technology.
- e) *Modeling*. Another category of learning technologies is that of modeling tools. Modeling is seen as a core scientific practice and as such, modeling is advocated as a valuable pedagogical approach to learning science (Coll, France, & Taylor, 2005; Gilbert, 2004; Halloun, 2006; Schwarz & White, 2005; Sensevy, Tiberghien, Santini, Laube, & Griggs, 2008). Similarly to simulations, modeling software supports the systematic manipulation of variables for testing theories and developing conceptual understanding. Increasingly, computer-based modeling environments also embed models that can be inspected and used as the basis of new or improved models, but which can also be run as simulations. Unlike simulations, which most frequently run on a black-box design, modeling tools such as *Model-It* (Jackson, Stratford, Krajcik, & Soloway, 1994), *STELLA* (Richmond & Peterson, 1990), *ModellingSpace* (Dimitracopoulou & Komis, 2005), *ThinkerTools* (Frederiksen & White, 1998), *NetLogo* (Wilensky, 1999), and *Stagecast Creator* (Smith & Cypher, 1999) afford the creation and manipulation of models by the users themselves, thus adopting a glass-box design (Wilensky, 2001). Glass-box environments are inspectable and modifiable by the user and can, thus, invite theory-based experimentation and reflection. In response to the identified learning challenges, designers have developed modeling software that allows users to engage in qualitative modeling (e.g., *Model-It*) and making the pedagogical approach amenable to younger learners (e.g., *Stagecast Creator*). Continuing

technological development has allowed learners to model at different levels (micro and macro), and even engage in participatory modeling activities, such as the ones provided by the networked environment of *NetLogo*.

8.3.2 Tools for Reflection, Argumentation, and Communication of Ideas

Learning technologies present learners with an increasing variety of tools to conduct scientific investigations. Such technologies are scaffolded, in that the designers have gone through a process of identifying developmental and other learning obstacles and have customized or adopted the technology so that the learning activities are within the realm of the intended target users. However, even after a motivating context has been setup and after the tools are made available, research shows that learners need further support to engage in inquiry. The nature of this support can be regulative and organizational or supportive of reflective inquiry. Examples of learning technologies which can offer support to help learners manage the investigation process (Quintana et al., 2004) include *SYMPHONY* (Quintana, Eng, Carra, Wu, & Soloway, 1999), *KIE/WISE* (Linn, Davis, & Bell, 2004a), and the *Progress Portfolio* (Loh et al., 1998).

Reflective inquiry practices that bridge the local inquiry activity with important scientific ideas are another area that can be supported through the use of learning technologies (Davis, 1998; 2003; Linn, Davis, & Eylon, 2004; Loh, 2003). For instance, several tools within *WISE* can support students' building of arguments (Bell & Davis, 2000; Linn, 2003); *Belvedere* (Suthers, 2003) supports students' construction of evidence-based arguments, while tools like *ExplanationConstructor* (Sandoval, 1998) support disciplinary explanation building. *STOCHASMOS* (Kyza & Constantinou, 2007), a web-based learning and teaching platform, provides scaffolding for supporting students' reflection-in-action about the processes and products of inquiry.

8.3.3 Tools to Support Communities of Learners, Extending Beyond the Science Classroom

The idea of creating communities of learners is appealing to science education, as it has the potential to support the appropriation of scientific practice as an essentially collaborative culture. This pedagogical approach is also grounded in the socio-cultural paradigm of learning and teaching as it emphasizes learning occurring in a culture of participation in community-important activities (Rogoff, Matusov, & White, 1996). Learning technologies, such as the ones described in the previous pages, are well suited to the sociocultural perspective of learning as they provide students with the tools to not only talk science but also engage in science. The Internet has extended access to data and tools to support synchronous and

asynchronous communication between learners, and learners and experts (Linn, Davis, & Bell, 2004b). Environments such as the *Knowledge Forum*, and its precursor, *CSILE* (Scardamalia & Bereiter, 2006), provide powerful tools for community knowledge building.

8.3.4 Tools to Support Teaching and Learning

Learner needs vary across several dimensions such as time and locale. Stepping away from the textbook as a rigid and authoritative source of information it is important to support teachers in authoring or customizing learning environments to support their students' needs. New technologies can provide the tools and the guidance needed to support this customization (Baumgartner, 2004). Environments such as *WISE* (Linn, 2003), *STOCHASMOS* (Kyza & Constantinou, 2007), and *SimQuest* (van Joolingen & de Jong, 2003) offer scaffolded authoring tools to support teacher adaptation of existing digital materials and the creation of new materials tailored to specific needs. These efforts have the potential to support student motivation and learning at the local level of the classroom while also supporting teachers' professional development.

8.4 New Developments in Technology-Enhanced Learning in Science

When we speak of technology-enhanced learning in science we are, in fact, speaking of a great variety of cognitive tools that can support many different aspects of science learning. New projects developing out of work supported by Kaleidoscope are examining the potential of new, open learning environments that integrate interoperable tools to support most of the goals already described as the primary areas of contribution of new technologies. Some state-of-the-art resources include open-source software, the customization of the learning environment by the user, and technologies for increased participation, such as video games, wikis, and blogs. For instance, developing video games for science learning is quickly becoming popular, even though research on these technologies is still nascent (Annetta, Cook, & Shultz, 2007). Another type of technology that is increasingly becoming popular is multi-user, virtual environments (MUVes), such as *River City* (Nelson, Ketelhut, Clarke, Bowman, & Dede, 2005), in which learners access a virtual world, interact with digital objects, and collaborate to solve problems. Other examples of new ground-breaking work include project *CIEL* (van Joolingen, de Jong, & Manlove, 2007) and the *Scalable Architecture for Interactive Learning* (SAIL) framework (Slota, 2005). This work, also described in van Joolingen and Zacharia (Chapter 2), foregrounds the development of what is promising to be more flexible, open-source learning environments, which will allow learners ease

of navigation and use of the affordances of learning technologies more consistently over a longer period of time.

8.5 Concluding Remarks

In this chapter we discussed the potential of learning technologies to support learning and teaching in science. Part of our discussion has been organized around the potential of new technologies to support important aspects of inquiry-based science learning such as contributing to the development of scientific reasoning skills, creating opportunities for authentic learning and providing the tools to engage in such learning, and promoting conceptual understanding. We have presented some representative examples of new technologies in support of these science education goals, whose development was evidence- and theory-based.

Traditional science classrooms do not support students' participation in scientific inquiry, in general, and in particular aspects of inquiry such as theory-evidence coordination (Erduran & Jimenez-Aleixandre, 2008; Siegel, 1995). Rather, traditional classrooms emphasize students' acquisition of conceptual outcomes of science – the declarative knowledge. Procedural knowledge (or knowledge of strategies, heuristics and criteria that justify and enable knowledge growth) is typically overlooked. Our understanding is limited with respect to the actual impact of new technologies on the above-mentioned aspects of science learning. The extent to which technology supports students' engagement in activities and modes of thinking that enable knowledge growth in scientific inquiry is of tremendous interest to science education research.

In discussing the role of TEL in science we believe we should advance questions such as the following: As science educators, what aspects of science in general and scientific inquiry in particular are supported by new technologies? How do technology-enhanced science learning environments promote science learning? What evidence is there for the effectiveness of technology-based instructional approaches in the learning of science? These questions not only are critical to ask at a time when TEL is increasingly playing a major role in educational settings but also offer an exciting challenge in application to everyday science classrooms. Dillenbourg, Järvelä, and Fischer (Chapter 1) discuss the “myth of media effectiveness”, which they explain as the expectations created each time a new technology is introduced in education. Indeed, the advent of computer technologies has sparked many debates about their effectiveness to support learning. However, as research indicates, new technologies can be catalytic in supporting learning but they cannot, merely by their use, lead to better learning outcomes. Issues of student and teacher motivation, task setup, the choice of pedagogical approach, and the dynamics between collaborating peers are all pieces of the puzzle we call learning. Without understanding how the pieces of the puzzle fit together we cannot, as of yet, fully understand the potential of new technologies to reform science education. New technologies for participatory and collaborative design and learning emerge at an

increasingly rapid pace, and as they do we see improved tools that are better aligned with social constructivist pedagogies. When examining the use of such technologies it is crucial that one considers the learning environment in which they are embedded and the role of the other contributing participants, such as the teacher, peers, and activity structures. In order for key science learning to occur, these different participants should work synergistically (Tabak, 2004).

Decades of classroom-based research has resulted in the clarification of two main goals for science education. On the one hand, there is the goal of education of the scientists for careers related to science. On the other hand, there is the education of the general public for informed citizenship where science is an integral aspect of everyday life. More than anything else we see technology as a tool to support human activity, and as such, the primary considerations about their use should be on whether they afford, scaffold, and encourage mindful and meaningful learning. Technology-enhanced learning approaches hold the potential to contribute centrally to both goals of science learning and to the design of learning environments that are consistent with the cognitive, epistemological, and sociocultural framing of science learning.

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Part III
Shaping the Learning Environment

Chapter 9

External Representations for Learning

Headed Towards a Digital Culture

Erica de Vries, Stavros Demetriadis and Shaaron Ainsworth

Abstract This chapter provides the state of the art on learning with external digital representations and elaborates on some landmarks for understanding the design and use of emergent learning technologies. We start by identifying a pervasive underlying distinction into dyadic and triadic views of representation which triggers the question of the role of culture and context in the study of the construction and the interpretation of digital representations. Three issues are discussed in more depth: learning with a multiplicity of digital representations, adjusting the representational density of digital representations and externalizing symbolic processing to the computer. Based on these issues, we conjecture that the future of digital learning might require bringing together a variety of spheres of representational practice, namely those of domain experts, teachers and learners, as well as those of researchers and developers in the field of learning technologies.

Keywords External representations · Digital representations · Learning · Semiotics

9.1 Introduction

Imagine a number of screen dumps of a set of randomly taken computer-enhanced learning environments that are developed in research laboratories, commercially available, or freely distributed on the Internet. You probably find yourself confronted with a wealth of different types of inscriptions: texts, images, charts, graphs, diagrams, schemas, tables, equations, etc. Nowadays, in learning research, the term “external representations” is used to designate any configuration of inscriptions on a computer screen that has been created by a teacher, an instructional designer or a learner and that allows the learner to interact with some content domain (Ainsworth, 2006; Schnotz & Lowe, 2003; van Someren, Reimann, Boshuizen, & de Jong, 1998). The term highlights the fact that these configurations are external, that is, outside the head of the learner, as opposed to internal mental representations, and,

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furthermore, that they represent or stand for the objects, states of affairs and phenomena of a content domain. In fact, educational situations rarely involve learners interacting directly with the objects and phenomena of interest, such as the working of a bicycle pump, the behaviour of molecules or the movement of tectonic plaques. Moreover, some objects, in principle, can be dealt with exclusively through external representations. Consider different ways of representing a linear function: a verbal description, a straight line in a coordinate system, an equation, a list of coordinate pairs. None of them should be (mis)taken for the mathematical object of the linear function itself. It is only through manipulation of several external representations of the same object, and through conversion from one type to another, that one can learn the distinction between a mathematical object and different ways of expressing it externally (Duval, 1995).

The advent of computer technology dramatically increases possibilities for developing dynamic and interactive representations. The broad spectrum of different computer-based representations revives a longstanding research question for cognitive scientists and instructional designers: how do learners construct internal representations from the multiplicity of external representations offered to them? Moreover, the issue of the specific features of external representations on the computer, in comparison to traditional media, is in itself a recurring issue (cf. the Clark versus Kozma media debate).

The Kaleidoscope Network of Excellence offered an opportunity to examine ways of exploiting the representational promise of computer technology for learning as well as to review and extend current scientific knowledge of the interaction of internal and external representations (see Demetriadis, 2004). The resulting blend of different approaches to external representations, rather than allowing the construction of a unified framework, leads to the observation that several theoretical perspectives, founded on essentially different views of representation, coexist. Within this context, the chapter aspires to provide a synthesis of the state of the art on approaches to external representations for learning and to identify their theoretical groundings with a view to developing landmarks for understanding the design and use of emergent learning technologies.

9.2 Defining Representation

Regarding representation, the field of learning technologies is at the crossroads of a number of disciplines, amongst which are philosophy of mind, cognitive psychology, linguistics and semiotics, philosophy of language and computer science (artificial intelligence). In fact, the relations between knowledge, language and representation are at the centre of epistemological debates that go back to Plato and Aristotle (see the Stanford Encyclopaedia of Philosophy; Zalta, 2008). Rather than retracing these debates, we pinpoint a pervasive underlying distinction into dyadic and triadic views of representation in order to present and discuss approaches to learning with external representations.

9.2.1 *The Dyadic Perspective*

The term representation refers to the act of bringing something to someone's mind or to evoke something absent. In cognitive psychology, in its broadest sense, the term refers to Palmer's (1978) definition: A representation is something that *stands for* something else. Thus, a cognitive perspective can be characterized as dyadic: representation is a two-place predicate. Palmer argues that a particular *representational system* can be described in terms of a represented world and a representing world, the aspects of both worlds that are represented and representing, respectively, and the correspondence relations between the two. In this view, one and the same represented world can be projected onto different representing worlds, and inversely, one and the same representing world can be the projection of different represented worlds depending on the choice of the represented and representing aspects.

Following Paivio (1971, 1990), cognitive psychology has typically distinguished two types of internal representations depending on the type of correspondence relations: propositional representation, which is a verbal or text-like mode, and mental images which correspond to a visual-pictorial mode of representation. In addition, a third kind is often postulated which are mental models as structural or logical analogues of the world (Johnson-Laird, 1983). Palmer's (1978) definition of representational systems allowed clarification of a number of fundamental features of internal mental representation. The application of the framework in educational technology initiated research which regards learning as the construction of internal representations by perceiving and cognitively processing external representations through selection, organization and integration (see Section 9.3.1 of this chapter).

9.2.2 *The Triadic Perspective*

A semiotic perspective embraces a triadic view, following one of Peirce's (1931–1958) definitions of a sign as *something* which stands to *somebody* for *something* in some respect or capacity. According to this view, representation, as a three-place predicate, involves three entities instead of two: the referent or object existing in the world, the signifier or *representamen* (a mark, a form, an idea, a word, an image, a sound, a smell), and the signified or *interpretant* (the idea evoked in someone's head). The main consequence of this perspective is that a signifier can evoke a multitude of things; it can have multiple signified. Thus, the term *inscriptions* (e.g. Kaput, 1998; Lehrer & Schauble, 2002) is more appropriate for designating decontextualized traces, marks, carves, sounds, etc. considered independently of any signification it might have for an individual. The term, used mostly in archaeology, highlights the fact that, in the absence of context and/or of knowledge of the representational system, the extraction of meaning can be impossible due to the spatial, temporal, material or cultural distance between the producer and the user of the

inscription. Note how this can only be recognized cross-culturally, that is, in stepping out of one's own culture or language, such as in the case of the *Phaistos* disc that experts are unable to decipher today. Another key issue relates to choosing, for a particular inscription, between alternative, but equally probable, significations under different representational systems, irrespective of the referent object. For example, the letter sequence /main plane/ probably evokes "the most important aircraft" in the mind of an Anglophone and alternatively "flat hand" in the mind of a Franco-phone, but which one of these two interpretations would prevail in the bilingual mind that understands the two competing languages? Philosophers of language, such as Eco (1984), argue that, instead of selecting a representational system in order to decode an inscription, extraction of meaning *precedes* the attribution to a language. In other words, in the above example, the "aircraft" interpretation of the letter sequence leads to the conclusion that the inscription must be in English, *not* the other way around.

A semiotic perspective provides many alternative ways of classifying representations (cf. Peirce (1931–1958)), and also more recently (Eco, 1973/1988) and amongst them is one of Peirce's in terms of the type of correspondence relations between representamen and object. It has three (instead of two) types: icons for resemblance relations (visual, auditory, structural or other), symbols for arbitrary relations existing by virtue of a law, a habit or a convention and indices for spatial, temporal or causal contiguity relations. However, from a semiotics point of view, icons, symbols and indices cannot be distinguished from one another in the *absence* of or prior to a signification process; it requires the third, the interpretant. For example, a picture (representamen) of a fisherman (object) has multiple interpretants: it is an icon if it evokes "a man holding a big fish" by virtue of a resemblance relation, a symbol if it evokes "a husband at work" by virtue of a cultural convention or habit and an index if it evokes "evidence of a big catch" by virtue of the causal relation between the event and the photograph.

Thus, in a genuine triadic approach, *interpretation* is the key process by which humans make meaning out of external representations. Interpretation depends on cultural conventions and on person, task and situation characteristics. Applying such a framework to educational situations implies one must take into account the eventuality (as has been argued by von Glasersfeld, 1987) that different actors, and in particular teacher-designers and learner-users, interpret inscriptions in a variety of different ways (see Section 9.3.2 of this chapter).

9.3 Learning with External Representations

Transposing these perspectives on representation to learning research is far from straightforward. In particular, conjectures as to the role played by external representations in learning depend strongly on the learning theory embodied within the instructional setting. As a result, studies on learning with external representations have different emphasis and foci.

9.3.1 *Individual Cognitive Approaches*

In an individual cognitive approach, the basic assumption is that existing knowledge about the world has somehow to be conveyed to the learner. For example, both Mayer's (2001) theory of multimedia learning and Schnotz and Bannert's (2003) cognitive theory focus on the effectiveness of (combinations of) external representations, studying the impact of the use of different sensory channels and/or modalities (auditory/visual and/or textual/pictorial). Gerjets and Kirschner (Chapter 15) deal with these approaches in more detail. Interestingly, individual cognitive approaches hold a dyadic perspective of internal as well as of external representations; both represent (knowledge of) objects and phenomena in the world. More specifically, they categorize external representational formats, in the same vein as internal ones, as *descriptive* (a symbolic system for describing of the world, such as natural language (text and speech) and mathematics) or *depictive* (depicting reality by analogy, such as static or dynamic images, maps, diagrams, graphics, animation and video). Individual cognitive models postulate selection, organization and integration processes (Mayer, 2001) or construction and elaboration processes (Schnotz & Bannert, 2003) that allow building internal representations from the external ones. This has been called a learning "from the computer" approach (Jonassen & Reeves, 1996): external representations, mainly text and pictures, are principally considered as conveyors of knowledge and computers as repository of content.

Applying the depictive–descriptive distinction to external representations also raises a number of issues, some of which are related to the imagery debate for internal representations. Goodman (1976), for example, argues for the arbitrariness or conventional character of *all* external representations. Pictures and diagrams, with their purpose to highlight a selection of relevant aspects of a situation, make them not merely depictions of the considered object but in fact gives them a descriptive role (Demetriadis et al., 2004). In other words, in reference to Piaget (1969), one cannot learn about the world by copying, since it has to be known beforehand in order to know what aspects to copy. A fortiori, learning with external representations requires some prior knowledge of either the represented world or the representational system, or both.

9.3.2 *Constructivist and Situated Approaches*

In constructivist approaches, knowledge is viewed as tied to the individual knower and computers are seen as cognitive tools for the learner's self-construction of knowledge or learning "with" the computer (Jonassen & Reeves, 1996). Thus, the main focus is on encouraging learners to construct and design external representations for analysing, expressing and organizing their knowledge. For example, learners may create concept maps in order to understand interrelationships and to relate emerging knowledge to prior knowledge. Examples of constructivist

approaches are seen in the design of cognitive tools (Jonassen & Reeves, 1996) and cognitive flexibility theory (Spiro & Jehng, 1990). Cognitive flexibility theory emphasizes the importance of the transfer of knowledge and skills to new situations. To achieve this, a theme should be illustrated with multiple examples (or cases) and a case should be studied from multiple perspectives (or themes). Through the process of schema assembly, rather than intact schema retrieval, learners are thought to construct flexible representations of knowledge applicable in many contexts. Cognitive flexibility theory explores advanced knowledge acquisition in complex and ill-structured domains such as literature, history, biology and medicine. Typical applications are in the design of hypertext environments that allow learners to flexibly access information following a wide variety of learning paths.

Constructivist approaches can be characterized as triadic since learners construct their own knowledge of the world through multiple ways of accessing information structures. An even more triadic view can be recognized in situated approaches. Greeno (2006) presents such an approach for studying learning in activity systems focusing on the principles of coordination between their components: the participants, the tools and the *representational practices* in the subject-matter domain. In fact, representation is seen as both mental and socially distributed in practices; meaning is not context-free but attributed in context and according to cultural conventions in relation to joint actions of achieving mutual understanding. Examples can be found in discourse analysis approaches to science learning (Airey & Linder, 2007) that aim to study the construction of meaning in learning as a process of acquiring disciplinary discourse, that is, learning ways of representing in a domain. Even very common words and their everyday meanings can lead to confusion when used in relation to science concepts. For example, in using the expression “to move more”, students may refer either to higher frequency (i.e. going back and forth more often) or to higher amplitude (i.e. travelling a longer distance). In very carefully designed situations, students are able to identify and resolve their differences both conceptually and on the level of the words used (de Vries, Lund, & Baker, 2002; see also Parnafes, 2007).

In triadic approaches, learning is seen as *semiosis* (Cunningham, 1992; Driscoll & Rowley, 1997) which refers to the sign processes involved in the production of meaning. However, semiotics is not often explicitly mentioned as the frame of reference in educational technology (an exception within Kaleidoscope is Cadoz & Arliaud, 2004). Semiotics shows the way to a classification of signs founded on signification mode, which is the relation between representamen and interpretant. For linguistic signs, these are *denotation* for primary or literal meaning, *connotation* for figurative meaning and *metalanguage* (Barthes, 1964). Such a classification has profound repercussions for how one considers external representations in learning environments (de Vries, 2006). In Fig. 9.1, a rectangle appearing in an environment for mathematics learning is to be interpreted as a quadrilateral polygon with four right angles (denotation). But in most multimedia learning material, the same inscription is to be interpreted as a box, a building brick, a recipient or a cylinder (connotation). And finally, the exact same inscription in a graphical

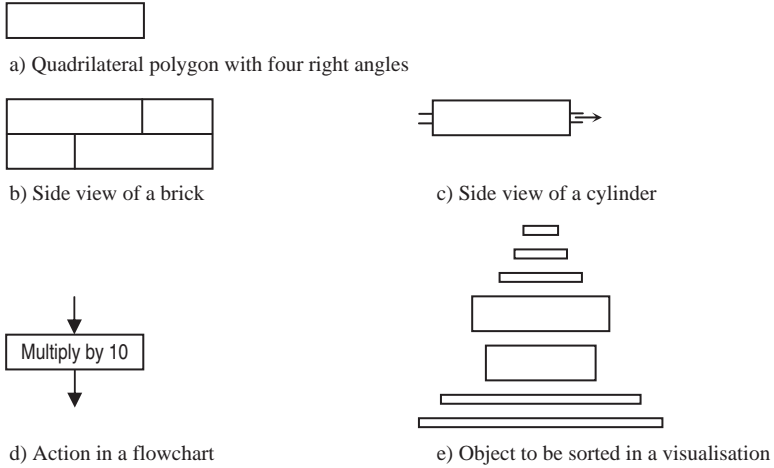


Fig. 9.1 Three signification modes for a rectangle: (a) denotation, (b) and (c) connotation, (d) and (e) metalanguage

modelling tool has to be interpreted as a concept, a variable, a task, an action or data (metalanguage). What if the learner’s interpretation does not match the designer’s intentions? External representations that comply with a formal code in the eyes of the constructor are not necessarily interpreted in a unique way by a learner reading or manipulating them in a learning context.

Conversely, there are multiple ways in which an object, a phenomenon or a concept may be represented *within* a particular type of external representation (see Fig. 9.2). Each of them embodies a selection of the relevant aspects in a particular context by presenting an object from a certain point of view. Consequently, external representations must be seen as highly domain dependent, in line with the aforementioned reasoning of Goodman (1976), Kaput (1998) and Greeno (2006); for example, a mathematician, a mechanical engineer and an instructional designer do not use the same inscriptions for representing a cylinder.

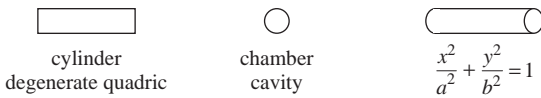


Fig. 9.2 Multiple graphical and linguistic ways of representing the same object

9.4 En Route for a Digital Culture

In exploring the future of learning with digital technologies, Kaleidoscope has brought together researchers, developers and practitioners from different cultures, across different knowledge domains and that speak different languages. In addition,

regarding external representations, we observe a tendency for digital technologies to conceal diversity in the origin of the information, the mode of construction and the type of media used. The question arises whether, in assembling learning environments across cultures and technologies, we could speak of a progression towards a digital culture that smoothes out all those sources of variation and furthermore simply refer to external representations on the computer as *digital representations*. In the field of learning technologies, such digital representations may be

- *Dynamic*, continuous just-in-time changes, such as in narration, voice-over, audio cues, animation (2D or 3D) and video clips. For example, an animation, rather than playing a video with a fixed scenario, may be dynamically produced. Such animations typically use a model of the phenomenon to calculate changes over time, such as high- and low-pressure areas on a weather map or the earth rotating as seen from space. Dynamic representations can be effective if their specific computational properties match the learning task (Tversky, Morrison, & Bétrancourt, 2002). Indeed, a recent meta-analysis proposed an effect size of around 0.4 (Hoffler & Leutner, 2007). However, dynamic representations also require complex strategies and may create an “illusion of knowing” (see Ainsworth, 2008).
- *Interactive*, enabling and encouraging extended learner–system interaction. Interactive representations allow learners to act upon them and see the consequences of their actions, such as in simulations. A simulation contains a model of a phenomenon (e.g. the relationship between prey and predators), so that students can perform experiments by changing variables (such as the rate at which the prey breed) and observe the effects of their actions (e.g. by interpreting a phase plot of population density) in order to discover the properties of the underlying model (such as the Lotka-Volterra Model). Interactive representations require learners to master specific subtasks, for example, formulating hypotheses, choosing which variables to change and when, interpreting the output of the simulation, identifying when to confirm or disconfirm hypotheses (Chapter 8; de Jong, 2006; Chapter 2).
- *Co-constructed*. Enabling and encouraging co-construction by groups of learners, such as in concept mapping tools and computer-supporting collaborative learning environments (see Chapter 1).
- *Visualization based*. Applying visualization techniques to data, such as in algorithm or program visualization, and graphical argumentation tools. In fact, the term “visualization”, rather than animation, is used for phenomena that are not inherently visual, such as the forces acting upon an accelerating car or the execution of a program or algorithm (such as the sorting algorithm depicted in Fig. 9.1e). The pedagogical value of applying techniques from algorithm visualization has been recently investigated (Demetriadis & Papadopoulos, 2004; Hundhausen, 2002; Hundhausen, Douglas, & Stasko, 2002).
- *Multiply linked*. Providing hyperlinked nodes for crisscrossing, such as in hyper-texts and semantic networks (see Section 9.3.2).

Learning environments may also be hybrid and incorporate multiple digital representations. Furthermore, digital representations often depend on input from the user and one might want to be able to adapt them to the particular needs of the learner. Finally, digital representations are generated by a computational model instead of by an instructional designer or teacher. In the remaining of this chapter, we elaborate on these three issues, multiplicity, adaptability and the off-loading of symbolic processing, with a view to identifying directions for future research.

9.4.1 *Advantages and Drawbacks of Multiplicity*

Simultaneous production of multiple digital representations is one of the key advantages of computer technology. The aspect of multiplicity can have several benefits for learning, but these benefits come with associated costs and concerns. Ainsworth (2006) argues that multiple representations can be used to complement, constrain and construct. *Complement* refers to the use of multiple representations which are complementary to each other either in the information that each contains or in the processes that each supports. A multi-representational environment provides increased potential for adjustment to individual differences in representational preference or skills, for allowing multiple strategies or for fulfilling a range of different tasks. *Constrain* refers to the way that a familiar representation can help to avoid misunderstanding by constraining the interpretation of an unfamiliar representation. Pictures, for example, by explicitly representing spatial relationships between objects can constrain the interpretation of verbal representations. The reverse holds for texts which, by inherently presenting temporal relations between events, may constrain the interpretation of visual representations. As another example, an animation of a moving body could help learners in understanding more complex representations such as a time-series graph. Finally, *construct* refers to the use of appropriate multiple representations for supporting learners to develop deeper or more abstracted understanding of the domain. In the absence of the represented world, multiple representations are crucial in constructing deep understanding, provided that learners grasp how representations relate to one another (cf. the cylinder example in Fig. 9.2).

There are also specific difficulties when learning with multiple representations. First, the richness of multi-representational possibilities does not necessarily enhance learning. Presenting two external representations may not be better than one (Petre, Blackwell, & Green, 1998) and learning from multiple representations crucially rests on mastering a number of tasks (Ainsworth, 2006; van der Meij & de Jong, 2004).

First, learners must understand how an external representation encodes information; they have to *identify* its relevant aspects amongst available inscriptions. For example, they must comprehend the appropriate representing attributes such as lines, colours, labels and axes. Lowe's (2003) study in meteorology indicates that it might be problematic for learners to "distinguish the conceptually important from

the perceptually rich". Expert meteorologists know what to look for and what to ignore, whereas novices can only focus on what merely attracts their attention. In this respect, Chi, Feltovich, and Glaser's (1981) study provides another example, in that novices only identify surface features, whereas experts recognize the underlying domain principles in categorizing physics problems. Many findings may be traced back to Bartlett's (1932) work on how people with different backgrounds structure the environment differently.

Furthermore, knowing a representational system involves knowing what operators to apply or, in other words, how to *process* the representation in order to produce new information. Thus, different representations allow essentially different information processes, that is, they have *operational significance* (Duval, 2007). For example, how to transform a particular algebraic equation into another one, how to isolate the area bounded by a line or to find the distance in a velocity time graph? The representational effect refers to the differential processing possibilities of different representations with a common formal structure (Zhang & Norman, 1994). Thus operations are representation specific (Zhang, 1997) and, in the presence of multiple representations, one must select the one that allows the processing needed for the particular situation and task. The question is of course, when encountering a new type of representation, whether learners are sufficiently aware of the operational meaning of the format for knowing when to use it (see also Section 9.4.3).

Learners must also understand how external representations relate to one another and how one may be *translated* or converted into another. Specifically in mathematics, there is evidence that conversion from one representation to another is a crucial ability in learning. Moreover, the ability to convert from one type of representation to another, such as constructing a line graph from an equation, does not imply the ability to go in the other direction (construct the equation that defines a line graph) (Duval, 1995).

In sum, the assumptions underlying the use of multiple digital representations for learning crucially rest on learners' prior knowledge of and experience with multiple representational formats.

9.4.2 Adapting Digital Representations to the Learner

Demetriadis and Papadopoulos (2004) introduced the notion of *representational density* referring to the number of aspects of the represented world that are projected onto representing aspects of an external representation. Representational density is *not* to be confounded with chart junk or with data-ink ratio (Tufte, 1983) which are indicators of the amount of, merely decorative, non-representing inscriptions.

As a first step towards developing a model on how to adapt the representational density, Demetriadis and Cadoz (2005) present a taxonomy of computer-based learning environments with varying degrees of interactivity. The kernel of this approach is to provide learners with the opportunity to adapt to the environment. Such

an adaptable environment would exhibit interactivity at a number of levels depending on the learning needs in the specific situation. The levels of this taxonomy are

- *Reactive*: low level of interaction. The learner can use basic navigation tools to search and access information. Only learners who can efficiently process the representations in such environments are expected to benefit.
- *Perceptually coactive*: the learner can adjust some presentational aspects to achieve appropriate perceptual conditions, for example by adjusting the speed of the animation in a dynamic representation.
- *Conceptually coactive*: the environment primes learning by presenting interactive and animated analogies (Hansen & Narayanan, 2000).
- *Exploratory proactive*: the environment enables the learners to alter basic features, such as defining input data, and explore the effects.
- *Constructively proactive*: the environment enables learners to construct their own external representations (e.g. in a microworld).
- *Enactive*: Enactive environments promote the idea of learning by doing, not in the sense of manipulating representations as in a proactive interface but by experiencing a “given environment” through sensory-motor interactions (Varela, Thompson, & Rosch, 1991). Such environments should establish the appropriate sensory-motor loops for learners to experience the results of their actions.

However, the representational density of a learning environment can only be established a priori by its designers. In fact, learners encounter a major obstacle in the identification of the representing aspects in the first place; how to distinguish them from non-representing aspects in the absence of the relevant domain knowledge? Whereas natural language allows signifying about signification (conveying about *how* language itself conveys meaning), all other external representations, and digital ones too, are non-reflexive; they do not communicate *about* their representational format. We trace this argument back to Wittgenstein’s (1922/1993) *Tractatus Logico-Philosophicus* and to Benveniste (1974). As an illustration, compare an office floor plan, the periodic table of elements and a flowchart; how does one identify the representing relations (i.e. those that are meant to map to relations in the world) and the correspondence relations (i.e. the particular mapping between the two worlds)? For example, spatial relations (next to, far from, larger than) may or may not project onto the world; they do in the office floor plan, but not in the periodic table, nor in the flowchart. Hue relations (darker than, lighter than) do not project directly onto the same relations in the world in any of the three representations. A red rectangle does not mean a red office, a red chemical element or a red action; their correct interpretation relies on prior knowledge of spatial layout or of chemical elements. The crux is that external representations do not provide a full specification of the way in which they should be interpreted. Therefore, learners with little domain knowledge, especially in the case of emergent representational formats, need to work first with simplified or less dense representations that represent as small a number of represented features as possible. It has been suggested that designing representations in an adaptable format may allow instructors to achieve an optimal coupling between learner’s prior knowledge and representational density

in any specific context of instruction (Demetriadis & Cadoz, 2005). In practice, the designer's job is to take into account both representational density of the digital representation and the profusion of inscriptions introduced by the necessary controls on the user interface; the learner's job is to distinguish between signifying inscriptions, interface controls and embellishments (de Vries, 2006). Future research should address these relations between representational density, adaptability and reflexivity.

9.4.3 Externalizing Symbolic Processes

The possibility to externalize symbolic processing, according to Shaffer and Kaput (1999), has led to a novel stage of cognitive development with profound impact on learning and society. Externalizing processing refers to the off-loading, to the computer, of part of the production, the transformation and the translation of external representations, such as executing an analysis of variance, carrying out a spell or grammar check or constructing a line graph from an equation. Shaffer and Kaput speak of "the power of the empty sign" (1999, p. 104) referring to the fact that external processing involves (1) discrete notations, (2) transformation rules and (3) an autonomous system for applying those rules, *without* considering potential interpretations in terms of a represented world. In fact, triggering interpretation of a formal system even entails the danger of suggesting illicit manipulation rules (i.e. active meaning; Hofstadter, 1979). Thus, symbolic processing is fundamentally dyadic or monosemic; knowledge of the signification of each inscription *precedes* observation of the configuration of inscriptions (Bertin, 1967). Therefore, detaching processes from representations is problematic to the extent that the set of rules of the autonomous system (whether internal mental or external digital) may not correspond exactly to the intended set under the formal system.

In studying mental processing of internal representations, researchers can ignore this problem because internal processes and representations cannot be examined separately, either from the inside by the cognitive system itself or from the outside by a researcher (Anderson, 1978). But in analysing external representations as if they were internal ones (as in Larkin and Simon, 1987), one overlooks alternative interpretations that learners are likely to make due to the disconnection between the learner-user and the expert-producer view on a representation.

At the core of a differentiation of dyadic and triadic views is Rastier's comment (1998, p. 202):

As such, the semiotic triangle from the Aristotelian tradition, whose canonical version had been offered by Ogden and Richards, is restored, with a major qualification: the *symbol*, by which the authors singled out the signifier, also turns out to be the semiotic format of the top pole of the triangle (that is, *Thought*).

In other words, computational models of human cognition fuse two (of the three) poles of the triadic perspective, the representamen and the interpretant or the signifier and the signified, by using the same term "symbol" indistinctly for inscriptions on paper and on screen and for entities processed in the computer and

in the human mind. In effect, the idea that processing external representations involves full knowledge of the representational system is seldomly acknowledged (but see Ainsworth, 2006; van der Meij & de Jong, 2004), or only almost in a trivial way, such as by Stenning and Oberlander (1995, p. 100), when adding a *key* to Palmer's (1978) representational system for "that part of the mapping from representation to world which has to be made explicit to users of the representation because they do not carry it as part of their general knowledge".

Externalization of processing thus obscures the boundaries between (1) notations of formal computational systems, (2) their visualizations or renderings and (3) the space of possible interpretations by the learner. As an illustration, let us compare visualization techniques and computer-generated imagery (CGI). Visualizations may create different isomorphs of an identical underlying formal structure, much like the line, number, shape and colour isomorphs of tic-tac-toe (Zhang, 1997) and the waitress and coffee or waitress and oranges isomorphs of the Tower of Hanoi (Zhang & Norman, 1994). For those authors, only theorists know and work directly on the underlying formal structure; task performers only "see" the material problem setting. Typically, some rules are implemented in the environment, just like they may be in a visualization, but some of them have to be inferred, memorized or learned by the learner (i.e. the so-called external versus internal rules). But in any case, visualization techniques aim at the learner's identification of the underlying model without further interpretation.

Computer-generated imagery, on the other hand, produces 3D animations of real or imagined objects that are essentially *polysemic*; knowledge of the signification of an inscription must be inferred from the configuration of inscriptions. For example, a blue spot is only interpreted as an eye to the extent that the whole configuration suggests a face. Learners do not have to identify the underlying computational model which is only used for dynamically rendering a 3D animation out of a number of possible ones. In conclusion, both visualization and CGI rendering may of themselves be considered interpretations of an underlying formal system. But whereas learners have to figure out the model and refrain from inferring any other meaning in the former, they have to build an interpretation in the latter case. Moreover, just like in a material problem setting, passively watching changes does not suffice to construct the appropriate set of rules. Learners need to discover representing relations and rules and to come to ignore irrelevant non-representing relations and illicit rules by active participation.

Taking advantage of the processing capabilities of humans and machines, learning with digital representations can be conceived of as a case of Perry's (2003) *distributed cognition* par excellence, precisely because it involves a triple distribution across (1) internal and external locations, in respect of (2) the producers and the users of (3) representations and processes of knowledge. The question arises whether sets of symbol processes, and notably those implemented in essentially different processors (computer agents, experts, learners), can be considered to be equivalent. This implies that the field of digital representations needs careful study as to which processing to allocate to which processor, the human or the computer. In particular, it could be a pitfall to externalize processing to the computer that is

essential for learning in a domain and should be left to the learner (cf. de Vries & Ainsworth, 2007; Duval, 1995).

9.5 Conclusions

In conjecturing about the future, few foresee learners to easily find their way through the myriad of (combinations of) digital representations that even today's learning technologies offer. Existing approaches with a dyadic perspective justifiably pinpoint the constraints related to the human information-processing system and focus on the verbal–visual divide as the main distinguishing feature of external representations (Chapter 15; Reed, 2006). But as a valuable alternative, a triadic-inspired enquiry into learning as meaning making has to examine the cultural embeddedness of emergent representational systems as well as the availability, in the learner, of the symbolic or interpretation processes that these require. A truly digital culture supposes what may prove to be an excessive confidence in the learner's ability to deal with any digital representation, regardless of the cultural origin of its representational system or of its signification mode, in the way the producer meant it to be. Blending languages, technologies and knowledge domains thus begs a novel question: are texts (language), pictures (cultural conventions), algebraic equations, Cartesian coordinate systems and matrices (mathematics), flowcharts, boxes-and-arrows, bar charts (common graphical representations), domain-specific representations such as electrical circuits, diagrams of forces and molecular structures (cautioned by experts; diSessa, 2004) and visualizations (ad hoc representational formats) all pieces of the same cake? The difference between dyadic and triadic perspectives boils down to the question whether or not culture and context are central for learning with digital representations. The future of digital learning then will require a kind of synchronization of the spheres of representational practice of domain experts, developers of learning environments, teachers, learners and the researchers in the learning sciences themselves.

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Chapter 10

Computer-Supported Collaboration Scripts

Perspectives from Educational Psychology and Computer Science

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Abstract Students are often at a loss for what to do or have inadequate ideas of how to build knowledge collaboratively through computer-supported collaborative learning (CSCL). Facilitating specific CSCL processes by providing learners with computer-supported collaboration scripts is regarded as a promising approach. Implemented in CSCL environments, computer-supported collaboration scripts specify, sequence and distribute roles and activities. Scripts are intended to scaffold activities that students could not yet engage in on their own. One of the main challenges of this approach for realising effective CSCL is the continuous adaptation of scripts to learners' needs and knowledge. Efforts to specify and formalise script components and mechanisms have led to an integrative framework for computer scientists, educational scientists and psychologists of what constitutes computer-supported collaboration scripts as well as a growing library of prototypical CSCL scripts.

Keywords Collaboration script · Computer-supported collaborative learning (CSCL) · External script · Internal script · Scripting · Modelling · Formalisation · Adaptivity

10.1 Challenges of Implementing Effective Collaborative Learning

Collaborative learning is a central component of many current theoretical and practical approaches to learning and instruction and is assumed to foster specific learning processes and outcomes. Having ownership of their learning processes,

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collaborative learners are expected to elaborate and share knowledge with peers and thus acquire and become able to apply domain-specific knowledge as well as attain soft outcomes, such as self-esteem, motivation, and social skills (Johnson & Johnson, 2002; Lave & Wenger, 1991; O'Donnell & King, 1999; Slavin, 1995; Vygotsky, 1978). However, implementing effective collaborative learning in schools and universities today is a challenging task. Imagine a university teacher giving an introductory lecture to about 100 students on some basic approaches in educational psychology, such as theories of attribution. Beyond the lecture itself, in which the basic theories should be introduced, the lecturer wants the students to learn how to apply the psychological theories to single problem cases collaboratively, including additional literature in their work. Therefore, students are expected to learn collaboratively through solving complex problems. Guiding a large number of students through a problem-oriented learning environment including facilitation of specific activities and providing feedback is a challenging task. Throughout this chapter, this example will be revisited to outline how computer-supported collaboration scripts can help to realise effective collaborative learning scenarios.

Computers can support collaborative learning through a number of communication and representation tools, such as asynchronous discussion boards or wikis, creating a virtual space for students to work on learning tasks together (Chapter 1; Stahl, Koschmann, & Suthers, 2006). Yet merely assigning a collaborative task and providing learners with communication tools may not suffice to establish effective (computer-supported) collaborative learning. Teachers therefore need to scaffold learners in building and maintaining shared understanding (see Chapter 1; Dillenbourg, 1999; Fischer & Mandl, 2005; Mäkitalo, Weinberger, Häkkinen, Järvelä, & Fischer, 2005; Weinberger, Stegmann, & Fischer, 2007b). As educational psychologists and computer scientists, we must investigate ways of supporting both learners and teachers in reaching their goals in collaborative learning and teaching.

Computer-supported collaboration scripts (CSCL scripts) are an approach to setting up and facilitating effective collaborative learning and can be defined as a specific type of instructional support or scaffold. There is a variety of scaffolding techniques for very different purposes (see Quintana et al., 2004). What makes collaboration scripts special (both for face-to-face groups and for computer-mediated groups) is their focus on the collaboration process between two or more group members. That is, collaboration scripts do not necessarily provide guidance on a conceptual level (for example by providing content-specific prompts such as “Explain why ball A moved slower after it hit ball B”), but rather on a (collaboration) process level (e.g. “Listen to your partner’s explanation and think about counterarguments for her explanation”).

On a macro-level, CSCL scripts can structure and link lectures, individual and collaborative learning phases in face-to-face or in computer-mediated environments. For instance, the university lecturer in the above example might design a script that coordinates the distribution of resources between the lecture and an online environment. Additional literature that is downloadable in an online course management system could be identified in the lecture. After handing out specific reading and writing assignments to individual learners, groups of three or four students could be formed. In these groups, learners could be assigned the task of collaboratively

analysing problem cases on the basis of theoretical texts they have read and initial ideas they have noted down individually.

On a micro-level, CSCL scripts scaffold specific collaborative learning processes and provide learners with more or less detailed instructions concerning the types and sequence of different activities and roles they are expected to perform during collaboration (Kollar, Fischer, & Hesse, 2006). Unlike early scripting approaches, CSCL scripts may be designed flexibly to guide learners to communicate and share representations of their knowledge. CSCL scripts could be adapted by learners as well as by teachers to fit specific pedagogical scenarios and goals.

Besides supporting the implementation of scripts in a specific learning environment, computers can also support the design and adaptation of scripts to different learning environments. In the university lecture example, specific interaction patterns could be facilitated by assigning different roles to the students, such as case analyst and constructive critic. These roles in turn can be supported by sentence starters provided in asynchronous discussion boards within the CSCL platform, such as “The most important theoretical concepts that can be applied here are . . .” or “What I did not understand was. . .” (see Weinberger, Ertl, Fischer, & Mandl, 2005).

For the remainder of this chapter, the university lecture example will be used as a reference when synthesising recent theoretical, empirical and design-related developments in educational psychology and computer science leading to the specification and formalisation of CSCL scripts. The following sections elucidate how CSCL scripts can be designed to facilitate learners’ transition from other- to self-regulation and outline a vision for future research and practice.

10.2 Outlines of a Script Theory of Collaborative Learning

An essential aspect of most forms of collaborative learning is that peers verbally negotiate with each other about how to solve specific learning tasks, with the goal of acquiring knowledge individually. Learners’ interaction processes are therefore assumed to be related to cognitive processes of learning in “spirals of reciprocity” (Salomon & Perkins, 1998, p.20). In constructing explanations and arguments, learners outline and thereby restructure their individual knowledge in a linear form. Reciprocally, learners hear their peers’ arguments, which may comprise additional resources in solving a task and prompt learners to reply and construct new (counter-) arguments. Learners who are able to balance arguments fairly will thus acquire knowledge individually, which in turn enables them to execute cognitive activities on a higher level (Schwarz, Neuman, Gil, & Ilya, 2003).

10.2.1 Internal and External Scripts

One reason for the wide variation in students’ learning and academic success lies in different patterns of socialisation in the classroom (e.g. teacher–student or

student–student interactions, actual instruction, teacher’s expectations; Brophy & Good, 1986). Students may know little about how to collaborate and learn together. For instance, learners often lack procedural knowledge of how to construct and interpret arguments. This procedural knowledge has been conceptualised as *internal scripts* (Kollar, Fischer, & Slotta, 2007).

From a cognitive psychology perspective, internal scripts are understood as a particular type of cognitive schemata: cognitive constructs that help individuals understand and act in meaningful ways in dynamic events (Kolodner, 2007; Schank & Abelson, 1977). In other words, individuals have already existing expectations, a set of beliefs and a repertoire of possible actions to choose from in certain situations. If the situation is new, individuals refer to similar past experiences and modify their behaviour accordingly to better fit the new situation. From a schema theory perspective, collaborative learners would share some more or less elaborated knowledge on what events and activities could be expected during the learning process. For instance, some learners might expect to communicate with their partners and participate more or less equally in working on a joint task. Depending on the novelty of the situation, learners may also have more elaborated scripts and sub-scripts, such as introducing yourself and your perspective on the task, asking questions, giving explanations, providing counterarguments, synthesising different opinions, documenting group processes and outcomes (with specific artefacts) and coming to a joint conclusion.

Contrary to Schank and Abelson’s (1977) initial conceptualisation, scripts are not rigid plans that determine processes from start to end (cf. Suchman, 1988, 2003), but culturally shared knowledge represented within the individual mind about abstract events and activities that take different concrete forms in single instances of collaborative learning events. As a result, internal scripts are postulated to be flexible enough to adjust to changes in the collaborative situation as well as to be applied in different collaborative learning situations. As CSCL may pose a particular novel situation for most, learners’ internal scripts may be less elaborated, lack specific sub-scripts or bias learners’ perceptions and lead to inadequate activities with respect to the collaborative learning goals.

As internal scripts often appear to be fragmentary and even dysfunctional, collaborative learning has been facilitated with experimenter-generated (O’Donnell & Dansereau, 1992) or *external scripts* (Kollar et al., 2007). External scripting involves an approach that aims to scaffold learners and facilitate knowledge acquisition at the level of the groups and the individuals by specifying, sequencing and distributing roles and activities. Different from theatre scripts, external collaboration scripts are to guide and scaffold rather than impose learners’ collaborative activities. Different from internal scripts, which are flexible and adaptive to changes in the collaborative situation, external scripts are generally set up prior to collaboration and cannot be adapted to situational demands arising during the collaborative process. One major issue of CSCL research on scripts is therefore to investigate how external scripts can become more flexible for learners to use in different collaborative scenarios and CSCL platforms through specification and formalisation of scripts (see Section 10.3.2).

Another key difference between internal and external scripts is that the latter are represented first by means of cultural artefacts, such as chairs and tables, pen and paper or online discussion boards. External scripts may also be represented in teacher contributions or in a text handed out to the learners (Kollar et al., 2006). Only as a second step are external scripts internally represented by the learners. That is, learners are challenged to make sense of the situation with the help of external scripts, but also to make sense of the external script itself. External scripts thus complement and potentially alter learners' internal scripts. This is especially desirable when the external script represents important strategies within a domain that should ultimately be acquired individually by the learners. To illustrate, goals of science education may include learning how to construct and analyse sound arguments in a domain, how to review literature and critically reflect on hypotheses or how to investigate hypotheses and interpret data. Research on scripts that aimed to facilitate the construction of single arguments and argumentation sequences has shown to facilitate not only the specified activities during the collaborative phase but also the individual acquisition of argumentative knowledge (Stegmann, Weinberger, & Fischer, 2007).

However, not all scripts are to be internalised. Some scripts or script components may regulate effortful functions that are not directly connected to cognitive activities of learning, such as group formation or regulating turn taking within these small groups (e.g. Pfister, 2005). CSCL scripts should be represented in the individual learners' mind to different degrees and time spans for the purpose of modifying the emerging interaction patterns in CSCL environments. These observable interaction patterns can be referred to as another representation of scripts (see Section 10.2.2). They do not result from any single script being executed, but from the combined and reciprocal effect of different learners' internal and external scripts including non-intentional situational affordances.

An important design decision that must be made in the university lecture example is whether the script itself should induce a strategy and to what degree it should be internalised. The university teacher may decide that the students in the course should learn to construct sound arguments based on psychological theories. To this end, learners' messages could be classified as arguments or counterarguments and contain prompts suggesting that learners warrant and qualify their claims. The teacher may also consider what an ideal argumentation sequence in terms of emerging patterns of student interaction is supposed to look like (cf. Stegmann et al., 2007) and what aspects of the argumentative interaction are thought to need support or are already represented within students' internal scripts.

10.2.2 Scripts and Observable Interaction Patterns

The basic rationale of scripted collaboration implies that students acquire knowledge individually by engaging in specific learning activities. Consequently, script design depends essentially on the designer's theoretical model of which specific collaborative learning activities and interaction patterns impinge on individual

knowledge acquisition. In one such model, termed *argumentative knowledge construction*, collaborative learners acquire knowledge individually in particular when they construct sound, elaborate and well-interlinked arguments (Weinberger & Fischer, 2004).

Scripts are meant to facilitate individual knowledge construction mainly through supporting these specific activities. However, learners do not necessarily follow a particular external script in full. When several scripts come into play learners' actual observable activities and interaction patterns may not resemble any particular script. Both internal and external scripts as well as situational components co-determine the actual interaction patterns observed. Although it has been shown that students basically adhere to external script structures, some variance can be found with respect to the degree to which external scripts regulate collaborative learning activities (Weinberger, Stegmann, Fischer, & Mandl, 2007). Over longer periods of time especially, external scripts may become redundant or even dysfunctional when they are not dynamically adapted to learners' needs throughout the course of the learning process. This dynamic adaptation could be realised by teachers who continuously monitor the collaborative learning activities, by the learners themselves who could choose what script support to select or drop, or by software that could propose scripts to teachers or learners based on automatic analyses of learners' interaction patterns (Dönmez, Rosé, Stegmann, Weinberger, & Fischer, 2005).

There is yet little knowledge about how internal scripts may guide collaborative learners and how learners converge or diverge with respect to how they handle learning tasks together. Typically, students may not make their internal scripts explicit. One may assume that learners quickly converge on a common style (e.g. through primacy effects) and participate according to how motivation and competencies are distributed within the small group of learners (Weinberger, Stegmann, & Fischer, 2007a). As little is known about the ways in which internal scripts of group members interact, there is also little knowledge on how internal and external scripts interact in qualitatively different ways. Thus far, researchers have converged on the notion that external scripting needs to be adapted to learners' internal scripts. The more learners are able to self-regulate their collaborative learning processes, the less elaborated and regulative an external script should be (Cohen, 1994).

With respect to the university lecture example, this leaves us with the question of how to adapt external scripts to learners' internal scripts. After the university lecturer analysed what kinds of internal scripts the students held and how elaborated these internal scripts were, the lecturer could select external scripts that regulate activities that the respective learners would normally not engage in, such as constructing warranted claims. Based on continuous analyses of learners' arguments – possibly supported through automatic discourse analysis software (Dönmez et al., 2005) – the lecturer could decide if and when to gradually fade out the script.

10.2.3 Internalising External Scripts

Early scripting approaches were proposed before computers became ubiquitous learning tools and aimed to facilitate collaborative learning processes by instructing

learners to engage in a specific sequence of activities (O'Donnell & Dansereau, 1992). Some of these approaches additionally provided learners with scaffolds, such as sentence starters or prompts that learners were expected to respond to and complete when learning together (King, 1999). Unlike CSCL scripts, learners were taught how to use these early scripts prior to collaborative learning phases, mostly by teacher-guided instruction. Such scripts were represented in paper form or through verbal instructions only. These early approaches often emphasised that the actual goal of scripting collaboration was to help students become self-regulated learners (e.g. King, 2007). At least during the initial stages of the learning process, the facilitation of self-regulated learning therefore entails a certain degree of other-regulation (see Kollar & Fischer, 2006), which in later stages may be gradually reduced or faded out (Pea, 2004). From a script perspective, the transition from other- to self-regulation can be conceptualised as a gradual internalisation of scripts. The goal of this internalisation is for learners to become more and more self-guided individuals who can solve problems by relying primarily on their internal resources. Scripts are more effective once internalised, because they are more accessible and a smaller load to working memory capacity than external scripts.

In a study conducted in an inquiry learning context, Kollar and colleagues (2007; see also Kollar, 2006) found that highly structured external CSCL scripts can indeed overlie the internal scripts that learners bring to the collaborative learning situation. However, after the external script was faded out and not available to the learners any more, the learners did not engage in the activities suggested by the external scripts and mainly followed their original internal scripts. Thus, there was no evidence for a strong internalisation of external script components. However, the duration of the learning session was rather short. Internalisation of external scripts may be more likely to be observed over longer periods of time. This, however, is subject to further examination.

Another possibility could be the pace of fading of external scripts. Transition from other- to self-regulation can possibly be realised with a gradual fading of external script components rather than an on-off switch of scripts. CSCL scripts may be more flexibly designed and capable of being faded out in comparison to teacher-instructed scripts (Kobbe et al., 2007). Additionally, regulation of activities may be temporarily shifted from external scripts to co-learners, who could continue to control the engagement in the formerly scripted activities. An empirical study on fading out of computer-supported collaboration scripts in a university context produced promising results by showing that distributing metacognitive functions to co-learners when the script fades out is a fruitful way to facilitate the internalisation of scripts (Wecker & Fischer, 2007).

The university lecturer in our example thus needs to decide how to support the transition from other- to self-regulation and successively fade out the external script components. There are indications that fading out in terms of switching scripts on and off does not necessarily lead to learners' internalisation of the script and continued engagement in activities suggested by the script (Kollar et al., 2007). The lecturer might want to motivate students to continue the scripted activities after the script components are faded out by having the learners mutually control the

continued engagement in the specified activities and possibly also by rewarding engagement in these activities.

10.2.4 How Do CSCL Scripts Work?

CSCL scripts are considered an effective means of facilitating specific interaction patterns in computer-supported collaborative learning situations (see Fischer, Kollar Mandl, & Haake, 2007). External scripts are, however, ill defined in terms of how their effects unfold in collaborative learning. Reducing process losses and inducing specific cognitive activities related to individual knowledge acquisition are two major functions of scripts. Introducing computers to classrooms drew attention to the fact that learning and instruction are not only distributed between teachers and students. Cognitive functions may be also distributed among the environment and the tools being used in the learning process. For a first approximation, Kollar and colleagues (2006) therefore proposed viewing CSCL as an instantiation of a “person-plus-surround” system (Perkins, 1993, p. 89). The basic assumption of such a systemic view is that cognition does not (only) happen in the minds of individual learners (the person-solos), but that the group as a whole including the artefacts it is using participates in cognition (person plus surround). A crucial question in analysing a person-plus-surround system is which component(s) execute metacognitive control such as goal setting or performance monitoring (Perkins, 1993, p. 96, calls this the “executive function” within the person-plus-surround system). The question as to whether students need a script that helps them to perform a particular activity (and thereby takes over the executive function for the system) thus depends heavily on the extent to which the collaborators (or at least one of them) are capable of effectively regulating the group processes themselves.

With respect to inducing activities related to individual knowledge acquisition, scripts should represent the procedural knowledge learners have not yet developed. Still, even when internal and external scripts complement each other, they do not simply combine so that learners are enabled to engage in specific activities, accomplish the learning task and acquire knowledge individually. Internal and external scripts may interact in qualitatively different ways that are yet to be investigated.

From a scaffolding perspective, external scripts induce activities that learners could not engage in without additional support, in the sense of Vygotsky’s zone of proximal development (1978). The scaffolds provided to the learners do not make activities necessary to complete the task redundant, but lead learners to engage in the activities relevant for individual knowledge acquisition. From this perspective, it is important to limit scripts to the regulation of specific functions and to include the possibility for learners to take over the activities relevant for individual knowledge construction without further support. If scripts relieve learners of vital collaborative learning activities they might interfere with the social dynamics of the group and even impede learning – a situation known as over-scripting (Dillenbourg, 2002). Scripts might also provide too little help for some students or groups, which could

be called under-scripting. Therefore, there is a need to strike an optimal balance between internal and external scripts. One of the major issues in scripting is thus how scripts can facilitate self-regulated learning and which collaborative and cognitive activities the actual human agents in learning and teaching processes in authentic classroom contexts are meant to take over when interpreting an external script and when following script suggestions.

Scripts may also induce specific activities by shaping learners' expectations of what is going to happen in the collaborative phase. Learners expecting to engage in specific activities (e.g. giving explanations) have been found to acquire more knowledge individually than learners who do not (Renkl, 1997). Making the collaborative scenario more transparent through scripts may also alter the motivational configuration of the learning group. For instance, scripts explaining that all group members are required to participate similarly may reduce social loafing and sucker effects (Kerr, 1983; Latané, Williams, & Harkins, 1979). Scripts may also clarify how specific activities may eventually lead to desired outcomes and thus increase learners' motivation (Weinberger & Fischer, 2004).

With respect to reducing process losses, scripts may be designed to take over effortful tasks not directly related to individual knowledge acquisition independent of learners' capabilities. For instance, students may be perfectly able to distribute responsibilities of sub-tasks or develop a schedule of who is doing what at what time. External scripts may, however, take over these organisational tasks, thus allowing learners to spend more time on the actual learning activities (cf. Weinberger, Stegmann, Fischer, & Mandl, 2007). Given that learners generally adhere to script prescriptions, external scripts may also reduce process losses by harmonising different internal scripts. Internal scripts can be considered as culturally shared procedural knowledge, so that learners of one culture may carry similar internal scripts. Collaborative learners from different cultures may thus particularly benefit from following external script prescriptions (Weinberger, Clark, Häkkinen, Tamura, & Fischer, 2007).

With respect to the university lecture example, the script may be designed to first make explicit to the students that they are expected to construct arguments and thus acquire important argumentative knowledge. The script may further contain a task schedule to reduce process losses and facilitate the construction of arguments, as by providing learners with an interface in which messages are titled arguments, counterarguments and syntheses by default (see Stegmann et al., 2007).

10.3 Specification, Formalisation, Design and Deployment of CSCL Scripts

Research on scripts has predominantly been undertaken in the context of European CSCL research, in which the script approach has had an increasing impact over recent years (Fischer, Kollar et al., 2007; Fischer, Weinberger et al., 2007). The CSCL context poses specific difficulties that scripts address, such as learners being

at loss of what to do in complex CSCL environments. It has been suggested that unstructured, problem-based CSCL environments are too demanding for learners to actually benefit more from them than from traditional instruction (cf. Kirschner, Sweller, & Clark, 2006). There are indications that collaborative learners surpass individual learners in a complex computer-supported environment only if they are supported by a script (Weinberger et al., 2007b).

The script approach has been at the crossroads of several research and development fields and has attracted special attention, especially in the e-learning community, although sometimes under different terminology. Approaches such as educational modelling languages (EML) in instructional design (Learning Technology Standards Observatory, 2007), workflows in business processes (Vantroys & Peter, 2003) or patterns and visual languages (Botturi & Stubbs, 2008) share many ideas, assumptions and trends with the CSCL script approach (Vignollet, David, Ferraris, Martel, & Lejeune, 2006). Such a confluence heightens the need to take advantage of all previous and current related work, merge these perspectives and converge to a stable and widely accepted solution for all stakeholders (researchers in education, psychology and engineering, together with educational practitioners, or even technology and service providers).

In the university example, the teacher faces the problem of how to put into practice on short notice and without excessive effort all the ideas for a script, taking into account limited time availability and experience in technology-enhanced environments. Thus, the teacher needs to consider the widely adopted learning management system (LMS), which has strong support from the university administration, and an EML, which allows expression of the main characteristics of the script. In addition, the script should be easy to describe and design in common language based on established knowledge or innovative approaches towards collaborative learning.

10.3.1 Life Cycle and Framework for CSCL Scripts

Considerations such as those arising in the university lecture example of specifying and designing scripts drive many current efforts that aim to provide scientific and technological support for different phases of the life cycle of a CSCL script. The integrated framework proposed by the European Research Team CoSSICLE (Computer-Supported Scripting of Interaction in Collaborative Learning Environments; Kobbe et al., 2007) allows understanding and specification of components and mechanisms, that is, the elements and procedures that are necessary for study and research on CSCL scripts. The formalisation of such a framework in computational terms opens the path for the use of computer-based tools for modelling and design of the scripts, while on the other hand it enables the interpretation and execution of such scripts in CSCL environments.

Formal expressions in terms of a computational language disambiguate the specified components and mechanisms. This is a prerequisite for adapting scripts to different learning environments, so as to avoid the proliferation of ad hoc

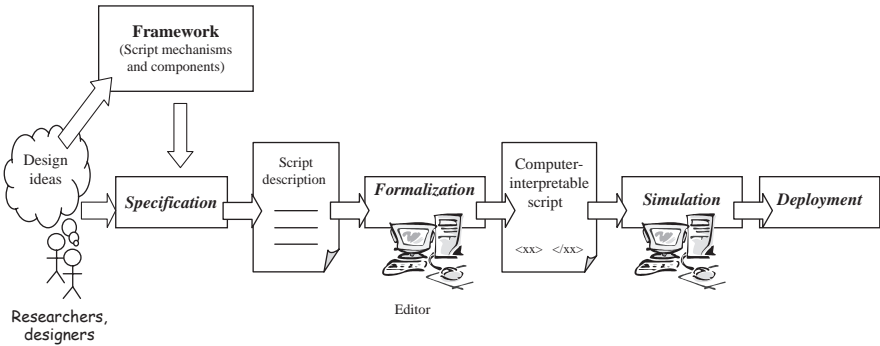


Fig. 10.1 Life cycle of and technology support for CSCL scripts

implementations that are hardwired in a specific system. There is a practical need for a specification and formalisation of scripts to provide teachers and designers of collaborative learning environments with a script toolbox, dynamically adapt scripts during phases of collaborative learning and make scripts transferable from one learning environment to another (see Fig. 10.1).

Teachers may be supported by tools for the conception and delivery of scripts in a general-purpose LMS or a specific CSCL environment. Besides the individual teacher, instructional designers may be more productive in the setup of similar environments, creating a community of teachers who exchange and tailor scripts, data and tools for their classes. It is then possible to expect wider adoption of the CSCL script approach, taking into account the needs of all stakeholders and providing appropriate support.

A stratified approach has been adopted to specify scripts in the CoSSICLE framework, differentiating between schemata and families. While schemata follow some general design principles, script classes are variations of schemata prototypes that are adapted to the specific educational context (i.e. the extrinsic constraints), while complying with the script intrinsic constraints (Dillenbourg & Jermann, 2007). Similar to a pattern-based approach (Hernández-Leo, 2007), this framework builds on existing knowledge that is widely adopted by practitioners while being based on extensive educational research. Its main advantage lies in the flexibility provided to practitioners or educational designers, since they can properly instantiate schemata and families, and facilitates specific interaction patterns that are best suited for specific scenarios.

Different script schemata have been identified (Dillenbourg & Jermann, 2007) such as those that refer to *jigsaw* grouping and re-grouping learners with complementary knowledge (Aronson, Blaney, Stephan, Sikes, & Snapp, 1978), *conflict* grouping learners of contradictory knowledge and roles (e.g. Weinberger et al., 2005) and *reciprocal* facilitating questioning and tutoring activities (King, 2007). Similarly, collaborative learning flow patterns, such as jigsaw, pyramid and think-pair-share, have been detected and included in the pattern-oriented framework that supports

similar levels of abstraction and specialisation (Hernández-Leo, Harrer, Dodero Asensio-Pérez, & Burgos, 2007).

In addition to general script schemata and more specialised script classes, the CoSSICLE framework specifies a structural decomposition that conveys a minimal number of elements that cover the needs of a CSCL script. While scripts can be broken down into components, the dynamic and distributed character is defined through mechanisms. With respect to components, roles, for example, are supposed to facilitate specific collaborative learning activities such as question asking, explaining or finding evidence (see King, 2007). On the other hand, participants in the activities may form groups (e.g. expert and super groups in the jigsaw script class) and use computer and network resources, which may be offered as services (e.g. a shared workspace), although individual activities and non-ICT (information and communications technologies) resources are also considered. The dynamic mechanisms that govern CSCL scripts include task distribution among groups and roles, group formation and sequencing of activities. It is noteworthy that many instances of script classes can be described through a small set of components and mechanisms. For example, the specific group formation and rotation of roles are characteristic of the jigsaw script class fostering homogeneous participation in complementary learning activities.

10.3.2 Languages and Tools for Modelling and Deployment

The selection of a formal language for representing a CSCL script is a crucial aspect, since this modelling language has to be sufficiently expressive for collaborative situations as well as complying with standards. The general approach of EML, such as Instructional Management System – Learning Design (IMS-LD; IMS, 2003), does not take into account all specific characteristics of CSCL, as it has various deficiencies in terms of expressiveness (Caeiro-Rodríguez, Anido-Rifón, & Llamas-Nistal, 2003). However, a de facto standard supported by international organisations motivates independent service providers to create tools that support the whole life cycle and therefore promotes the creation of sustainable technological solutions. Thus, an important dilemma has drawn the attention of researchers and developers in this field: whether to use a proprietary language that allows for richer, more precise and more efficient formalisation of CSCL scripts or to adopt a standard but likely insufficient language such as IMS-LD. While a specialised language for CSCL scripts may coexist, there is a clear trend and need for a solution based on standards that may offer the option for gateways to specific solutions, or paths for future enrichment. There is then the chance for wider adoption by the broad technology-enhanced learning community and it is hoped by educational practitioners, in the direction of solutions based on standards and open source in the general CSCL field.

The difficulties of this approach are shown in a study related to the widely used WISE science inquiry tool that employs scripting (Berge & Slotta, 2007). Authors found that the SCORM (Sharable Content Object Reference Model) standard

(ADL, 2004) imposed serious limitations on the pedagogical functionality, while use of IMS-LD (IMS, 2003) was feasible and enabled gateways to scripts (projects) developed by third-party designers. Additionally, the adoption of open-source principles and tools is probably one of the major assets that should be taken into account, as exemplified in the Scalable Architecture for Interactive Learning (SAIL) architecture (Slotta & Aleahmad, in press). Thus, the issue of standardisation seems to present the same problems and advantages as in the general discussion of the wider technology-enhanced learning community, namely the trade-off between portability and reuse on the one hand and expressiveness or flexibility on the other.

Tools and computer-supported environments are final elements that must be provided and considered with respect to technological support for the CSCL script life cycle. For example, an editor is necessary for a researcher, instructional designer or educational practitioner to be able to define the components and mechanisms that formally describe a CSCL script in a computational language. For instance, the Collage editor (Hernández-Leo et al., 2006) allows customisation and generation of hierarchical combinations of collaborative learning flow patterns (script classes), such as jigsaw or pyramid, represented in IMS-LD. An extensive multi-case study (Hernández-Leo, 2007) has shown that educational practitioners are able to successfully formulate their scripts in their specific contexts. An additional element of the CSCL script toolbox points to a simulator which allows designers to run their scripts in a simulated environment and then to reformulate them for a more effective and error-free implementation class environment (Harrer, 2006). Also, players are necessary to interpret the CSCL scripts that have been designed and modelled, such as Copercore for IMS-LD. Finally, computer architectures are useful to embed CSCL scripts in existing computer-supported learning environments, such as the “remote control approach” (Harrer, Malzahn, & Roth, 2006) or to enable tailoring of CSCL scripts using available tools offered as services, such as Gridcole (Bote-Lorenzo et al., 2008).

In the university lecture example, the teacher may decide to use the jigsaw script schema depending on the respective educational objectives. Then, the basic script components and mechanisms employing the concepts of the previously mentioned CSCL framework can be specified, as, for example, to define an *activity* for a final exchange of arguments between the members of the supergroups that were formed beforehand by the teacher, using the *resource* of an online argumentation forum integrated in a popular LMS. An editor could then be used to formalise the script and produce a machine-interpretable file, eventually in standard EML. Before the deployment of the script, the teacher may detect any eventual problems and reflect on the structure and performance of the script through the use of the available simulator. Finally, an interpreter integrated in a general-purpose LMS may deliver the script in the class, with a possibility of dynamic adaptation, as well as an eventual fading out of the external script.

Notably, teachers may have substantially different requirements than researchers. While researchers may focus on studying the adaptive fading in and out of script components depending on learners’ individual needs and deficits, practitioners or administrators are more interested in effectively and efficiently delivering these

proposals in the real classroom with certain guarantees for sustainability and scalability. A solution to this dilemma may be of crucial importance and may drive the research and development roadmap in this field.

10.4 Discussion and Outlook

Considering that collaborative learning is partly about adapting and modifying learners' internal scripts, external scripts may provide too little appeal for being internalised. Instead, scripts focus learners on their specific instructions. As a result and depending on the specific script type, learners may, for instance, reply to script prompts rather than to their learning partners or may disregard solving the task in favour of specific social activities or group-formation activities. Apparently, scripts must be adapted to the individual needs of the collaborative learners on multiple dimensions. Otherwise scripts may at best be ignored, but could just as well impede the collaborative learning process (Dillenbourg, 2002; Mäkitalo, Weinberger, Häkkinen, Järvelä, & Fischer, 2005). The approach to this problem suggested here through modelling and design tools that support the deployment and adaptation of scripts seems feasible, but also highly challenging for educational psychology and computer science. First, learners' internal scripts need to be analysed. Second, external scripts need to be adapted accordingly by designers, learners and teachers. Script components could be faded in or out according to the identified learners' needs or their actual effects on the collaborative process. Then again, scripts are entire procedures and may lose their actual instructional meaning when being technically described and broken up into single components.

One of the challenging issues in instructional design of CSCL scripts is to better integrate scripts into wider social planes such as overall classroom activities. The specification and formalisation of scripts can augment the use of scripts in the classroom regardless of the technical learning platform applied. Technical descriptions of scripts realised with specific script modelling tools can not only preserve and convey the underlying educational principles of scripts but also support teachers to realise and orchestrate scripts of different granularities within their classroom. This includes, for instance, the orchestration of individual and collaborative learning phases as well as identification of the role of the teacher within a wider classroom script.

However, there are several limitations in the use of external scripts in authentic classroom contexts that outline steps for future educational research. On the one hand, external scripts do not take into account learners' already existing internal scripts and might capture learners' attention differently than expected. On the other hand, external scripts can predict neither changing needs of individual students nor those of groups. In order to offer the right support at the right time, it is important to track real-time processes so that scripts can fade in or out as necessary. A promising approach is to analyse processes in real time with tools for automatic analysis of natural discourse corpora (Dönmez et al., 2005). Interaction analysis methods

and tools (see Chapter 11) should provide sufficient and significant indicators of the real process and its relation to the external scripts, thus enabling flexible script adaptation. This new element of interaction analysis tools, and probably to a lesser extent tools for trails analysis (see Chapter 12), imposes new requirements for interoperability, as already discussed with respect to script design tools. Additionally, longer-term follow-up studies in research on collaboration scripts can identify how fading of scripts can support students in becoming self-regulated learners.

With a few notable exceptions, the social and emotional aspects of self-regulation in collaborative learning scenarios have attracted less attention than its cognitive features (Crook, 2000; see also Chapter 1). However, there are many studies arguing that a sense of community and an open and sensitive atmosphere are necessary pre-conditions for collaborative learning (Cutler, 1995; de Jong, Kollöffel, van der Meijden, Kleine Staarman, & Janssen, 2005; Rourke & Anderson, 2002; Rovai, 2000; Wellman, 1999). A strong mood of group togetherness can enhance the flow of information, the availability of support, commitment to group goals and satisfaction with group efforts (Wellman, 1999). de Jong and his colleagues (2005) consider that in order to establish and maintain a secure and collaborative atmosphere, learners should give precise expression not only to ideas and knowledge but also to social and affective propositions. Scripts can be seen as situational and contextual resources in learning environments (Häkkinen & Mäkitalo-Siegl, 2007) that can affect learners' motivation. Therefore, research on learners' goals when using scripts might help us to understand in what ways scripts can also affect student and group goals and whether scripts can contribute to changing these goals in addition to changing internal scripts.

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Chapter 11

Users' Data

Collaborative and Social Analysis

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Abstract Interaction analysis has been used in computer-mediated settings for approximately two decades. Its main purpose has been to understand and identify the characteristics of electronic communication, collaboration and coordination. In recent years, however, its scope has expanded to include the support of students and teachers during online learning activities. This chapter documents the findings from three European projects that focused on this novel, supportive role for interaction analysis. Following the definition of interaction analysis indicators and their computation, the use of unified data formats and interfaces is considered as means for utilising tools and data beyond their original scope and settings. Finally, the issue of visualisation of analysis results is discussed.

Keywords Interaction analysis · Tools · Data formats · Network visualisations

11.1 Introduction

Interaction analysis has been used in computer-mediated settings for approximately two decades (Harasim, 1990). Its prevalent use has been for researchers to understand and identify the properties of electronic communication, collaboration and coordination as well as the conditions for success or failure of its usage. Some early examples of interaction analysis sought to capture patterns of email exchange in scientific discussion and resulted in diagrams showing the discussion threads evolving between the discussants, a representation that helps to follow the communication flow in the discussion. Recent examples can be found in the observation of social Web phenomena, such as blogospheres and Wikipedia.

In addition to this analytical use, automated computer-based “interaction analysis” (IA) has been introduced as means to provide direct support to students and teachers involved in learning activities. One example of this application is *Exxelant* (Granger, Kraif, Ponton, Antoniadis, & Zampa, 2007; see also Chapter 6), a tool

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that supports teachers in analysing students' actions in order to trace errors in their writing skills.

Computer-based interaction analysis is an emerging field that seeks to provide direct and indirect support to participants in all kinds of technology-mediated activities. The automated analysis of participants' interactions is developing in two main directions. One direction is that based on the output of interaction analysis, the system takes into account the profiles and cognitive processes of individuals or collaborating groups to adapt the learning environment to their own needs and preferences – or even to provide appropriate messages that guide them therein. A second direction is to provide information directly to the participants based on the automated interaction analysis, so as to self-regulate their decisions, actions and behaviour, thus supporting them in a level of awareness and metacognition (Jermann, 2004). In the first case, it is the system (usually a learning environment with an embedded IA component) that makes the decisions (leading to so-called “Intelligent Tutoring Systems”), while in the second the locus of control is on the human actors' side. The participants in technology-mediated activities can typically be teachers, moderators and students (in a wide variety of roles in a range of learning situations), or also the members of a scientific network, such as the Kaleidoscope Network of Excellence.

The topic of computer-based interaction analysis intended to support participants in highly interactive learning environments was a strong research theme within Kaleidoscope and has been relevant in several activities. The approach described by Choquet, Iksal, Levene and Schoonenboom (Chapter 12) is related to this theme, but more oriented towards the analysis of general trails of users in learning applications (i.e. also navigating through hypermedia learning courses).

The outline of the present chapter is as follows. First, a rationale for computer-based approaches to interaction analysis is given. This is followed by a conceptualisation of interaction analysis indicators and their computation. Then the use of unified data formats and interfaces is considered as means for utilising tools and data beyond their original scope and settings. Finally, visualisation approaches for analysis results are discussed and practical implementations are presented. The chapter concludes with a summary and an outlook on the potential of interaction analysis in future technology-enhanced learning (TEL) systems.

11.2 Interaction Analysis as a Support Tool for Technology-Enhanced Learning

The development of appropriate interaction analysis methods is a major issue in many research areas, including computer-supported collaborative learning (CSCL). Within this field of study, interaction analysis methods are used to help understand the collaborative learning process. Additionally, analysis results can serve as basis for offering support to learners in a CSCL environment. For instance, students' and teachers' self-regulation can be supported by giving feedback about the current

state of the learning situation (e.g. if all group members are participating equally in the group discussion). Another example involves facilitating the assessment of the learning experiences by providing teachers with data on the average level of activity, continuity, etc. (Dimitracopoulou et al., 2004; Soller, Martínez Monés, Jermann, & Mühlenbrock, 2005). Both functionalities are important for the design of technology-enhanced learning environments that go beyond offering the mere communication and information sharing tools that are normally provided in CSCL.

Analysis methods can be completely or partially supported by computer-based tools that enable better and more efficient procedures. Although the development and practical usage of such tools is increasingly attracting the attention of researchers, current research in the field is mainly based on unstable prototypes applied to isolated experiences. As these tools are not meant for the general public, their usability is generally limited.

This state of affairs prompted us to develop a joint conceptualisation of interaction analysis indicators and the process of their computation from the learning data. This initial conceptual integration laid the foundation for terminology, methodology and comparability of different forms of interaction analysis. To cater for the use of interaction analysis in the evaluation of technology-enhanced learning environments, we also elaborated on aspects of interoperability between different interaction analysis methods and associated tools by means of a common framework: the CAViCoLA analysis process model (see Section 11.4). Through unified data formats and interfaces, this model enables researchers to apply analysis tools and research data beyond their initial, often limited scope.

Such broad use of interaction analysis methods obviously poses challenges. A computational issue is how to formally define characteristics of interaction and collaboration (called indicators) so a machine can detect these automatically or based on the researcher's input. Another challenge concerns the interpretation of analysis results by the researcher. One possibility is to use insights from the field of information visualisation (Card, Mackinlay, & Shneiderman, 1999) and represent the results in a diagrammatic and graphical way that allows for comprehension at a glance. In CSCL, such diagrammatic representations can take the form of sociograms (Moreno, 1951) that represent persons and their relations as a graph. Other possibilities include statistical representations (e.g. bar charts for absolute number of contributions, pie charts for relative shares of participation) and metaphorical representations such as botanical representations that show activity by flourishing or withering of plants (e.g. the "Wattle Tree"; Kay, Maisonneuve, Yacef, & Reimann, 2006).

11.3 Towards a Conceptualisation of Interaction Analysis Indicators and Methods

The analysis of student interactions is usually driven by some sort of hypothesis which can be confirmed or rejected by certain observations. So the first question for a researcher is "What do I want to analyse?" or "What are the important questions

to ask?”. The role or the perspective of the questioner will determine the intention of these questions (i.e. the reason for which the analysis is conducted, which could be a teacher making an evaluation or a student informing herself/himself about the progress of work). The answer to this question influences the choice of indicators used to conduct further analysis, as indicated by the large arrow in Fig. 11.1. The researcher must choose indicators that can express the concept(s) he or she wants to analyse. That is, the choice of an indicator is influenced by the target group and will vary as function of the interest of the researcher.

In the area of CSCL, potential awareness of collaborative and social traits through analysis, representation and especially visualisation is deemed relevant for several target groups, including researchers, teachers and students. Researchers can use the results and visualisations as means to support other methods of analysis (Harrer, Zeini, & Pinkwart, 2006; Martínez et al., 2006), such as statistical and qualitative analysis, because triangulation research designs are common within the interdisciplinary CSCL field. Teachers could benefit from interaction analysis to better understand the group structures in their computer-supported classes and courses (e.g. for classes using discussion forums or blogs, and university courses with blended scenarios). Teachers could also use this information to guide and advise their students as when the participation of specific students is extraordinarily high or low. Students could use the visual feedback for self-reflection and self-regulation in reaction to the information and the style in which it is represented. Research has shown that the presentation of analysis results can indeed have a substantial impact on participation and behaviour (Bratitsis & Dimitracopoulou, 2008; Sun & Vassileva, 2006).

The choice of an indicator determines the requirements a learning environment must fulfill; this is indicated by the dashed arrow in Fig. 11.1. Every indicator determines “what should be available” in the learning environment to compute the indicator’s values. To illustrate, when analysing social structures or patterns of interaction, it is necessary to capture the information “Who is sending messages to whom?”. Learning environments that do not meet this requirement (e.g. class

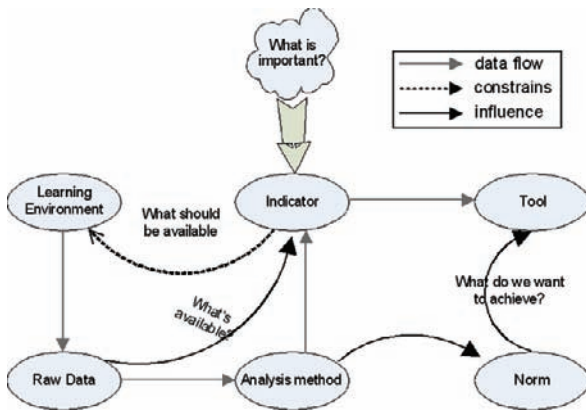


Fig. 11.1 Schema of interaction analysis

discussions, phone conversations) should not be used in the analysis. Since the learning environment usually exists beforehand and is not specifically implemented for one experiment, it should either be adapted to meet the constraints given by the indicator or not be considered a candidate for use in the analysis.

The learning environment generates the raw data (e.g. log files) that are used in subsequent steps to compute the selected indicators. As stated before, the kinds of data required by an indicator cannot always be supplied by the learning environment. A pragmatic solution (other than adapting the learning environment) would be for the researcher to narrow or re-assemble the set of indicators. In other words, the available raw data may influence the choice of indicators as well. This is indicated by the curved arrow in Fig. 11.1.

The raw data are processed by the analysis method, which results in indicators (see Dimitracopoulou et al. (2004) for an overview). This means that there are two meanings of the term "indicator". The first is pedagogical in nature and refers to the answer to the "what is important" question. So, for instance, "following a well-established argumentative schema" is a pedagogically and psychologically oriented indicator for learning. The analysis (e.g. whether an argument is met by a counter-argument) produces a numeric or symbolic representation of these criteria which is also called an indicator, but this time with a technical-computational meaning.

During the analysis the raw data are usually filtered because they must be "cleaned" and some of the analysis methods need special input formats. Filtering methods can range from simple (e.g. removing redundant system codes) to complex (e.g. plan recognition, pattern recognition). The analysis method eventually relays the indicators to a certain tool that uses these indicators and presents them to the intended target users. These tools can be the learning environment itself or dedicated tools such as visualising communication networks and participation diagrams.

A norm can be applied for the concrete utilisation of the indicator. This norm is used for metacognition or guiding (Jermann, 2004). That means that the norm defines desired values and behaviour, such as "less than 10% participation by one student is too low for good collaboration". As the norm must be expressed in terms of the analysis output format, the method influences the types of norms. In a similar vein, the choice of norms influences the choice of tools or the kind of representation used by the tool (indicated by the curved arrow in Fig. 11.1). The representation of analysis results against norms is generally done via metaphors (such as green for desired behaviour and red for undesired behaviour).

Reflecting on the schema of interaction analysis (Fig. 11.1), there are many decisions to be made by the analyst in the basic process of interaction analysis. Our aim was to enable users of this schema to apply the proposed analysis methods more easily or to recognise new opportunities for analysis: The schema provides an overview of analysis methods, indicators and norms and their respective prerequisites, possible outputs and interpretations. Yet, while the selection of one specific indicator from the inventory of available indicators (Dimitracopoulou et al., 2005) is supported by means of the schema of interaction analysis, this support is usually constrained to one isolated analytical activity. To extend the scope of analysis to the whole process of computer-supported collaboration analysis we defined a general

process model and connected this with technical tools/formats to make a seamless analysis feasible. This generalised analysis process model is presented in the next section.

11.4 The CAViCoLA Process Model

The European Research Team “Computer-based Analysis and Visualisation of Collaborative Learning Activities” (CAViCoLA) within the Kaleidoscope network devised a common analysis process model for the purpose of providing a common framework for researchers to model the analysis process in CSCL activities. It has been derived from four empirical research designs which have been (co-)conducted by research groups in Germany, Greece and Spain (Harrer, Zeini et al., 2006; Harrer, Kahrmanis, Zeini, Bollen, & Avouris, 2006; Martínez et al., 2006; Meier, Spada, & Rummel, 2007). These teams collaborated on the conceptual and technical integration of their research approaches. A graphical overview of the combination of different analysis methods and their facilitation by a unified data format (CAViCoLA Common Format) is depicted in Fig. 11.2.

The left-hand side of Fig. 11.2 shows the generic process sequence which has been used within the European Research Team. The right-hand side visualises how the CAViCoLA process model combines several quantitative methods such as interaction analysis of the participants’ actions in time, analysis of group structures in learning communities (Social Network Analysis and statistics; Harrer, Zeini et al., 2006; Martínez et al., 2006) and a rating scheme for assessing the quality of the collaboration process (Meier et al., 2007). These quantitative methods are complemented by a series of qualitative methods, such as content analysis, observations, questionnaires, focus groups and category building (Harrer, Kahrmanis et al., 2006; Martínez et al., 2006). All of these methods follow the classical procedure of

1. Data capture.
2. Data segmentation.
3. Preprocessing (e.g. annotation and measuring).
4. Qualitative, statistical and social network analysis.
5. Visualisation as a support (if possible).
6. Interpretation.

The overall approach follows the idea of the triangulation of results (Denzin, 1989) in a multi-method approach which is represented in the figure as the confluence of several branches of analysis into a joint interpretation.

To facilitate the flexible combination of different analysis tools during the process, a standardised data format was defined that captures the relevant information from collaborative learning activities (see Section 11.5). This allows the analysis of several types of captured data across learning environments with the same interoperable set of analysis tools. Among these tools are applications for qualitative coding

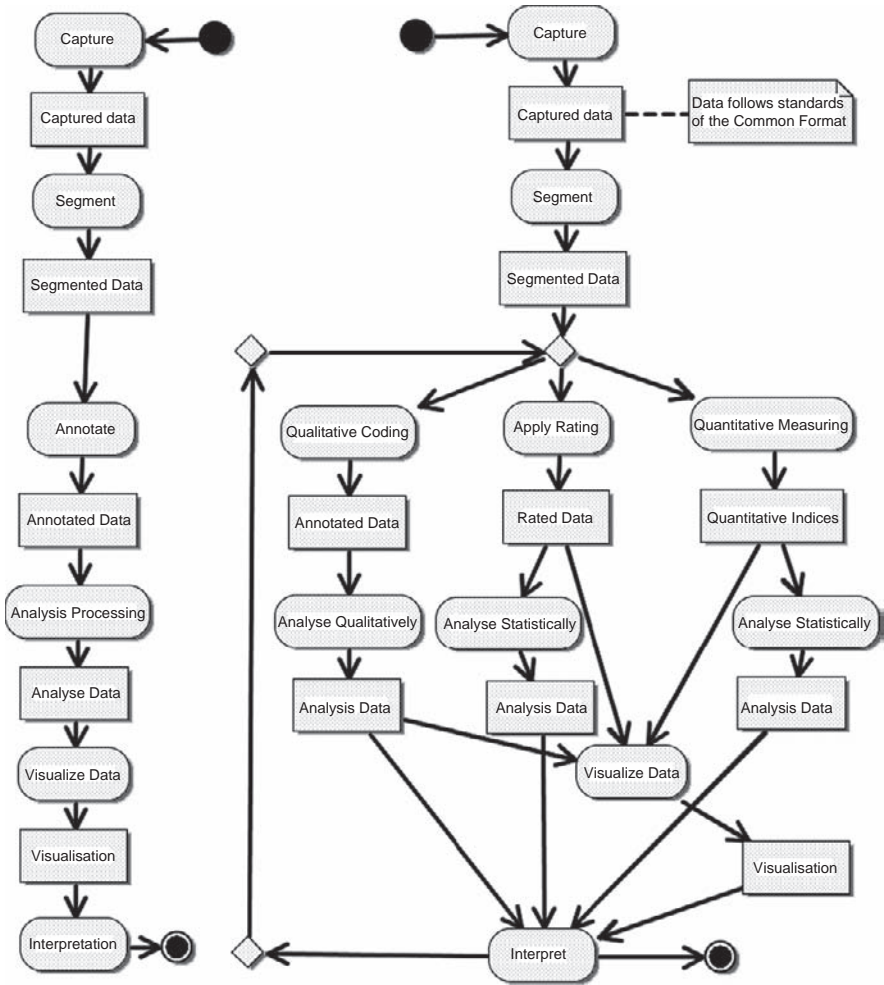


Fig. 11.2 The CAViCoLA process model

of observational data recorded on video, tools that generate logfiles that capture user interactions in CSCL systems and tools that gather sociometric data.

11.5 Interoperability Between Learning Environments and Analysis Methods

The conceptual integration described above was complemented with a technical integration that would further enhance the interoperability between learning environments and tools. Towards this end a common format was proposed to facilitate

the creation of a library of tools that can be used for different analysis purposes. This common format is ideally produced by all learning environments and is interpretable by all analysis tools within the tool library. The format enables the analysis of the same data set with multiple analysis methods in a triangulation approach. It also enables the use of one analysis tool with data from different learning environments, which can facilitate cross-discipline and cross-cultural studies that would otherwise have to be performed exclusively by manual comparison.

Interoperability between different learning tools is also relevant for learner support. In inquiry learning environments, for instance, different phases in the learning process are generally supported by different tools. Interoperability between these tools is needed to let learners conduct their inquiries efficiently. The methods and solutions chosen by researchers and designers in this field of study are described by van Joolingen and Zacharia (Chapter 2).

The common format described in this section was based on existing work on explicit representation of user actions in XML representations (Gaßner, Jansen, Harrer, Herrmann, & Hoppe, 2003; Harrer, Vetter, Thür, & Brauckmann, 2005; Martínez, de la Fuente, & Dimitriadis, 2003). Hence a structured data format using XML was chosen as the basis for the common format. This format has been tested for replaying, interpreting and annotating collaborative workspace activities.

11.5.1 Description of the Common Format

There are two seemingly contradictory requirements for defining a common format. On the one hand, the format should be well defined and well structured; on the other hand, it must be flexible enough to allow for the analysis of additional information generated by specific learning environments – which might be useful for some analysis techniques. Thus, the challenge is to define a reliable common denominator for the minimally required information that also comprises a mechanism to mix in important features flexibly on an as-needed basis. This is reflected in the required and optional elements of the Document Type Description (DTD) for the common format.

The required elements originate from our own experiences as well as other approaches described in the research literature (Avouris, Dimitracopoulou, & Komis, 2003). Crucial information to be captured for analytic purposes in potential collaborative scenarios is

- *Action type*: a description of the precise type of action according to the typology used within the learning environment. For more general categories an attribute “classification” is available with standard categories, such as read/write/modify etc.
- *User*: for collaboration analysis information is needed about the actors involved and the roles they assume with respect to the action, such as initiator and receiver of the action.

- *Time*: a timestamp that allows ordering and measuring of intervals of the captured information traces.

Since most user actions target one or more objects, especially in environments with direct manipulation interfaces, an optional *object* can be specified. When necessary, the object description can be enriched by *properties* such as the object's attributes and associated values. This provides a flexible mechanism, but unfortunately lacks the strictness of definition required to check if all needed elements for some specific analysis are available.

Usually a description of the general setup of a learning situation, such as participants, formal roles of the participants, subgroups and available external resources, helps to understand the scenario and point to potentially suitable analysis processes. Consequently, a section called "PREAMBLE" has been added to the common format to include the information that defines the learning scenario.

A graphical overview of the elements and attributes in the common format is represented in Fig. 11.3. The technical specification of the format is reported in Martínez, Harrer, Barros, Vélez (2005) and is currently being published as a format proposal in the international TEL community.

The common format is meant to be a flexible representation that preserves data of any type of input format. Consequently, many elements had to be declared as optional, which makes checking documents' integrity more complicated than with a fixed structure of elements. This is unavoidable, however, due to the potential difference in information richness of the original input formats. Still, not all information needed by some analysis tools can be enforced by the common format (e.g. links between postings are necessary for social networks and posting pattern analysis). Therefore, the information needed by an analysis tool could in some cases be derived by additional scripts/preprocessors in intermediate steps; all resulting intermediate products should use the common format to enable analysis chains and multiple analyses for each step.

11.5.2 Practical Use

The common format was tested with existing learning environments and tools. As a first step, decisions had to be made regarding the handling of the existing code. In the ideal case, every learning environment included in the testing procedure should produce the common format and every analysis tool should accept this common format as the input for analysis. In reality, however, alternative solutions are called for. One alternative would be to use the environment and its output as is and define a mapping from this proprietary output format to the common format. With an exact conceptual mapping, the definition of an appropriate XSL transformation or other means of transformation (such as an intermediary object structure written out as common format XML) can be implemented. Similar arguments can be made for the analysis tools, whether accepting input in the common format or in its original one.

All of the above alternatives have been tested in practice. Examples include the following:

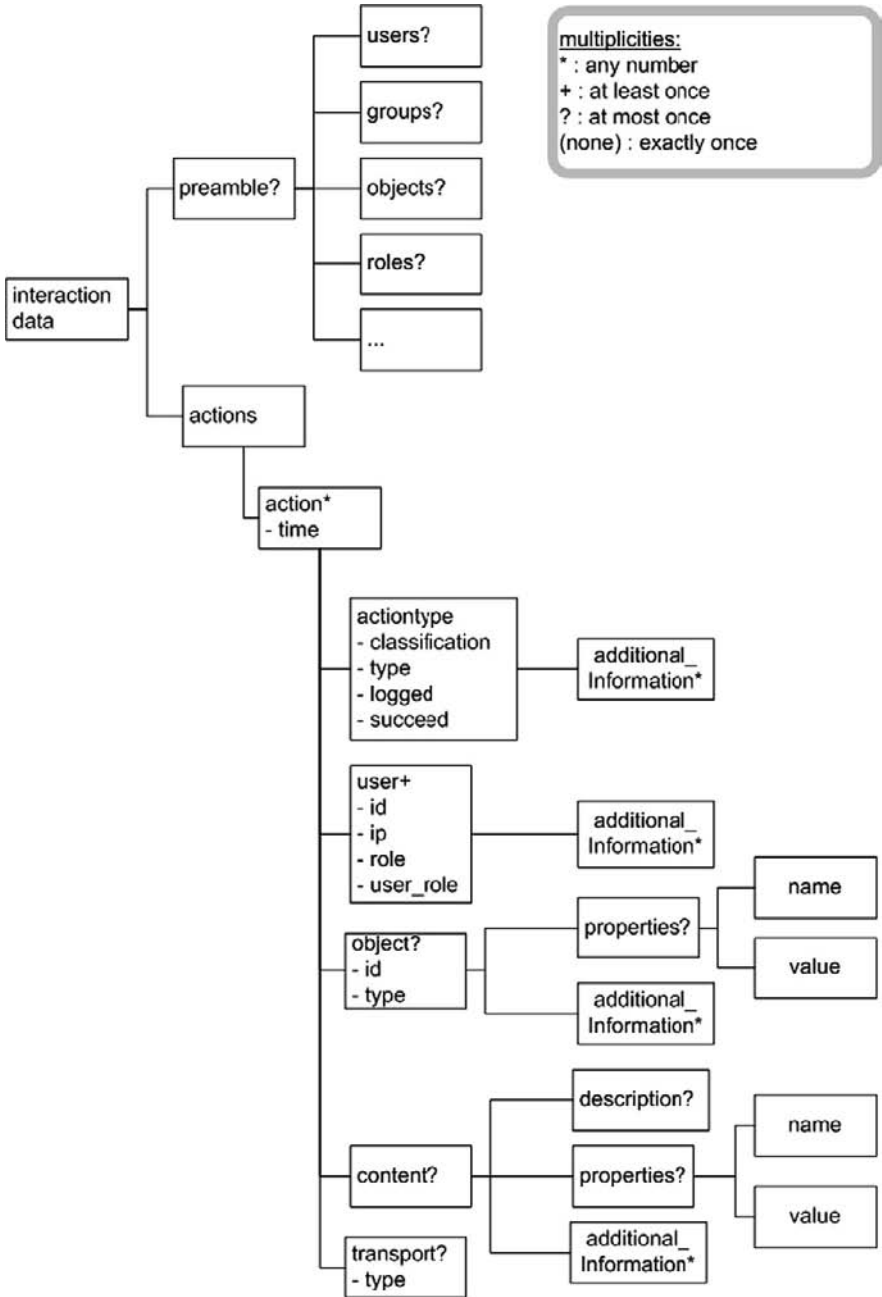


Fig. 11.3 Diagram of the basic structure of the common format

- The export from a discussion forum (that holds the postings in a database) was realised directly to the common format to be used by arbitrary analysis tools.
- The DIAS (Discussion Interaction Analysis System; Bratitsis & Dimitracopoulou, 2006) and the Pattern Discovery tool (Harrer et al., 2005) were modified to accept the common format as input.
- For the data used by the SAMSA tool (Martínez et al., 2003) with an XML-based format, both the transformation to the common format and the transformation from the common format to the SAMSA format were realised.

The interoperability achieved by means of the common format was tested practically by analysing the discussion forum logs of the DIAS tool (provided in the common format) with the Pattern Discovery tool (accepting the common format) that can detect patterns a researcher has specified beforehand or produce frequently occurring patterns with a mining approach. Mappings of the common format to related specifications, such as the more general data mining standard PMML (Predictive Model Markup Language, see <http://www.dmg.org/products.html>), are feasible and will be explored in future work.

11.6 Visualisation of Analysis Results

Another issue in interaction analysis concerns the utilisation of analysis results to facilitate its interpretation. The key question here is how to support users in making sense of the results from logfile analysis and how to employ social network analysis techniques. Useful guidance on this matter can be gained from the work in the field of information visualisation (Card et al., 1999), which prompted us to provide analysis results to the user in diagrammatic and graphical form that supports comprehension at a glance.

Several techniques have been developed, compared and discussed with respect to visualisation of logfile analysis. One of the challenges here is the integration of temporal information with actor-related information and their representations in the learning environment. Synergo, a collaborative shared workspace tool (Avouris, Margaritis, & Komis, 2004), uses an augmented replay functionality of the workspace content with superimposed information about the workspace objects. The Pattern Discovery tool (Harrer, Hever, & Ziebarth, 2007) can be used with all common format logfiles to search for user-specified interaction patterns or supervise automatic mining of characteristic interaction patterns; results are displayed in a 2D timeline representation considering the initiators of actions.

With the proliferation of Web communities, “social software” visualisation techniques for online collaboration have been a popular means of making interactions explicit. These techniques are based on work in the field of social network analysis (Wassermann & Faust, 1994) that have been used in TEL scenarios for several years now (e.g. Palonen & Hakkarainen, 2000; Reffay & Chanier, 2003). Two approaches addressing the operationalisation of social network analysis for TEL users have been used in our own projects: The first is to provide interactivity by allowing

users to inspect the data about the actors displayed in the networks. The other approach enriches social networks with additional actor properties and measurements to integrate multiple dimensions of information into a network. Both approaches are detailed in the subsections below as elaborated extensions of social network analysis.

11.6.1 Augmentation of Social Networks Through Navigability

The first approach for enhancing the visualisation of social networks was one of the IA indicators offered to the Kaleidoscope community through a supporting service called CCI-IA (Interaction Analysis in the Communication and Collaboration Infrastructure). This service provided a set of personalised interaction analysis indicators to the network members, based on the information collected from their actions on the Kaleidoscope Web pages. Figure 11.4 shows one of these indicators, which displays the resources associated with a concrete keyword and the visitors who have accessed these resources. This indicator is useful for finding resources and people related to a set of research interests (i.e. keywords). Besides the official structure of a network, a user can be interested in the emerging communities based on the shared use of resources. Social networks built on the use of these shared resources can lead the user to these communities and thus help to identify and join people with common research interests.

This indicator was enriched with navigation facilities so that the user can observe the information shown in the sociogram and visit the resources or people she/he considers most interesting (e.g. the resources visited by some relevant member, the most popular resources with this keyword or the profiles of those researchers connected to a particular resource) using the links provided by the indicator.

For example, Fig. 11.4 depicts the social network of researchers and resources for the keyword “CSCL”. The squares represent the publications related to this keyword and the circles indicate the users who have inspected those publications. The table matches the short name used in the sociogram for the resource (e.g. res627) with its complete name (e.g. “Framework for integrated learning”) and includes links to the resources.

Users can also locate and access the resources visited by relevant researchers in the network. Moreover, if users know a particular document that appears in the sociogram (and it is relevant for them), they can access the resources visited by members who also visited this relevant resource.

With this information it is possible to identify people with common research interests and choose the resources they visited. This prompts the idea of using this social network tool as a kind of recommendation system.

The CCI-IA service was evaluated by Kaleidoscope members by means of an online questionnaire. They highly appreciated the social network indicator and also provided some suggestions for its improvement. The features discussed in this section were in fact included in the service on the basis of the users’ feedback.

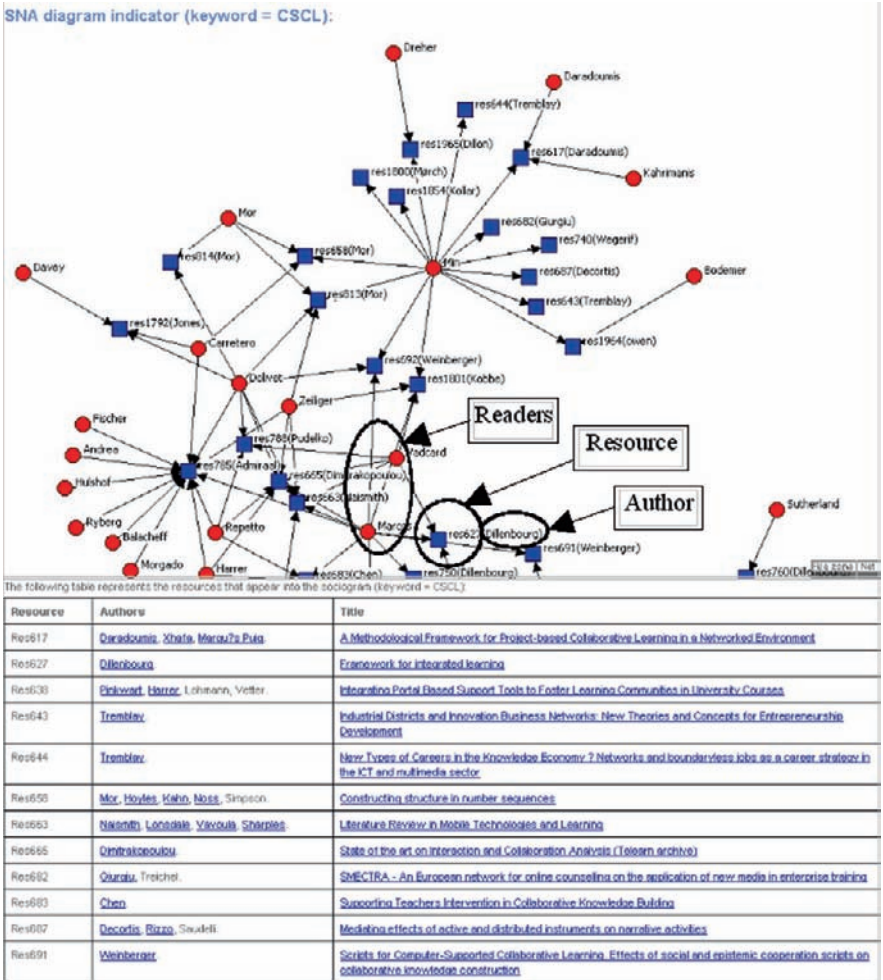


Fig. 11.4 Social networks in Kaleidoscope around the keyword “CSCL”

11.6.2 Augmentation of Social Networks with Measurements and Properties

A second approach for enhancing the visualisation of social networks is to embed advanced measurements into the visualisation. According to Krempel (2005), techniques exist to integrate structural properties of networks in the display. Toward this end we created the Weaver application, a 3D visualiser for social networks that arranges and renders the nodes into specific action spaces according to properties such as degree, centrality or other externally defined features (e.g. formal roles in a learning scenario). The Weaver application thus enables users to perceive the properties of a node at a single glance (e.g. what is the most central topic in the network).

One important means for understanding and supporting interaction in computer-based scenarios is the identification of relations between the different actors. Because of their high availability, Web-based communities tend to grow to large network structures, which might inhibit both researchers and community members from observing relevant aspects. The identification of substructures and decomposition of large networks into smaller constituents are methods of providing overviews and selectively focusing on specific aspects (de Nooy, Mrvar, & Batagelj, 2005). This is especially important for visualisation of networks in diagrams and requires information about common attributes to define subgroups in a network (Krempe, 2005).

The literature on social network analysis proposes several ways to define subgroups and substructures of sociograms (Wassermann & Faust, 1994). A rough distinction can be made between groupings that provide a disjoint split into subsets (i.e. a partition) or groupings that create smaller, partially overlapping sets. The preferred method depends on the purpose of the analysis. Partitioning is desirable when separate parts of the network should be analysed in isolation; overlapping structures are suited for showing the relations between two sets of actors, such as overlap, embedding into larger subgroups, etc. The Weaver application (Harrer, Zeini, Ziebarth, & Münter, 2007) contains both grouping methods (disjoint or inclusive sets) to be used by the analysts as needed.

The identification of subgroups within communities and of core actors is especially important for coordinators and reviewers of the community. It might also be used as a feedback mechanism to let community members reflect on their own roles and positions in the network.

To illustrate and test these ideas, an analysis was conducted of the Special Interest Group “Artificial Intelligence in Education” (SIG AIED) within the Kaleidoscope network. As natural data we used participation in the project planning activities facilitated by the SIG (see Fig. 11.5).

Squares represent the eight activities initiated by SIG members in the first 2 years of Kaleidoscope. Teams are represented by triangles and links show the participation of the teams and their members in the planned activities. The resulting network based on this data is visualised without specific network analytical aspects. The arrangement that separates the different node types into circles (projects in the inner circle, teams in the outer) serves to enhance readability.

Figure 11.6 shows the result of grouping into disjoint sets. The teams visualised in the circle at the bottom form a group in which each pair of teams either has been involved in a joint project directly or has collaborated with a mediating team that also collaborated with the other team of the pair.

As Krempe (2005) pointed out, the augmentation of networks with additional information gives an improved visual perception of the networks for the user, both at expert and non-expert levels. Actors in a network often have relevant attributes that can be independent of social network analysis properties. The visualisation of these attributes can be an important feature to enhance the interpretation of these networks.

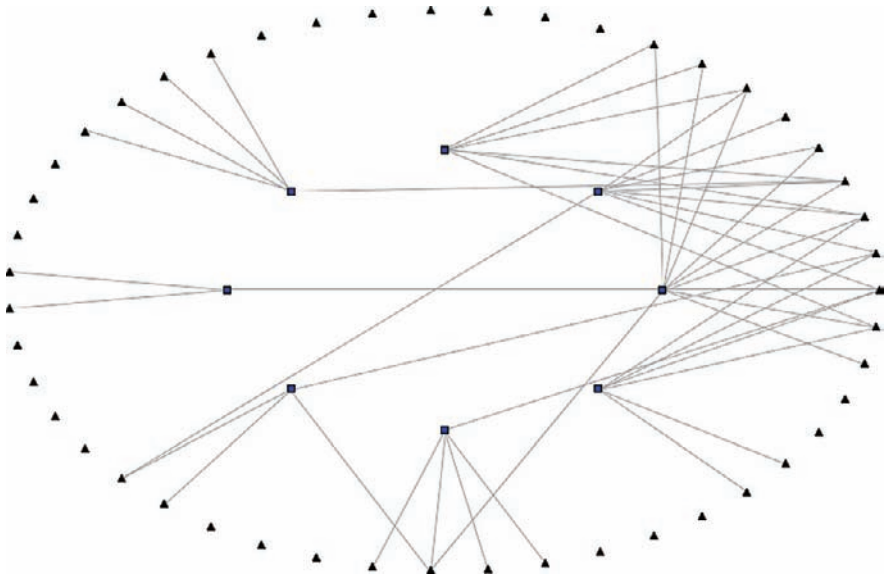


Fig. 11.5 Network diagram showing projects (*squares*) prepared by SIG AIED teams (*triangles*)

Impact on the scientific community by means of conference publications is one of the crucial aspects identifying the main actors in an international research network. Thus, we reviewed all papers and posters published at what we considered the most relevant conferences for this field (i.e. AIED 2005 and ITS 2006), and counted the contributions of the SIG AIED members to each. Thus, in Fig. 11.6 the grouping is combined with visual marking of teams participating at both conferences (large

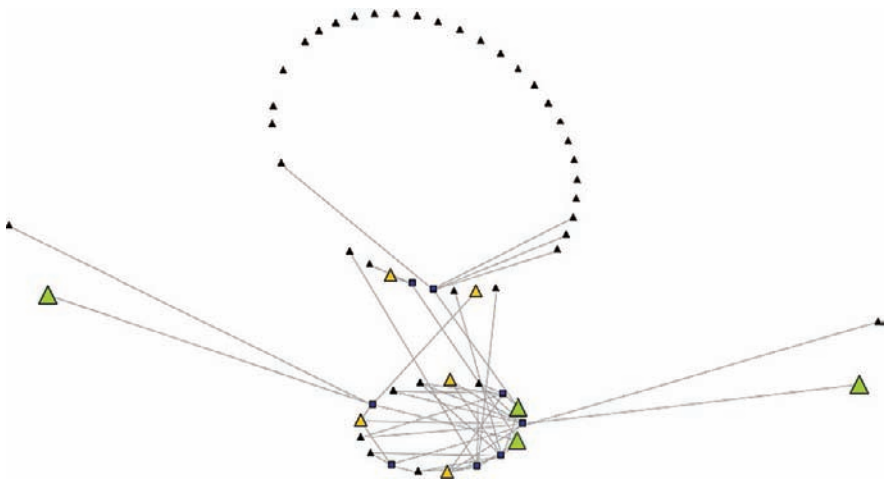


Fig. 11.6 Diagram augmented with information about publication activities

triangles), at one (medium-sized light triangles) or at neither (small dark triangles). The interpretation of the diagram indicates that all of the teams publishing at the main conferences are either part of the group or at least collaborated with parts of the group.

Inspecting and interpreting such diagrams provides a deeper understanding of participation patterns and activity within a community. This seems particularly important to coordinators/moderators of the community, reviewers of the activity, and – when fed back to the participants themselves – also to inform the participants, potentially influencing their behaviour in a self-regulative manner.

11.7 Conclusion

This chapter discussed several aspects of interaction analysis, starting with a conceptualisation of interaction analysis indicators and the process of computing indicators based on the learning data. This conceptual integration laid the foundation for a uniform terminology, methodology and comparability of interaction analyses between the different research teams involved.

To complement the conceptual integration with a technical equivalent, we elaborated on aspects of interoperability between different interaction analysis methods and tools by means of unified data formats and interfaces; this enables the cross-usage of analysis tools and research data beyond their initial scope, which is usually tied to one specific learning environment and one analysis tool.

The representation of results is a decisive factor in making the results of interaction analysis methods understandable to both experts and laypeople. Based on principles of information visualisation, we presented two characteristic examples, where we used and designed visualisations for social networks that incorporate the most important properties of the collaboration, thus enabling analysts to interpret the nature and intensiveness of collaboration more easily than by using plain numbers, measurements and data tables. It is to be noted that the different information needs of students, teachers and researchers and their capabilities of understanding these representations must be considered in choosing the appropriate level of detail and data richness.

For more widespread and professional use of computer-supported interaction analysis techniques, we expect advances in the design methodology and technical architectures. While manual analysis of such data as video captures has been elaborated and refined to a reliable methodology (e.g. Goldman, 2004), this consolidation has yet to happen for analysis processes using a substantial degree of computer-supported analysis methods. Our conceptualisation of the schema of interaction analysis and the general analysis process model in this chapter have been first steps, but need to be followed up by guidelines and tool-based support on how to design interaction analysis processes using complex learning environments (potentially several at the same time integrated into one activity) and analysis tools. Otherwise, concrete situations can occur where the requirements for conducting

interaction analysis are not met, in that the raw data do not represent the relevant data properly, causing the whole analysis process to fail. This is a challenge for the methodology as well as the technical systems that must be refined to support analysts accordingly in defining their analysis processes, so that all of the research questions can be explored and answered.

Besides this methodological aspect, another future research topic involves the empirical validation of the effectiveness of IA indicators as a means for reflection and self-regulation during the learning or community activity. Scattered research (e.g. Sun & Vassileva, 2006) has been conducted on the effects of visual representations on learner behaviour, but the interdependencies of the concrete learning situation, visual aspects of the indicator representation, additional cognitive load on the learner and personal traits of the learners are still to be explored in more detail.

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Chapter 12

Users' Data

Trails Analysis

**Christophe Choquet, Sébastien Iksal, Mark Levene
and Judith Schoonenboom**

Abstract With the development of Web-based distance learning environments, acquiring and analysing trails has become a very important issue for the technology-enhanced learning (TEL) community. We consider a trail (or a track or a trace) as the digital or non-digital record that learners – or more generally, the different actors within a learning session in a TEL system – leave behind. This chapter addresses the life cycle of such trails from a computer science point of view. In particular, we elaborate on the engineering and usage of the different kinds of trails by highlighting the main scientific issues raised by the trails analysis process and by presenting research findings from the Kaleidoscope Network of Excellence in this field.

Keywords Curricular activities · Design pattern · Indicator · Instructional design · Trails analysis · Trails classification

12.1 Using Trails for Supporting Curricular Activities

12.1.1 *The Relevance of Trails Analysis*

It is the very nature of distance learning and teaching applications to provide a multitude of user data which can be used for perceiving and understanding the users' activity. Analysing this data will enable learners to reflect on their activity for the purpose of self-assessing their progress and measuring the suitability of their curriculum with respect to their learning objectives. Analysing this data will also enable tutors and teachers to regulate the learning session and/or evaluate the learners' activities. On the other hand, designers need session feedback for evaluation purposes as well as for improving the quality of their learning environments.

With the development of Web-based distance learning environments, acquiring and analysing trails has become a very important issue for the technology-enhanced

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learning (TEL) community. We consider a trail (or a track or a trace) as the digital or non-digital record that learners, or more generally, the different actors within a learning session in a TEL system, leave behind. There are different kinds of trails depending on (1) the nature of the pedagogical situation, (2) the possibilities for interaction and the learning context and (3) the purpose for which the system is used (i.e. knowledge acquisition, assessment, session regulation, reflection, system reengineering).

This chapter considers the life cycle of trails from a computer science perspective. In particular, the chapter will elaborate on the engineering and usage of different kinds of trails by highlighting the main scientific issues raised by the trails analysis process as well as presenting research findings of the Kaleidoscope Network of Excellence in this field.

12.1.2 Trails Analysis in Tracking Problems: An Example

The trails analysis process and its relevance will be demonstrated in two tracking problems (i.e. how trails can be used to support those involved in education in solving educational design problems) that could occur when designing an educational system where learners must perform learning activities by navigating through digital learning materials (called here “learning objects” or “Los”).

Both tracking problems involve a system that supports students in studying English grammar, as described by Turcsányi-Szabó, Kaszás, and Pluhár (2004). The system supports the students in selecting Web resources (i.e. LOs) that match their topic of interest and proficiency level by advising them about the trail to follow. The system was created on the basis of materials in five free, good quality, intermediate level English language grammar teaching portals. In the system, the materials are organised into *topical units* that contain explanations, exercises and self-assessments for each exercise, and a topical unit test for the entire unit. The topical units are classified into three difficulty levels (beginner/re-starter, pre-intermediate, intermediate). Students’ results are stored on several occasions to enable personalisation. At the very beginning, students’ knowledge level is determined using a general grammar test with more than 50 items. After taking this test the student is presented with a *knowledge map* (see Fig. 12.1).

The knowledge map shows a set of trails containing the topics that have already been mastered by the student (i.e. mastered nodes, where all test items corresponding to these sub-topics have been successfully completed) and do not need to be revisited. Mastered nodes appear in grey, indicating an existing route, but not a recommended route. Those topics where the student’s knowledge is unsatisfactory are distinguished using a different colour (black), indicating an unmastered node. This colouring indicates to the student those topics in the map where deficiencies were recorded (as well as providing the outline of an advised route for visiting the topics of the material). When visiting topical units, students can also take a test on that specific unit, from which the system receives feedback. After the student completes any topical test successfully, the colouring of that particular topical unit node in the map turns white to indicate that it is now *semi-mastered*.

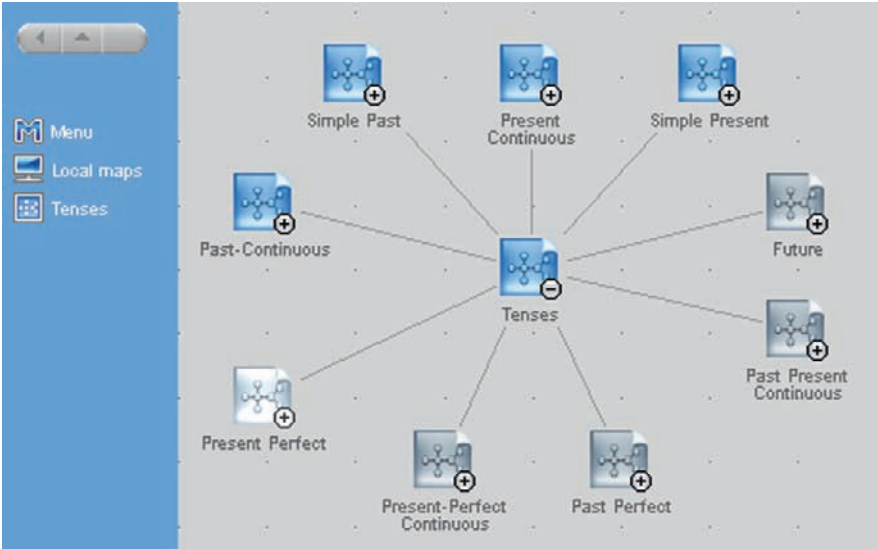


Fig. 12.1 Knowledge map of a semi-mastered node (adapted from Turcsányi-Szabó et al., 2004, p. 33, by permission of the authors)

Both the TRAILS (personalised and collaborative TRAILS of digital and non-digital learning objects) project and the DPULS (Design Patterns for recording and analysing Usage of Learning Systems) project – actions of the Kaleidoscope Network of Excellence to address tracking problems in TEL – have provided means to better understand and support the use of trails in solving tracking problems. In the above example, the main tracking problem can be formulated as follows: “how can students be presented with those explanations and exercises on English grammar that best match their interests and current proficiency level at each point in time during the learning process”. But in such an educational system, several tracking problems usually occur simultaneously. An example of such an additional problem would be as follows: “how can the system detect when the learner is just playing around with LOs instead of visiting them conscientiously, in order to alert the learner and/or the tutor, or to adapt the interaction with the system”.

12.1.3 Trails Analysis as a Process of Deriving Indicators

Analysis of trails for solving such multi-faceted tracking problems consists of the deduction of meaningful indicators, based on the existence of trails data acquired during a learning session, which will assist the actor (human or not) in his/her task using the outcome of the analysis. An indicator highlights a relation between a trail and a significant envisaged event, which could be interpreted as characterising the activity of the actors within a learning session. With the help of Fig. 11.1, an indicator can be defined from two different points of view:

1. An indicator “stems from what is important” from a pedagogical and/or psychological point of view.
2. An indicator is a numeric or symbolic representation of what is important, a significant (structured or not) datum which supports the analysis of the learning activity.

This chapter focuses on the second, technical and computational definition of an indicator. The process of trails analysis includes first a modelling phase, where the main design questions are as follows:

- What is required for acquiring and understanding a trail?
- What are the indicators, and how can they be deduced from trails?
- What are the technical requirements for acquiring the data needed to shape a trail and to define or evaluate indicators?

The acquisition of data constitutes the second phase, where the main design questions are the following:

- What kind of acquisition techniques can coexist within a TEL system?
- Is the acquisition obtrusive (e.g., tests and questionnaires) or not?
- When does the acquisition need to occur (before the session for profiling a learner, during the session, or after the session, as for instance a debriefing)?

The analysis itself is the third phase. Based on raw data (e.g. directly collected from the learning environment; see Fig. 11.1 and the narrative for details), how can one – human or machine – extract and construct indicators and thus characterise the activity of the actors in a learning session?

Finally, delivering the results of the analysis to the end user is the last phase:

- Who is the end user (the learner, the tutor or the designer)?
- What tasks are supported by the analysis fed back to the user?
- What kinds of representations of trails are well suited for the analysis of trail results?

12.1.4 The Issues of Trails Analysis in this Chapter

Figure 12.2 illustrates how the analysis of trails can support curricular activities. Through their learning activities, learners create trails, and feeding these trails back to the learner in a suitable format can help learners, as well as tutors, teachers or designers, in reflecting on their activities.

Figure 12.2 also provides the basis for the questions that this chapter will address. These are the following:

For what types of learning and at what stages in the learning process can the use of trails provide support? The TRAILS project developed the trails cycle of learning, including the stages of planning, navigation, learning activities and analysis/reflection, which will be presented in Section 12.2.

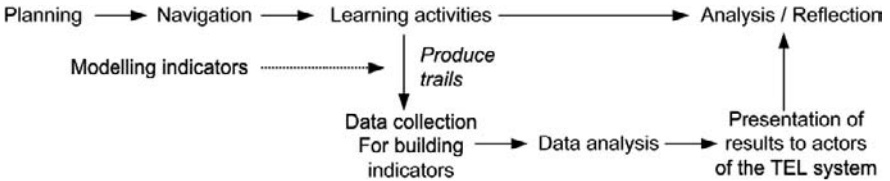


Fig. 12.2 Supporting curricular activities through the analysis of trails

The second question is related to the more low-level questions of whom we are supporting using trails, which actors performing which activities at which level of education. Actors, activities, levels and other relevant factors can vary widely from context to context and the TRAILS project produced a classification describing different contexts (see Section 12.3).

From Section 12.4 onwards, the focus is on the analysis of trails. Section 12.4 presents a typology of the kind of data that can be collected for trails analysis. This typology helps the designers of a TEL system model how an indicator could be derived from other data.

With the help of the example of the second tracking problem presented above, Section 12.5 presents a Design Pattern approach for supporting the designer who is facing concrete tracking problems for which trails analysis can be beneficial.

The last section discusses future directions we believe the community should follow that will shape the Kaleidoscope vision on trails.

The trails cycle of learning, the trails classification, the typology of trails analysis data and the design patterns are the results of two Kaleidoscope projects, DPULS and TRAILS. The TRAILS project formalised the concept of a trail and proposed a trails analysis process and a trails taxonomy based on a trail's use and content. The DPULS project focused on the issue of how to support the designer of a TEL system during the modelling phase. The project has proposed an open set of design patterns which provide instructional designers, teachers and tutors with improved and possibly reusable solutions to support them in solving recurrent problems when tracking students' activity. Together these projects have initiated a comprehensive approach for developing, capitalising, sharing and using trails analysis techniques which could be very valuable for the TEL community.

12.2 Learning Types and Stages Supported by Trails Analysis

The analysis of trails can provide support for various types of learning, which were identified and described in the TRAILS project and the subsequent edited book documenting the main results from the project (Schoonenboom, Levene, Heller, Keenoy, & Turcsányi-Szabó, 2007). The first type of learning supported is *navigational learning* (Peterson & Levene, 2003). With the advent of digital learning materials in general and the mass usage and growth of the Internet in particular, the volume of learning materials available to the learner has multiplied. As a

consequence both learners and teachers must navigate through learning materials. The second type of learning supported is *personalised learning*. Because of the increasing amount of learning materials, both teachers and learners need to create their own trails for navigating through an overload of materials. Learners need to be able to follow the trails that best match their needs and capacities. (Note that these two types of learning are not mutually exclusive. Personalised learning often, but not always, involves navigation.)

From a trails perspective, navigation occupies a very prominent position in learning. Trails are created when learners navigate through learning materials. For this reason, members of the TRAILS project concluded that traditional views of the learning curriculum were no longer sufficient, as they did not do justice to this prominent position of navigation. From a traditional curriculum perspective, there are three curricula: the intended curriculum envisioned in curriculum documents, the curriculum-in-action, interpreted by its users and consisting of the actual process of teaching and learning; and the attained curriculum consisting of the learning experiences as perceived by the learners and the resulting learning outcomes (van den Akker, 2003). From these curricula, three major phases in the learning process can be deduced: learning starts with *planning* the intended curriculum. In the

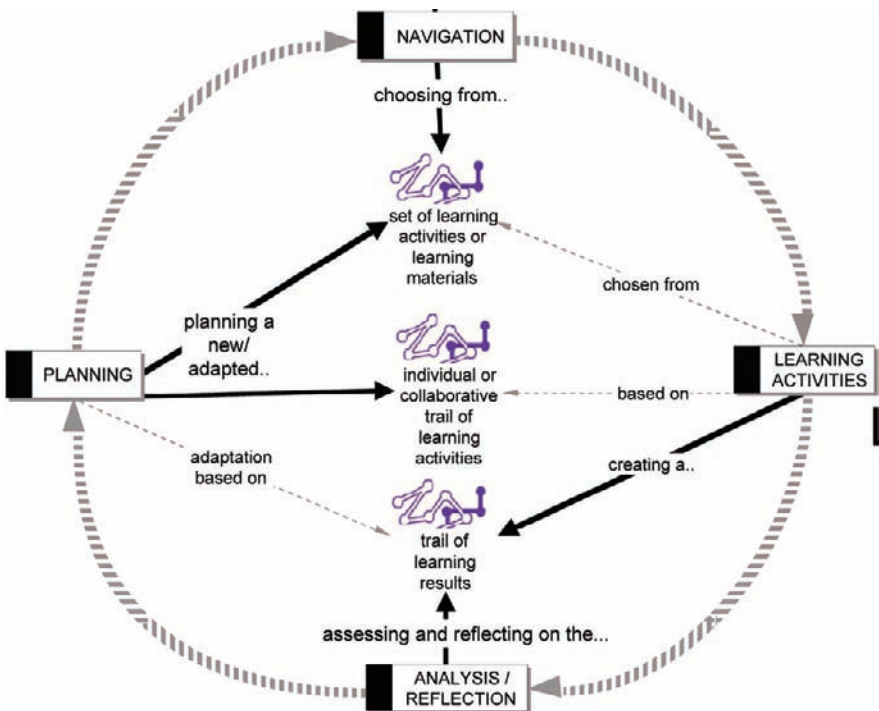


Fig. 12.3 The trails cycle of learning showing the creation and use of trails in each of the four stages of learning

curriculum-in-action, *learning activities* are performed. The learner interacts with the learning materials producing a trail of learning results. The learning results of the attained curriculum can be *assessed* or consulted for *reflection*.

The problem with this tripartite division of the learning process is that navigation does not have a place. Navigation in the sense of finding one's own path through learning materials is not a part of the planning phase, as it is not planned. But it occurs before performing learning activities, as it is the search for learning activities that fit one's needs. In fact, *navigation* constitutes a phase of its own, which is located in between planning and performing learning activities. Thus, the TRAILS project developed a four-part division of the learning process, which they called the "TRAILS cycle of learning" (see the introductory chapter of Schoonenboom et al., 2007).

In Fig. 12.3, learning starts with *planning*, which consists of either planning a fixed trail of learning activities or selecting a set of learning activities the learner can choose from. In the latter case, planning is followed by a *navigation* phase in which the learner chooses from the set of learning activities. Next, *learning activities* are performed in which the learner interacts with the learning materials and thereby produces a trail of learning results. These learning results can be *assessed* or consulted for *reflection*. After that, a new cycle can be started, which may be wholly or partly based on the trail of learning results.

12.3 Actors and Activities Supported by Trails Analysis: A Classification of Trails

As stated above, the actors and the activities to be supported in solving tracking problems can be very diverse. The TRAILS project developed a classification of trails for determining whom and what exactly to support. This section describes this classification in brief; a more detailed description is reported in Schoonenboom et al. (2007).

To start with a concrete example, Table 12.1 shows how the trails classification can be applied to the English grammar teaching case described in Section 12.1 of this chapter. This classification of trails is based on the curriculum classification of van den Akker (2003) and the preliminary taxonomy of trails of Keenoy and Levene (2004). Six elements can be used in classifying trails, as shown in Table 12.1.

The *stage in the trails cycle of learning* refers to the four stages of planning, navigation, learning activities and reflection. The *level of the trail* indicates the part of curriculum that the trail as a whole covers. Not surprisingly, the level can be very diverse, covering the whole range from a small part of a lesson, a lesson, a task, a module, a course, to an entire degree or school curriculum. Various *actors* can be involved in the learning process, all of whom might need support; actors include learners, teachers, researchers, managers and designers. *Activities supported* include, but are not limited to, such diverse activities as goal setting, timing of activities, locating activities, choosing from relevant learning activities, choosing learning materials and resources, assigning activities to specific learner roles, analysis and

Table 12.1 Classification of a trail used for the adaptive navigation support of pupils exploring materials on English grammar tracking problem

Classifier	Value
Stage in the trails cycle of learning	Navigation
Level of the trail	Course
Actors involved	Learner
Activities supported	Choosing from relevant learning activities
Units of the trail	Learning activities, materials and resources
Rationale for ordering the elements of the trail	The trail is a selection of elements that belong to a specific topic and level of proficiency

reflection. The *units that make up the trail* category refer to the type of curriculum elements that are connected within the trail. Four types were identified within the TRAILS project: aims and objectives, learning activities, materials and resources and learning outcomes. Finally, there is always a *rationale for ordering the elements of the trail*, a reason why the elements of the trail are put together in the way that they are. With respect to the rationale, Keenoy and Levene (2004) make a top-level distinction between temporal links and conceptual links. Temporal links allow LOs within a sequence to interact. Temporal links could be as follows:

- Hyperlinks between Web pages or pages in any hypertextual learning environment.
- Physical adjacency, such as exhibits in a museum being next to one another, or one chapter of a book following another.

In extending this definition beyond the scope of learning objects, a temporal link can also be formed, as in the case of learning objectives that must be mastered in a certain sequence. One frequently occurring rationale for the ordering of the elements of a temporal trail is that the ordering is the path that has been followed or is to be followed by a learner or by a group of learners (e.g. learners with specific roles).

Conceptual links, according to Keenoy and Levene (2004), reflect connections between LOs based on their content. Conceptual links could indicate the following:

- When LO_a covers prerequisite knowledge for being able to interact with LO_b .
- When one LO contains similar content to another LO, such as
 - LOs on the same topic.
 - LOs teaching the same competency.
 - LOs with the same learning objective.
 - LOs containing examples demonstrating the same principle.

12.4 Trails Analysis: From Data to Indicators

When the intended use of a trail is the analysis of (or the reflection on) the user's activity (the learner, the tutor, etc.) in a TEL system, the designer should a priori model the trail and its components. Most of the existing systems build a trail

by first manually or automatically collecting heterogeneous raw data (Champin, Prié, & Mille, 2003; Jermann, Soller, & Mühlenbrock, 2001), and then structuring them to establish “learning indicators” that are meaningful for a specific analysis purpose. The methods used for establishing these learning indicators are multiple but should be explicitly modelled, especially when the indicator is automatically inferred or calculated (see, for instance, Laflaquière, Settouti, Prié, & Mille (2006) and Mostow (2004) for details on data transformation for a tracking purpose). Explicit modelling is also needed when data are collected from heterogeneous sources such as manual, audio or digital records that need to be combined (see Marty, Héraud, France, & Carron (2007) for examples).

12.4.1 The Users' Data Typology

Based on the existing literature and on Kaleidoscope project results, essentially established by the ICALTS (Interaction & Collaboration Analysis' supporting Teachers & Students' self-regulation) and TRAILS projects, the DPULS project proposed a user's data typology, where types are defined in accordance with the intended use of the data and their provenance (see Fig. 12.4).

The *primary data* are not calculated or elaborated with the help of other data or knowledge. They could be raw data, additional data or subjective data.

Raw data are recorded before, during or after the learning session by the learning environment, for instance in a log file recorded by the system, a videotape of the learner recorded during the session, a questionnaire acquired before or after the session, or the sets of posts in a forum.

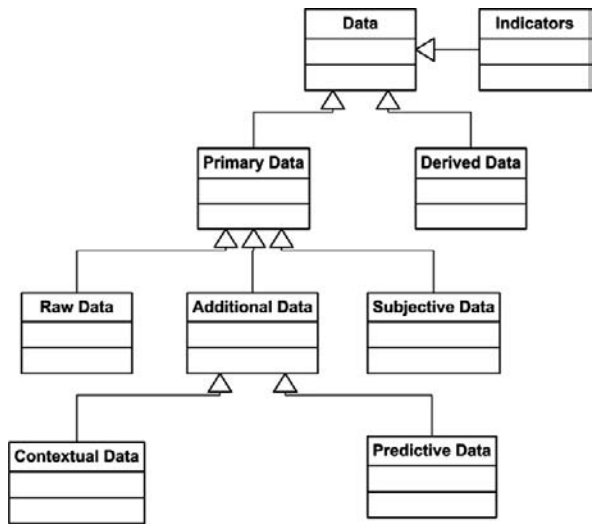


Fig. 12.4 The user's data typology of DPULS

The *additional data* type describes data that are linked to the learning situation and could be involved in the usage analysis. Additional data can be further classified as contextual or predictive. *Contextual data* can be picked from the learning materials, such as the metadata of a learning object, the formally planned scenario for the pedagogical situation or any information which is directly accessible. *Predictive data* on the other hand refer to the outcomes provided by the learning session actors (learners, tutors, teachers). This kind of data is mainly produced by the learners and is intended to be assessed, but could also come in the form of a tutor's report on the activity of a learner or the use of learning material.

The *subjective data* type refers to primary data which are a priori defined by an actor in the learning situation (a learner, a teacher, a tutor) or part of the analysis (output by an analyst, a designer, any learning staff member who is involved or concerned in the analysis).

The *derived data* are calculated or inferred from *primary data* or other *derived data*.

The *indicators* type refers to *derived* or *primary data* having pedagogical significance. Thus, an indicator is always relevant to a pedagogical context, and it is always defined for at least one useful purpose (e.g. validating the learning materials, assessing, reflecting, regulating). Based on the computationally oriented definition of an interaction analysis indicator (see Chapter 11), the DPULS project adopted the following definition: an *indicator* is a variable, calculated or inferred with the help of collected users' data, that describes something related to the quality of the interaction, the activity and/or the learning process of actors acting in the frame of a social context formed via the technology-based learning environment. The next section provides a short example in which this typology is used for modelling two indicators.

12.4.2 *Playing Around with Learning Objects Example*

In the context of individual learning, learners often play around with the system – especially at the beginning of a learning activity – by rapidly browsing the learning objects. It could be pertinent to detect this behaviour for regulation or a learner's purposes of reflection. The DPULS project proposed a generic solution to this tracking problem that is based on two indicators. The dependencies between data involved in their calculation are shown in Fig. 12.5.

It is assumed that every LO is described by LOM (Learning Object Metadata; LOM, 2007) or, at least, the typical learning time for each LO (the time needed for learners to correctly use the LO; see LOM specification for a formal definition of the “EducationalTypicalLearningTime” resource descriptor) can be estimated. It is also assumed that the sequence and time spent by a learner in consulting a LO can be recorded, for instance in log files.

The solution consists in recording for each LO the login time (date of connection in a log file) and the logout time (date of logout in a log file), and calculating the effective duration of use (the difference between logout and login times). The

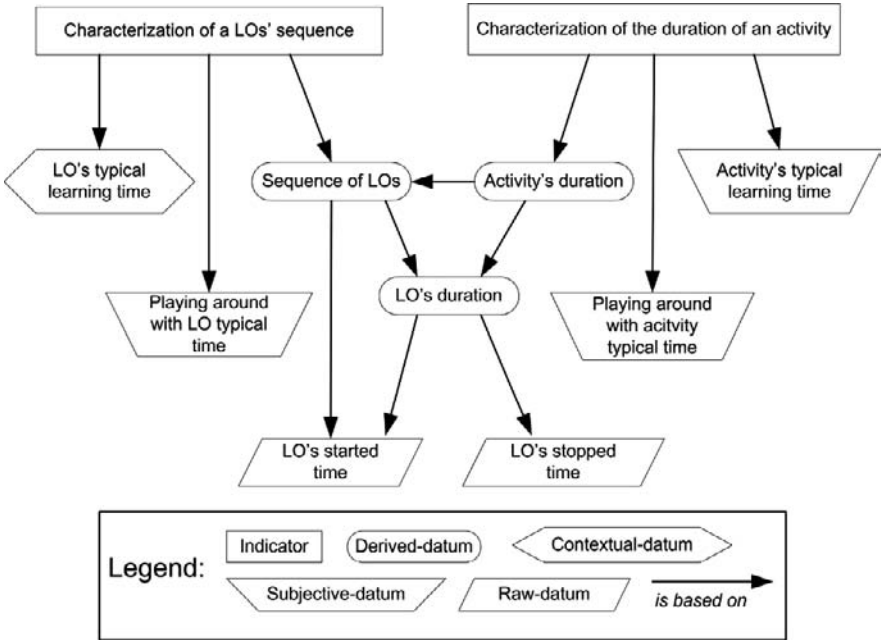


Fig. 12.5 Dependencies between data involved in “playing around” detection

sequence of LOs attempted by a learner could be labelled as “non significant” if the time spent on each LO in the sequence is less than the relevant Playing Around Typical Learning Time (a fraction of the typical learning time of a LO, typically 10%, which defines the duration under which a LO cannot really be consulted, but only browsed).

If such a sequence is detected at the beginning of a learning activity, one could presume that the learner is playing around with the system. If its effectiveness is proven by experimentation, this kind of solution for a tracking problem could be abstracted and capitalised and shared to support educational systems designers. The DPULS project chose a Design Pattern approach for doing this.

12.5 The Designer’s Support for Modelling the Use of a Trail: A Design Pattern Approach

The DPULS project focused on the know-how required for acquiring, modelling and analysing trails. The main aim of this project was to address the following question:

Considering usage analysis with a specific aim (e.g., a learning context, a pedagogical analysis purpose, or a considered trail’s end user – the learner, the tutor, the designer, etc.), what are the indicators one needs to collect, how could one analyse the usage, and what existing techniques or tools are well suited for this usage analysis purpose?

The DPULS project aimed at capitalising on the know-how of trails analysis by providing the TEL community with a structured set of Design Patterns that allow for sharing the users' data acquisition and analysis expertise. Each pattern addresses an acquisition or analysis problem in an identified context and proposes a concrete solution for it.

Each pattern is formatted within a template, and the Design Pattern language constituted by the entire set is accessible through a Web browser referenced by the TeLearn Open Archive (<http://telearn.noe-kaleidoscope.org/>). This set is open source and should be considered as a bootstrap for creating a wider set of patterns, fed and used by the TEL community.

The Design Patterns have a common framework for their representation. This framework is composed of a pattern template (displayed in Fig. 12.6), vocabularies for possible values of its fields and types of links which could be drawn between patterns.

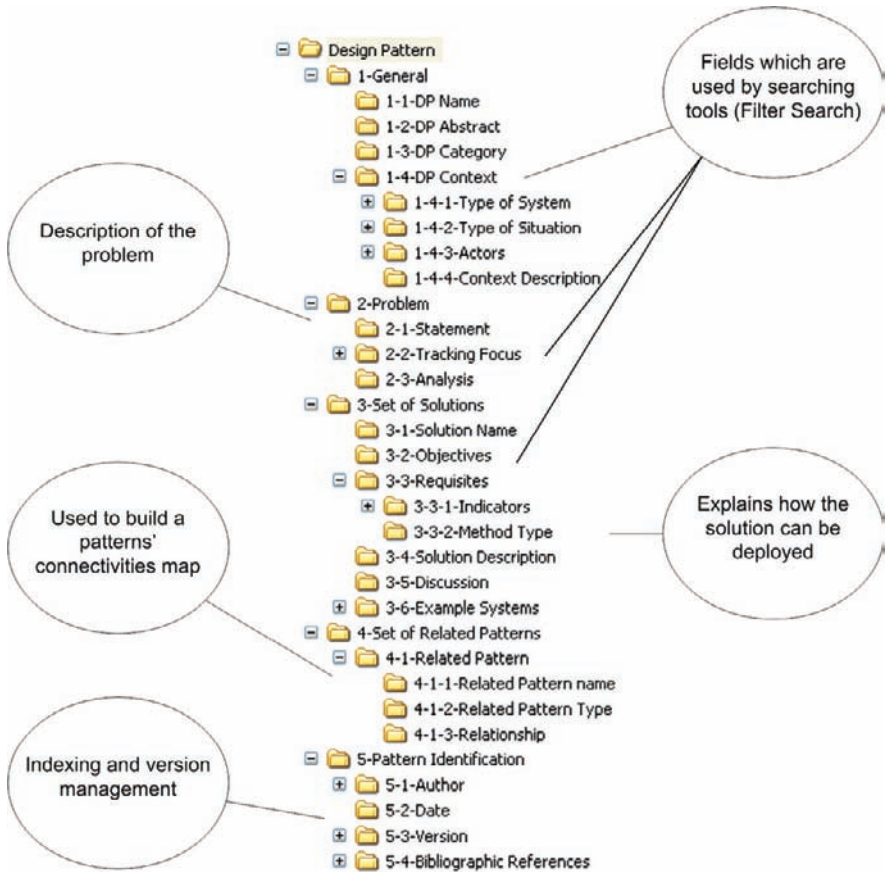


Fig. 12.6 The DPULS design pattern template

Table 12.2 General section of the design pattern “Detecting Playing Around with the System”

General		
Name	Detecting Playing Around with the System	
Abstract	This pattern provides an approach to detect playing around with the system by a student, at the beginning of an activity.	
Category	Course usage	
Context	Type of system	LMS (Learning Management System)
	Type of situation	Each student is alone in front of the machine. The teacher intervenes only when he is solicited.
Actors	– Instructional designer	
	– Tutor	
General Description	You can record and analyse tracks of resources used. It can be very valuable for describing the resources with metadata.	

The Design Pattern template is structured in five sections. The first one, *General*, is composed of fields that concern the *Identification* of the pattern. Each of the 40 Design Patterns defined by the project is indexed with a *Category* describing the learning *Context* where the pattern is relevant. The four categories tackled by the project are “Collaboration”, “Learner’s Assessment”, “Material Validation” and “Tutoring/Regulation of Learning”. The *General* section of the Design Pattern “Detecting Playing Around with the System” is presented in Table 12.2.

The second section deals with the *Description of the Usage Analysis Problem* that is addressed by the pattern. This section indexes the pattern by means of the *Tracking Focus* which helps to determine the kind of tracking addressed by the pattern: the Actors’ Behaviour, the Actor’s Performance, the System, the Contents, the Resources or the Tasks. The *Problem* section of the Design Pattern “Detecting Playing Around with the System” is presented in Table 12.3.

The third section details the *Solution* proposed in the pattern for tackling the problem. A synthesised version of the *Solution* section of the Design Pattern “Detecting Playing Around with the System” is presented in Table 12.4. The fourth section references the links drawn to other DPULS or external existing patterns. These links are relationships between patterns such as “More General”,

Table 12.3 Problem section of the design pattern “Detecting Playing Around with the System”

Problem	
Statement	You want to know if the student plays around with the system.
Tracking Focus	Actor’s behaviour/performance
Analysis	At the beginning of an activity, when the learner discovers the learning environment, he could play around with it, starting the LOs without really engaging in the activity. It could be problematic if it is not detected: the activity is not really engaged in and tutor’s and system’s reactions could need to take this into account, especially for the user’s profile evolution and for assessment.

Table 12.4 Solution section of the design pattern “Detecting Playing Around with the System”

Solution		
Solution name	LOs’ sequence characterisation	
Requisites	Indicators	Characterisation of a LOs sequence Characterisation of the duration of an activity
	Methods	Analysing the sequence of LOs consulted by the learner (semi-automatic/automatic)
Description	<i>[See Section 12.4 of this chapter]</i>	
Discussion	This solution is facilitated when the system records log files and when designers have described each LO with metadata.	
Examples		

“More Specific”, “Part Of”, “Has As A Part”, “Can Use”, “Can Be Used”, “Similar”, “Incompatible”, “Temporal Successor” and “Temporal Predecessor”. And lastly, the fifth section contains documentation about the pattern, such as its authors, the date of its creation and its version.

A complex design problem may require a large number of inter-linked patterns to solve it. Individual patterns do not stand alone, and the connectivity between patterns plays an important role in achieving a system design that meets the design goals and objectives for a complex problem (Deng, Kemp, & Todd, 2005).

DPULS design patterns follow the recommendation of Meszaros and Doble (1997) and are named by a “Noun Phrase Name” referring to the result implied by the name of the patterns. The problem and solution summary are in the abstract field to help the reader find the right solution.

The DPULS Design Patterns Browser is used for navigating inside the set of patterns, and, in fact, for sharing them. The browser contains all functionalities needed to manage, publish and share design patterns.

12.6 Discussion and Scientific Issues

The DPULS and TRAILS projects within Kaleidoscope have provided several results regarding the formulation of what trails are and how they can be useful in an educational setting. The trails structure and the analysis process have both been shaped in these two projects that we have discussed. We have also defined common vocabularies for naming the different types of trails, as well as all the data with which they are constructed.

The community now needs to embrace automated support for the trails analysis process. In order to realise this, two important additional issues need to be considered: (1) standardisation, which will allow us to capitalise, share and reuse existing and well-known techniques and (2) development of support tools for all phases of the trails analysis process.

Defining standards is crucial if a scientific community wants to spread its results and to foster wider research and experimentation in its field of study. If

we take the example of learning design with the recent specifications proposals, such as IMS Learning Design (IMS-LD, 2007), SCORM (SCORM, 2007) or LOM (LOM, 2007), we notice that, even if – or perhaps because – these proposals are not perfect, they have caused the research community to enter into a debate arguing for or against them, thus catalysing the research effort.

Standards aim to enable data sharing and interoperability of tools. In the field of user's data analysis, the following issues should be addressed in working towards standardisation:

1. *Enabling data sharing.* Each trail collected and each indicator constructed should be expressed so that it could be shared. The DPULS and TRAILS projects proposed a classification of trails, a user's data typology and some vocabularies that could form the basis of common formats. Some specifications have already been proposed, such as the common format proposed in Chapter 11 of this book for representing data and allowing their analysis by a variety of analysis tools. The Usage Tracking Language (Choquet & Iksal, 2006, 2007) is also an example of such a specification. This language is proposed for modelling user's data collected by different TEL environments and indicators constructed by different analysis tools in a unified format. Of course, these research outcomes need to be tested on a wide scale and improved through experience, but we think they constitute a fruitful approach for further work to define a standard for enabling data sharing.
2. *Allowing interoperability for analysis tools.* Addressing this issue would allow the community to define a common repository of analysis tools that could be used in different learning systems. Moreover, with interoperable tools one could combine these tools in order to define a new one. Here again, the interaction analysis projects described in Chapter 11 have proposed some solutions. We should also mention the "Track-Based System" approach (e.g. Laflaquière et al., 2006) that proposes a framework architecture in which collection, transformation, visualisation and query systems could be combined.

Since the beginning of research on technology-enhanced learning, a vast number of techniques and tools have been proposed for modelling, collecting, analysing and visualising users' data. Most of these were defined for a specific purpose, in a specific context, and only a few have been studied from an engineering point of view. When it matures, each scientific discipline must consider the possibilities for how to develop engineering methods and processes for spreading its results and engaging the research and practice community in rational and concerted growth. Some research teams are now engaged in this approach as, for instance, the LISTEN project (Mostow & Beck, 2006), and we think that further thought needs to be given to trails analysis techniques in order to better support the whole process of users' data analysis. When a tool, a technique, a model or a language is proposed for supporting an activity in this process, it should be studied from an engineering point of view. For facilitating reuse, these proposals should be characterised by answering the following questions:

- What is its general purpose? Is it a support for modelling, collecting, analysing or visualising trails? Is it done for a reengineering purpose, for assessing a learner's knowledge, for reflecting on the user's activity, for helping to regulate the activity?
- What is its application field and its expected results? We must develop a method for evaluating the quality of our proposals: to systematically test them in different contexts, to study their limits and their potentials closely. For instance, Beck (2007) has chosen this approach for analysing the knowledge-tracing model. Even if he takes his distances with this model, he points out the expected results when this model is used, while depicting its limitations, as the possibility of local and multiple global maxima – see Corbett and Anderson (1995) to learn more about this model.
- From a technological point of view, what are its reuse possibilities? Does it require a specific technology or a specific data format?
- From an educational point of view, for which learning framework is it well suited?

Addressing all of these issues will stimulate cooperation and collaboration within the trails analysis research community, as well as sharing of its results with the communities that concentrate on more practical issues.

In conclusion, the research community for users' data analysis should engage itself in a process where each effort is analysed from an engineering point of view, in order to bring the theory into practice. We think that consideration of the question of engineering of trails analysis is useful as such, but also and mainly because it would enhance the research in this field: working on users' data engineering will require us to define the proper place and the roles of theoretic proposals in the user's data analysis process, and we believe that it could enhance their quality.

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Part IV
Special Technologies

Chapter 13

A Patterns Approach to Connecting the Design and Deployment of Mathematical Games and Simulations

Dave D. Pratt, Niall Winters, Michele Cerulli and Henny Leemkuil

Abstract There has been a growing recognition of the educational potential of computer games. However, it is recognised that the process of designing and deploying technology-enhanced resources in general and games for mathematical learning in particular is a difficult task. This chapter reports on the use of patterns, referred to as p-d patterns, to address this challenge. Based on a review of the literature, a set of typologies of the domain was generated which formed the springboard for the development of over a hundred p-d patterns. These patterns are hierarchical by nature and constitute a pattern language that could be mobilised to facilitate pattern-specific communication and knowledge sharing between communities. Such patterns are, for example, shown to incorporate recurrent themes, such as scaffolding and reflection, instantiated in patterns across both design and deployment. Finally, we will set out how the patterns approach could be consolidated to become the stimulus for a much needed breakthrough in the articulation of how design needs and functionalities constitute theory in the field of designing for learning.

Keywords Design patterns · Pedagogic patterns · Mathematics · Games · Design experiments

13.1 Introduction

The inspiration for this chapter is drawn from work on a 1-year project of the Kaleidoscope Network of Excellence on the design and deployment of mathematical games.¹ We describe a methodology used to identify patterns in the design and deployment of mathematical games, referred to here as p-d patterns to capture their

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¹ Three of the four authors, including Dave Pratt and Niall Winters as co-directors, were involved in this project. Michele Cerulli was an important member of the project team, though we should acknowledge the efforts of other members of the team, not listed as authors (see *Acknowledgements*).

relevance across pedagogy and design. These patterns have potential to act as a language through which stakeholders with very different aspirations, agendas and working practices might nevertheless be able to collaborate. Our project brought together partner institutions from across six European countries with expertise in computer science, educational technology, teaching, pedagogical design and games. The network further involved partner schools in three of the six countries, with 21 people making up the core of the team. For more details on the social configuration of the team, see Winters, Mor, and Pratt (in press).

13.2 Introducing the Need for a Patterns-Based Approach

13.2.1 The Need to Fuse State-of-the-art Technology and Pedagogy

Computer games are a popular form of activity. In 2004, the US market alone was worth \$9.9 billion (NPD Group, 2005), and in the UK in 2002 the market was worth approximately £2 billion (Wilcox, 2006). As such, games are playing a more central role in peoples' lives than ever before and, as a result, games are becoming a topic of serious research interest, sometimes referred to as "ludology". The field's first peer-reviewed journal was only launched in 2001 (Aarseth, 2001) but already a collection of books (Juul, 2005; Salen & Zimmerman, 2003) and anthologies (Salen & Zimmerman, 2006; Wolf & Perron, 2003) show the extent of research produced. However, little of this has been focused towards the design of games but rather towards game studies, studies of players or studies of games in relation to other media.

An example, within the discipline of ludology, is Kafai (2006), who stresses making games for learning instead of playing games for learning and thereby indicates the importance of understanding the nature of games, so that one can create games with specific design goals. These design goals have to co-exist with characteristics that have been identified as being essential for activities to be pleasurable (Csikszentmihalyi, 1990), which in a game context translated to providing good game play (Järvinen et al., 2002).

Kirriemuir and McFarlane (2003) undertook a literature review of games and learning for the National Endowment for Science, Technology and the Arts (NESTA) in the UK. An overview of the main developments in research into gaming and the educational relevance of video games illustrated that, although the use of "mainstream" games in schools is rare, parents, carers and teachers increasingly recognise the potential of games to support valuable skills development, such as strategic thinking, planning, communication, the application of numbers, negotiating skills, group decision-making and data-handling. Significantly they also highlight the fact that educational games often fail to realise players' expectations because the games are often too simplistic or repetitive with respect to commercial computer and video games, and are often poorly designed, with little support for active learning to achieve understanding.

In 2002, the British Educational Communications and Technology Agency (BECTA) undertook a small-scale pilot study (British Educational Communications and Technology Agency, 2002) investigating the use of six computer games in a school setting. In summary, they found some promising potential for future work by researchers, teachers and games developers based on their initial, tentative findings that games can support students' ICT skills, increase their motivation, encourage collaborative working and have positive side effects such as increased library use.

The unrealised potential is nowhere more apparent than in mathematics and science education, where there is a history of the use of games which started out as simple drill-and-practice games. More recently, the Electronics Games for Education in Math and Science (EGEMS) was a collaborative project investigating the design and use of computer games in enhancing mathematics education specifically for students aged 9–14 (Klawe, 1998). In particular, prototyping educational computer games and conducting focused quantitative and qualitative studies to evaluate the effectiveness of various design and use options was a priority. The project findings suggest that computer games can be highly effective in increasing children's learning and enjoyment of mathematics when children actively

think about and value the mathematics embedded in the computer game [with] three factors to be particularly important in focusing students' attention on the mathematics: teacher attitudes, supporting activities and collaborative play (p. 13).

However, without these factors, almost no mathematical learning results from playing the game. Once more we see the centrality of the facilitator and pedagogic principles, which focus on mathematical thinking (see Jonker & Galen, 2004).

Thus, the current state-of-the-art is one of multidisciplinary design, frustrated by design fragmentation, whereby the communities involved are not fully cognisant of the structuring forces that impinge on each other's activities. In this sense, state-of-the-art lies in isolated projects, which (a) do not scale and (b) are not "self-conscious" about their methodology. As a consequence of design fragmentation (a) discontinuities between design and deployment impede the effectiveness of the product in practice and (b) the isolated projects do not contribute to cumulative knowledge about the design process that could inform future work. Therefore, designing games for education is difficult since it requires the integration of state-of-the-art knowledge about software engineering principles with the latest knowledge about pedagogy, the preserve of academics and pedagogues (Mor & Winters, 2007). Yet this needs to be addressed since there is tremendous potential in games for learning.

13.2.2 The Need to Fuse Key Stakeholders in the Creation of Technological Products for Learning

Technology-enhanced learning (TEL) is now three decades old. In this time, there has been considerable progress beyond initial attempts merely to recreate what was possible (and often preferable) with existing technologies, and there are now

some genuinely innovative and impressive computational environments available for learning. (For example, we have moved from the exploitation of products designed for commerce to educationally tuned software, such as dynamic geometry packages,² algebraic symbol manipulation software³ and statistical packages, focussed on the conceptual difficulties of young children.⁴) Yet major challenges remain, and one – the problem of design fragmentation – remains a real impediment to widespread innovation in the field. The problem of design fragmentation is, quite simply, that there has not been sufficient attention paid to learning and exploiting design as a research issue, building new artefacts and approaches on the theoretical and practical work that has preceded them. (Although we note some isolated successes, for example, Cavallo (2000), but see diSessa and Cobb (2004), for a theoretical take on the failure of design solutions that do real work at the classroom level.)

We can characterise the initial era of TEL as one of intense excitement and activity, as software engineering companies began to exploit the affordances of digital technology and curriculum developers attempted to apply those products, often developed for commerce (spreadsheets, for example), to classrooms and more informal learning contexts. The achievement during this period was to identify the immense potential offered by the new technology and to encapsulate best practices for their development with software engineering methodologies (Pressman, 2005).

However, we are no longer at the dawn of the Information Society and we have begun to recognise that we are failing to realise the potential that technology affords for education (Ruthven, 2007). We see, as a first step towards enabling such multidisciplinary teams to work together, the articulation through a map of p-d patterns of each other's working practices, including constraints, opportunities and aspirations.

13.2.3 What is a Pattern-based Approach?

Towards that aim, we propose exploiting the notion of a p-d pattern, a particular type of design pattern. In general, a design pattern is defined as a high-level specification for a method of solving a problem by design. Its particular strength is in highlighting *recurring techniques and solutions* to design problems that are found again and again in real-world application development. Design patterns enable this process of knowledge discovery by specifying the particulars of a problem, and how the designated design instruments can address them. Classically, design patterns have been proposed in a format that consists of the following components (Alexander, Davis, Martinez, & Corner, 1985):

² E.g., Cabri Geometre, <http://www.cabri.com>, and Geometer's Sketchpad, <http://www.dynamicgeometry.com/>

³ E.g., Derive, <http://www.derive-europe.com>

⁴ E.g., Fathom, <http://www.fathom.com> and Tinkerplots, <http://www.keypress.com/x5715.xml>

- An introductory paragraph, which sets the *context* for the pattern.
- A concise *problem statement*.
- The *body* of the problem – it describes the empirical background of the pattern, the evidence for its validity, the range of different ways the pattern can be manifested.
- The *solution* that describes the relationships required to solve the stated problem, in the stated context. It is preferable to state the solution in the form of an instruction. A *diagram* may be included here.
- A relationship between this pattern and others.

In the project on the Design and Deployment of Mathematical Games, we aimed to explore the feasibility of identifying patterns that captured the essence of how mathematical games were designed and deployed. In effect, we envisaged the possibility that a map of such patterns might play the role of a design language. We could foresee, for example, that, if successful, such an enterprise might be a first step towards enabling the various stakeholders to communicate the way in which they work, with the hope that these communities could increasingly work closely together in the future to harness the expert knowledge in each community, reducing the fragmentation and enabling the development of games that have widespread impact on learning.

13.3 The Nature of Patterns in the Design and Deployment of Mathematical Games and Simulations

To illustrate further the nature of p-d patterns, we discuss below the Guess-My-X pattern. An instance of Guess-My-X is the “Guess-My-Rule” game, an activity used by teachers to encourage students to discuss the formulation of rules, and in particular the equivalence (or not) of their algebraic symbolism (Matos, Mor, Noss, & Santos, 2005). It is one way of supporting sustained interaction between students, a process vital to the establishment of socio-mathematical norms (Yackel & Cobb, 1996) and to the collaborative construction of knowledge in the community.

In the Guess-My-Rule game, there are roles for proposer and responder but these can be fulfilled by either teacher or student. We first became aware of the game in one of our early workshops. A delegate described observing a teacher using Guess-My-Rule with a class of 11-year-old students. After announcing to the class that she, the teacher, had a rule in her head, she challenged them to guess the output for each input that she would write on the board. Subsequently, the game was played in total silence. The teacher, acting as the proposer, wrote 5 on the board. One student, acting as the responder, came to the front of the class and wrote 10 next to the 5. The teacher indicated that this guess was wrong by writing ☹. Successive children guessed until the teacher wrote ☹. The teacher then wrote up a new input on the board. As the procedure was repeated, gradually more and more students were putting up their hands to guess, having figured out the rule in the teacher’s head. Another delegate described how they had seen this game played between students in

pairs, with one student acting as proposer and another as responder. A third delegate described how the game can be played on a spreadsheet. These variations became part of the description of the Guess-My-Rule pattern.

Guess-My-Rule is powerful in the sense that it leverages the potential of reciprocity – responders feel a social need to respond to the proposer. Furthermore, challenges, perceived by students as interesting, may lead to prolonged interaction. Through reflecting on Guess-My-Rule, the Guess-My-X pattern was subsequently identified as an abstracted common theme, in a range of research activity in mathematics education. (Details on supporting the process of abstraction from case studies are provided in Winters & Mor, 2008, in press.) In particular, Guess-My-Robot (Matos et al., 2005; Mor & Sendova, 2003) and Guess-My-Garden (Cerulli, Chiocciariello, & Lemut, 2007), tasks designed for the Weblabs project, were used to generate the Guess-My-X pattern. To complete the pattern cycle (i.e. use of a pattern to develop a new artefact/activity), Guess-My-X was then used to develop the Guess-My-Die game (Pratt, Johnston-Wilder, Ainley, & Mason, 2008).

The Guess-My-Garden task was a game based on a simulation of random sampling with replacement from a garden of objects such as flowers, tools or in fact any object the proposer might choose to place in the garden, to create any discrete sample space. The proposer can then extract a random sequence of objects from the garden itself. The sequence of objects can be packed and sent (for instance via e-mail) to a responder, who can analyse it, and try to guess what kind of sample space could generate such a sequence of objects. The Guess-My-Garden game consists of exchanges of this kind, where a team of pupils act as proposer to send a sample of objects from their own gardens to another team, acting as responder, who proceed to try to guess the proposer's garden composition.

We have given some detail with respect to Guess-My-Garden so that the reader might detect the common structure between it and Guess-My-Rule described earlier. The same structure can be identified in Guess-My-Robot, where a robot, programmed by the proposer, carries out a task and the responder is challenged to identify how the program was written. Similarly, in Guess-My-Die, the proposer creates a simulated die, and the responder attempts to infer the configuration of the die by blindly generating data. The four examples, Guess-My-Garden, Guess-My-Robot, Guess-My-Function and Guess-My-Die can all be taken as examples of the pattern, "Guess-My-X", which uses Alexander's approach of a design pattern to express the common structure the reader will by now have identified.

Patterns do not exist on their own – they form part of a pattern language and therefore are defined in terms of each other through four types of relationship: "Elaborates", "Elaborated by", "Follows" and "Leads to". "Elaborates" defines an "is a type of" relationship. For example, "Guess-My-X" elaborates "Challenge Exchange". This implies that "Guess-My-X" is a way of implementing "Challenge Exchange", which describes an activity where learners pose and respond to each others' challenges.

By placing more abstract patterns at a high level and the more specific ones lower down, we build up a pattern hierarchy. As such, no pattern exists on its own – it is supported by others above and below. In addition to the hierarchical structure,

“Follows” and “Leads to” indicate immediate preceding and proceeding patterns, in terms of *implementation*. For example, “Guess-My-X” leads to “Post Ludus”, which describes how learners may reflect on their actions and experiences, in this case, after doing a “Guess-My-X” type activity (e.g. Guess-My-Garden).

13.4 Distilling the p-d Patterns

The process of distilling p-d patterns is non-trivial. This is because patterns by their very nature are abstractions of ideas. Engaging in the cognitive process of abstraction requires deep reflection on practice. Retalis, Georgiakakis, and Dimitriadis (2006) propose a method of eliciting patterns, which involved four steps: identifying and sketching patterns; drafting a design pattern; critiquing design patterns and identifying related patterns. For example, in the Design and Deployment of Mathematical Games project, we converged on a method that mixed face-to-face collaborative pattern development with an online approach through a suite of specially developed web tools (see <http://lp.noe-kaleidoscope.org>). We used a workshop model for developing patterns (Winters & Mor, 2008), extending the breadth and depth of the emerging language. The workshops also helped to identify relationships between the patterns, which began to form a hierarchical structure as we came to understand which patterns were in fact instances of others, and which patterns espoused a higher level of abstraction. To begin the process of distilling the p-d patterns, the building of typologies and case studies proved essential.

13.4.1 Typologies

The aim of the typologies was to provide a structured lexicon for framing the initial design space. In effect they acted as a resource in the form of a content-based relational map, for classifying the different aspects of design knowledge required in the process of the design, development and deployment in the classroom of mathematical games for learning. For our purposes, the typologies used were mathematical content, learning and instruction, educational context, games, interaction design and software design. The typologies were developed to reflect the synergistic collaboration between the design and deployment strands of the project. In fact, the project team, in bringing together a range of interdisciplinary expertise, was well positioned to address critical aspects of the process across both strands. In developing the typologies, issues of scope and definition were often confronted and discussed. An example was discussion around what was mathematics content. There is of course no universally accepted definition of mathematics. There is though considerable overlap across curricula and so, rather than taking a position on the nature of mathematics itself, we took the pragmatic decision to focus on *school mathematics*. Detail on the mathematical content can be found at <http://lp.noe-kaleidoscope.org/outcomes/typologies/mathematical-content/>.

13.4.2 Case Studies

The purpose of the case study development was multifold: (1) to provide concrete examples of practice within disciplines, (2) to map practices and content detailed in the case study to the set typologies, (3) for the team to identify linking points between disciplines and (4) to provide the starting point for pattern development. Each case was relatively short and was designed to act as a starting point for discussion around design knowledge. Each case was broken down into (a) the context it describes, (b) the relationship to the typologies, (c) the aims of the particular case, (d) development/deployment details and (e) outcomes. It was around these aspects of each case that we expected to find common starting points for the development of the initial set of “seed” patterns.

The typologies were subsequently applied to the cases in order to interrogate them to help identify critical aspects of the TEL design process. Those design decision that worked were identified and, together with reasons for their success, formed the basis for potential p-d patterns that describe and connect both the design and deployment dimensions. Table 13.1 is a selection of 10 cases, chosen to give the reader a sense of the types of games that were explored within the case studies.

Table 13.1 An illustrative selection of games considered in the case studies

Name	Summary
Add-Up surprises	Students are challenged with a programming puzzle: “Get a familiar component to generate unexpected outputs.”
Aliens and trains	A game designed in qbasic to help students to learn multiplication tables.
ChanceMaker	ChanceMaker simulates everyday random generators, called gadgets, such as coins and dice. Some gadgets were intentionally broken. The students were challenged to identify which gadgets were not working properly and mend them.
Guess–My–Garden	Students provide a sample of objects chosen randomly from a garden. Other students have to guess the garden from the objects that were generated.
Guess–My–Robot	Students build a small program, such as a number sequence generator in ToonTalk, where the program is represented by the actions of a robot. Other students have to figure out how the robot creates the output.
Juggler	A game built on E-slate, where the user must try to juggle two balls using two rackets. The educational idea of the game is to build a simplified model that embodies specific notions of mathematics and science and to apply mathematical concepts in a virtual simulation of a real phenomenon.
MoPix	Design and development of a game environment for learning mathematics on mobile devices.
Small change challenge	A programming puzzle in which students are asked to modify a familiar tool to obtain a new result.
The rabbit numberline game	A problem-solving game based on a problem-solving tool, the numberline.
Timez Attack Game	This is a game which was designed to assist 8- and 9-year-olds in mastering the multiplication tables.

13.5 Games and Simulations

By developing p-d patterns that cut across the design and deployment of mathematical games, it becomes apparent that certain themes are common to both dimensions. In fact, we have found that these themes are also very much the concern of designers in the related domain of computer simulations. Simulations and games are environments that have some basic elements in common. Games are competitive (usually), situated, interactive (learning) environments, based on a set of rules and/or an underlying model, in which under certain constraints and uncertain circumstances a challenging goal has to be reached. In games, players (sometimes in co-operation with others) are actively solving challenging situated problems. Simulations are environments that are also based on a model of a (natural or artificial) system or process. In a simulation, learners can change certain input variables and can observe what happens to the output variables. The goal is to discover the underlying rules and principles.

The main distinctions between games and pure simulations are that games contain elements of competition, chance, surprise and fantasy that are typically not found in simulations. Furthermore, the goal is different. In simulations, the goal is to discover the underlying principles of the simulation model, while in a game one typically tries to win the game or beat the system, the highest score or other players. In a simulation, the learner has more freedom to act and experiment and in most cases does not have to cope with limited resources. Finally, in a simulation it is relatively easy to recover from wrong choices. In games, participants have to think about the trade-off between costs and profits of actions and it is not possible to “undo” the actions. One has to face the consequences of one’s actions, while in a simulation it is easy to restart and experiment in the same situation. This dichotomy, however, is not as straightforward as it sounds. *Guess-My-X* describes a pattern that could be applied to either games or simulations. Thus, *Guess-My-Rule* has the feeling of competition associated with a game in trying to beat the proposer by identifying the rule. However, making wrong guesses does not really cost and can be undone by making future correct guesses. *Guess-My-Garden* is a simulation in so far as it plays out a random process through which elements of the garden are chosen (as is also the case for *Guess-My-Rule*), but it is a game in so far as there is a clear goal. In our view, patterns such as *Guess-My-X* are not always categorisable as games or simulations though as one moves down the hierarchy to more and more specific instances, it may be possible to make such a classification. Certainly, it is not surprising that much of the research available about the design of simulations applies equally well as that on games to patterns such as *Guess-My-X*.

Indeed, the approach to learning in both environments in many cases is similar. According to de Jong (2006b), in simulations a domain is not directly offered to learners, but learners have to induce the characteristics of the domain from experiences or examples. This is also true for games that are not focused on practicing, drilling and automating existing skills. Characteristic learning processes in both types of learning environments are exploration, orientation, generation of different options/possible solutions, valuation of these options, evaluation/monitoring of the

outcomes and reflection on their own behaviour (so far) and on the system's (or other players') reactions to this.

We noted in our process of capturing patterns that similar issues were evident and we discuss them under two headings: scaffolding and reflection. We use "scaffolding" in a non-technical way to refer to the need to provide support within or outside of the game itself in order to optimise the chance that pedagogic objectives are met. In discussing "reflection", we found it was appropriate to widen the notion of reflection to include optimising initial orientation and consideration of the effect through evaluation. We will now look at each of these two recurring themes in more detail.

13.6 Scaffolding

Researchers have reported that simulations used for training and learning were only effective when the learning process was adequately scaffolded (de Jong, 2006a; de Jong & van Joolingen, 1998). Now, large-scale evaluations have shown that simulation-based learning, when properly designed, can be effective. de Jong and van Joolingen (1998) found that students using simulations experience problems in performing these processes, especially with hypothesis generation, design of experiments, interpretation of data and regulation of learning. They stated that cognitive scaffolds should be integrated into simulation-based environments to support learners. Cognitive scaffolds may structure a task, take over parts of a task or give hints and supporting information for the task (de Jong, 2006a). Kirschner, Sweller, and Clark (2006) also pointed to the fact that some form of guidance was needed in rich problem-based experiential learning environments to prevent learners from missing essential information (see also Mayer, 2004), experiencing a cognitive overload and being unable to construct adequate mental representations. If this was true for simulations then it is also true for games.

The above research emphasises the need to build scaffolding into the design of games and simulations. However, this is not always possible since very simple designs, such as Guess-My-X, do not have the scope to embrace complex help systems. Nevertheless, patterns in how deployment can take place in the classroom are able to provide for this shortfall.

Let us provide an example of how this can take place. The Random Garden simulator used for Guess-My-Garden is a quite simple device, and the teacher needs to intervene systematically in order to scaffold the teaching/learning process. The key point of the Guess-My-Garden game is to guess the composition of the garden that produced a given random sample of objects from the garden. However, given a garden, there is an infinite number of gardens that can produce the same sample of objects. On the one hand, the infinite set of possible gardens can be attributed to the random process. Thus, a sample of 1 red flower, 2 yellow flowers and 3 blue flowers (1R, 2Y, 3B) may have been randomly generated from any garden with at least one red, yellow and blue flower. Some students however will accept that such a sample

is more likely to have been generated by some gardens than others. Thus, a (1R, 2Y, 300B) garden is less likely to have generated the given sample than a (2R, 4Y, 6B) garden. (Though, it is true that some students will argue that is only a matter of chance and it does not matter what the garden was like in the first place.) However, the issue is more subtle even than this, and scaffolding will be needed to bring out that subtlety if the main learning point is not to be missed. There are an infinite number of gardens that will, with equal likelihood, generate the given sample (1R, 2Y, 3B). Thus, since the sampling is with replacement, a (2R, 4Y, 6B) garden is as likely to produce the given sample as a (4R, 8Y, 12B) garden or for that matter any garden of the form $(nR, 2nY, 3nB; \text{integral } n)$. Thus what does it mean to guess a garden? Does it mean to guess exactly the given garden or does it mean to guess an equivalent garden? Scaffolding discussion around these questions is very important if the game, *Guess-My-Garden*, is to be affective in engaging students in thinking about probability (Cerulli et al., 2007).

Perhaps in a more complex environment, such scaffolding could be provided through artificial intelligence but in using the simple *Guess-My-X* pattern, teachers needed to provide the structure ad hoc:

1. It was implicitly agreed that the rules had to be shared among all the teams.
2. At the beginning of the match, the rule for validating answers was left open, intentionally not even mentioned to pupils.
3. It may happen that all the proposed answers are clearly wrong or clearly correct, with no ambiguity. In such a case, the teacher can introduce a garden that could easily cause ambiguities.
4. Once the match reached a point where answers had to be validated in order to establish who were the winners, the teacher set up specific class discussion, focused exactly on the issue of what it means to guess a garden correctly. More details of the activity and an example of one such episode and of the class discussion can be found in Cerulli et al. (2007).

Our central point here is that scaffolding is essential but non-trivial and may be described in the pattern with reference to deployment in the classroom or to systems integrated into the game or simulation.

13.7 Orientation, Evaluation and Reflection

Game characteristics can lead to all kinds of barriers in game play and learning that mainly have to do with the processes of orientation, evaluation and reflection (Leemkuil, 2008). Indeed, orientation, evaluation and reflection could form high-level organising nodes in a hierarchical map of p-d patterns. Barriers in orientation occur when players are not able to interpret changes in the situation they are facing and are not able to plan their actions, because they lack essential knowledge. Overcoming these barriers requires a particular type of scaffolding and so we have chosen to discuss these in a distinct sub-section.

Intelligent scaffolding could be included in the game design. Scaffolds that are reported to be effective in supporting orientation processes are the introduction of a problem-solving scheme (Stark, Graf, Renkl, Gruber, & Mandl, 1995), and the availability of just-in-time information (Leutner, 1993). In the research of the fourth author with a simulation game in the domain of knowledge management, KM Quest (Leemkuil, de Jong, de Hoog, & Christoph, 2003; Leemkuil, 2006), indications are apparent that the main elements of orientation support in the KM Quest simulation game are the availability of relevant background information that can be consulted whenever needed, and the availability of visualisations that help players in ordering the large amount of information that is available in the business simulation model.

Students, who used these resources frequently, learned more and in some cases had higher game scores. It was also observed that advice given by the system (containing warnings and hints) was heavily used by the players but it was not possible to find any relationship between the use of the advice functionality and learning results, and only a weak relationship with game performance.

Again, it is possible for the teacher to utilise patterns in how they are deployed in the classroom when the game design itself does not support orientation. For example, in the didactical context in which the game is played, the teacher might utilise the p-d pattern *Orientating students to make sense of data when gaming* (Table 13.2) to help scaffold the orientation barrier. The pattern describes how teachers may select particular pieces of controversial data in order to help a class orientate themselves to the body of data as a whole.

In games, players often have problems with the processes of evaluation and reflection because there are no reference data and because players are unsure to what extent the current state of affairs is a result of their actions or is caused by game elements like chance, unexpected events, limited resources and the behaviour of others. This could lead them to drawing wrong conclusions. An effective scaffold to prevent this from happening is process feedback. Games often contain only feedback about the output or result rather than about the process by which that result was achieved. In research with KM Quest, it was found that feedback that enables players to compare their own solutions with solutions generated by the system, or to value the role that the unexpected events are playing (bad or good luck), was affective. Students, who used this frequently, learned more. Process feedback can often be integrated into the game design itself.

In contrast, reflection may be better supported by elements that could be part of the broader didactical context in which the game is played. Several authors (Garris, Ahlers, & Driskell, 2002; Klawe & Phillips, 1995; Peters & Vissers, 2004) have stressed the importance of a debriefing activity. Peters and Vissers (2004) point to the importance of debriefing because not all participants of a simulation game will be equally able to reflect on the experiences acquired during the game and to draw conclusions and apply these to a real-life situation. Furthermore, especially in a multiplayer game, participants may have a limited picture of what was happening. While playing, they usually observe only those parts of the simulation game their position allows them. "From a learning perspective, then, it is useful to revisit the scene with all participants after playing has stopped, compare different pictures,

Table 13.2 Orientating students to make sense of data when gaming

Name: Orientating students to make sense of data when gaming

Problem: *How to orientate students to ask critical questions of data within a subject domain when playing a computer game?* The problem is that for students to engage they need to feel a sense of ownership over what they are doing.

Context: The pattern emerged from a context where students are working with pre-prepared data within a game simulation (such as SimCity, for example). Methods are required to provide a sense of ownership over data so as they can make sense of it.

Subject content: skill domain; handling data.

Learning and instruction: game; educational objectives; modalities of employment, approaches and theories.

Educational context: role of educator; teacher support; integration of game elements with subject elements.

Games: simulation; game as activity, game as social function.

Pattern:

- In whole class discussion the teacher discusses a “controversial question” with the students. It is important the question asked is related to the students’ own culture, as this provides them with a sense of ownership.
- The questions are refined to work within the context of the game, thus bridging real-world and virtual contexts.
- For example, if the teacher is using the SimCity game simulation, and climate change arose as an important topic of discussion, the teacher might choose to focus on power generation within SimCity (what type of power generation should be used (nuclear, wind, hydro, etc.)
- The students are provided with a city simulation and go about constructing their virtual world. The game provides them with the ability to make sub-choices within the topic (for example, where should the power station be placed in the city?) and record their consequences.
- At the end of game play, in whole class discussion, the students discuss what happened in each of their games. The teacher facilitates a reflective discussion on the choices and sub-choices made by the students and what the consequences were.

Related patterns:

Follows: None. *Elaborates:* Scenario.

Elaborated by: None. *Leads to:* None.

Category: Deployment

and encourage participants to make a joint analysis of what happened” (Peters & Vissers, 2004, p. 70).

Another intervention, perhaps more relevant when deployed in the classroom, to promote reflection is collaboration. In collaborative learning settings, learners are encouraged to share perspectives, experiences, insights and understandings. This can help learners to come up with new ideas, to debug their ideas and to notice the complexities of concepts and skills.

Klawe & Phillips (1995) report positive effects of collaborative play. Shostak & de Hoog (2004) found an indication that collaborative game play could be beneficial in learning with KM Quest. They found that players who played in dyads had a significant knowledge gain when pre-test and post-test scores that measured decision skills were compared, while students who played alone did not have a significant gain.

In the case of deploying Guess-My-Garden, teachers were able to encourage collaboration and reflection in other ways. The game itself was not an individual game, but a team game, played between teams from Italy and Sweden. Even the choice of the strategies was a source of discussion for each team (three or four pupils per team). However, a more global level of discussion and reflection was systematically organised. In the preceding year the Italian class had been keeping an *Encyclopaedia of Randomness* (Cerulli, Chiocciariello, & Lemut, 2006a) to report all the class findings concerning the topic. The production of such an encyclopaedia was an occasion and a stimulus for practicing collaborative forms of reflections and discussions, aimed at communicating the class findings to the Swedish pupils, participating in the project. Moreover, the system allowed the Swedish pupils to provide feedback, adding comments to the encyclopaedia, which could then be answered by the Italian pupils, giving birth to a typical cross-national online discussion.

We discussed earlier in the Scaffolding section how Guess-My-Garden raised important probabilistic issues because different gardens were equally likely to produce the same sample of flowers. The cross-national challenge brought this issue to the fore since the Italian students had to decide whether the Swedish answer should be judged as correct when they guessed a different but equivalent garden to that used by the Italian students. Collaboration within the Italian teams enabled a resolution to be found, which could be communicated to their Swedish pals, who were waiting anxiously to know if they had guessed the garden correctly (more details on the episode available in Cerulli et al., 2007). Agreements found by the class were “officially” reported in the Encyclopaedia.

At a very high level in the hierarchy, there is a need for on the one hand scaffolding and on the other for orienteering, evaluation and reflection, and such needs can be expressed as high-level patterns. We have documented some examples of how variously artificial intelligence can be integrated into the game itself or how teachers can support such activity. At that level of specificity it appears that such patterns become either digitally oriented patterns with respect to software design or human-oriented patterns with respect to the nature of deployment in the classroom. In either case, the aims are identical and we are able to emphasise this by placing both in the same hierarchy where at some level of generality they merge and at some level of specificity they separate.

13.8 Implications for the Connected Design of Mathematical Games

We have indicated above how ongoing work is setting out the design and deployment of mathematical games in a single hierarchical map. The connections between design and deployment have been enriched by integrating communications with the Technology-Enhanced Learning in Mathematics (TELMA) project, a Kaleidoscope European Research Team. Indeed, all the patterns, we designed, provide (through combining context and pattern) a *didactical functionality* (Cerulli, Pedemonte, &

Robotti, 2006b) to be associated with a game, either attaching a modality of employment to a game (addressing a goal) or designing a game to address a goal, and to be employed in a specific way.

In this paper, we have discussed the findings of research focussed on game and simulation design and found themes that recur across those areas in both design and deployment. We have seen how patterns can help in the design of scaffolding aids for orientation, reflection and evaluation both for teachers and for “intelligent” software. Our analysis provides further support for our conjecture that design is a relevant practice not only for software designers but also for practitioners and that a single map of p-d patterns can embrace the activities and purposes of both communities.

Even so, we would argue that obstacles remain and that a further step is needed if we are to reliably build on design knowledge that results in new games that have learning impact. We have proposed a methodology that brings together different stakeholders in the process of designing and deploying mathematical games and simulations. This approach is based around the identification of patterns through workshops that reflect on the experience of those stakeholders. We claim that patterns can provide the common language that enables practitioners and software engineers to communicate.

The development process that we envisage needs to acknowledge the constraints, opportunities and aspirations of the key stakeholders in the learning process as they work together. We are referring to such deep collaboration as *connected design*, a framework for fusing communities of software designers, curriculum developers and facilitators (such as teachers), building ever-deeper and richer knowledge through the construction of an emerging map of p-d patterns.

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Chapter 14

Mobile Learning

Small Devices, Big Issues

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Abstract Over the past 10 years mobile learning has grown from a minor research interest to a set of significant projects in schools, workplaces, museums, cities and rural areas around the world. Each project has shown how mobile technology can offer new opportunities for learning that extend within and beyond the traditional teacher-led classroom. Yet, the very diversity of the projects makes it difficult to capture the essence of mobile learning or to show how it contributes to the theory and practice of education. This chapter attempts to address the central issues of what is mobile learning and how can it be designed and evaluated. Drawing on a theory of mobile learning as “the processes of coming to know through conversations across multiple contexts amongst people and personal interactive technologies” (Sharples, Taylor, & Vavoula, 2007, p. 225), we discuss how learning contexts are created through interaction and how portable and ubiquitous technologies can support effective conversations for learning. We draw on the findings from recent major projects to show how people artfully engage with their surroundings, peers and technology to create impromptu sites of learning and to carry their conversations from place to place, from time to time, from topic to topic.

Keywords Mobile learning · Conversation · Context · Collaborative knowledge building

14.1 Introduction

The foundations for mobile learning were laid over 30 years ago with the far-sighted Xerox Dynabook project that proposed a “self-contained knowledge manipulator in a portable package the size and shape of an ordinary notebook” which would allow children to explore, create and share dynamic games and simulations (Kay, 1972). This project led to the development of personal computing and can be considered

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an enduring success of research in technology-enhanced learning. However, early innovations were desktop based, and only over the past 10 years has mobile learning developed as a set of significant projects in schools, workplaces, museums, cities and rural areas around the world. These projects range from providing revision questions to children by mobile phone (BBC Bitesize Mobile¹), through small group learning in classrooms using handheld computers (Zurita & Nussbaum, 2004), to context-sensitive learning in museums and workplaces (Brugnoli, Morabito, Bo, & Murelli, 2007).

We are in an age of personal and technical mobility, where mobile devices, including phones, MP3 players and PDAs, are carried everywhere. We have the opportunity to design learning differently: linking people in real and virtual worlds, creating learning communities between people on the move, providing expertise on demand and supporting a lifetime of learning. In order to understand how people learn through a mobile, pervasive and lifelong interaction with technology, we need to understand the implications of learning with mobile technology and build an appropriate theory of education for the mobile age.

The Kaleidoscope Network of Excellence has made a substantial contribution to exploring the issues arising from learning with mobile technology. In June 2006, a workshop at Nottingham, United Kingdom, brought together leading European researchers to explore six major issues of theory, design and evaluation. The workshop, and its subsequent report on Big Issues in Mobile Learning (Sharples, 2007), sparked a discussion that has continued through the Kaleidoscope Mobile Learning Special Interest Group (SIG).

This chapter explores these issues under three broad themes: “what is mobile learning”, “designing mobile learning” and “evaluating mobile learning”. It also discusses mobile learning projects, within the context of these themes, to exemplify the range of European research in the field as well as to identify issues and challenges that mobile learning presents for education and technology design.

14.2 What Is Mobile Learning?

There is little to connect delivery of location-based content on mobile telephones with group learning through handheld computers in the classroom, apart from a reliance on handheld devices, so early definitions of mobile learning were anchored on the use of mobile technology:

It's elearning through mobile computational devices: Palms, Windows CE machines, even your digital cell phone (Quinn, 2000).

The focus on technology does not assist in understanding the nature of the learning and overlooks the wider context of learning as part of an increasingly mobile lifestyle. While discovering a city during a vacation a tourist might learn

¹ <http://www.bbc.co.uk/schools/gcsebitesize/mobile/>

from a travel Internet site on a home desktop computer, a phone conversation to a friend who visited the city, an in-flight travel magazine and promotional video, a Google map of the city on a mobile phone, an interactive multimedia guide in the tourist information office, printed brochures and handheld audio guides in the tourist locations. It is the combined experience that constitutes mobile learning. In trying to unpack the “mobile” in mobile learning one finds

- *Mobility in physical space*: people on the move trying to cram learning into the gaps of daily life or to use those gaps to reflect on what life has taught them. The location may be relevant to the learning, or merely a backdrop.
- *Mobility of technology*: portable tools and resources are available to be carried around, conveniently packed into a single lightweight device. It is also possible to transfer attention across devices, moving from the laptop to the mobile phone, to the notepad.
- *Mobility in conceptual space*: learning topics and themes compete for a person’s shifting attention. A typical adult undertakes eight major learning projects a year (Tough, 1971), as well as numerous learning episodes everyday, so attention moves from one conceptual topic to another driven by personal interest, curiosity or commitment.
- *Mobility in social space*: learners perform within various social groups, including encounters in the family, office or classroom context.
- *Learning dispersed over time*: learning is a cumulative process involving connections and reinforcement amongst a variety of learning experiences (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003) across formal and informal learning contexts.

Research into mobile learning is the study of how the mobility of learners augmented by personal and public technology can contribute to the process of gaining new knowledge, skills and experience.

The following section presents theoretical foundations of mobile learning informed by a series of discussions amongst members of the Kaleidoscope Philosophy of Technology-Enhanced Learning SIG and by their detailed written responses to a series of publications (Sharples, Taylor, & Vavoula, 2005; Taylor, Sharples, O’Malley, Vavoula, & Waycott, 2006) resulting in an attempt to formulate a theory of learning for the mobile age (Sharples et al., 2007).

14.3 Theoretical Foundations of Mobile Learning

The theoretical foundations of mobile learning presented here summarize and extend the account published in Sharples et al. (2007). It places mobility and context as the objects of analysis. Rather than assuming that learning occurs within a fixed location, such as a classroom, over a bounded period of time, it examines how learning flows across locations, time, topics and technologies. The strategies and opinions formed in childhood influence the way we come to understand in later life.

Learning undertaken in one context, for instance informal discussions, can become a resource for other contexts, such as a seminar or a workplace. Learning activities and the technologies used to enact them are interleaved enabling us to maintain our long-term projects and our familiar personal devices, while also picking up incidental ideas and ready-to-hand tools, as we proceed through the day.

Context is a central construct of mobile learning. It is continually created by people in interaction with other people, with their surroundings and with everyday tools. Traditional classroom learning is founded on an illusion of stability of context, by setting up a fixed location with common resources, a single teacher, and an agreed curriculum which allows a semblance of common ground to be maintained from day to day. But if these are removed, a fundamental challenge is how to form islands of temporarily stable context to enable meaning making from the flow of everyday activity.

Following Dewey (1916), Pask (1976) and Stahl (2003) we propose that the fundamental processes by which we come to understand the world and our knowledge of it are exploration, conversation and collaborative knowledge building. Thus, we make distinctions between elements of experience (hot/cold, friendly/unfriendly, freedom/authority) which we label, explore and discuss with ourselves, as we refine our knowledge, and with others, as we move towards agreed understandings by shared discovery and discussion.

Exploration is essentially mobile in that it either involves physical movement or movement through conceptual space, linking experiences and concepts into new knowledge. Conversation is the bridge that enables learning within and across contexts, whether through a discussion that builds on ideas formed in different settings or from a phone call between people in different locations or by making a note to oneself that can be read at a different time or place.

One role of technology in these explorations and conversations is to form a distributed system of meaning making that promotes collaborative knowledge building. At a first level of analysis we shall make no distinction between people and interactive technology, instead examining how the human–technology system enables knowledge to be created and shared in a continual process of coming to know through the construction and distribution of shared external representations of knowledge. For example, Wikipedia is a massively distributed system for the construction of shared meaning out of differing perspectives and opinions. The technology of Wikipedia does not stand apart as a medium of inscription, rather it is an active participant in the process, enabling certain forms of activity and constraining others.

Proposing symmetry between people and technology, however, raises tensions concerning the legitimate place of technology in learning and the privileged role of human knowledge and activity. These demand further exploration to claim a central role for the teacher and learner and to determine the ethics of mobile learning in matters such as who owns the products of conversational learning (online discussions, Wikipedia pages, etc.) and what are peoples' rights to be free from continual engagement with educational technology. Technology can become a constant companion and guide to learning; it can also continually monitor activity so that

our every movement and conversation is stored and assessed as part of a lifelong record of achievement. If learning is continually mobile and evolving then it is also continually provisional. How can we distinguish between the intimacy of coming to know and the need to publicly record and register our attainments?

So, we come to a characterization of mobile learning as the processes (personal and public) of coming to know through exploration and conversation across multiple contexts, amongst people and interactive technologies. This analysis is not at odds with learning as a tool-mediated sociocultural activity (Engeström, 1996). Indeed, it draws on this conception to examine how knowledge is constructed through activity in a society that is increasingly mobile. Nor does it negate learning in formal settings. Conversation and context are essential constructs for understanding how mobile learning can be integrated with conventional education. Mobile learning offers new ways to extend education outside the classroom, into the conversations and interactions of everyday life.

14.4 Designing Mobile Learning

A central task in the design of technology for mobile learning is to promote enriching conversations within and across contexts. This involves understanding how to design technologies, media and interactions to support a seamless flow of learning across contexts, and how to integrate mobile technologies within education to enable innovative practices. To this end, much can be learnt from interaction design research (e.g. Jones & Marsden, 2006), which offers general principles for human–computer interaction on mobile devices. Furthermore, findings from mobile learning research (Naismith & Corlett, 2006) suggest the need to

- Create quick and simple interactions;
- Prepare flexible materials that can be accessed across contexts;
- Consider special affordances of mobile devices that might add to the learner experience (e.g. the use of audio or user anonymity);
- Use mobile technology not only to “deliver” learning but to facilitate it, making use of the facilities in current mobile devices for voice communication, note taking, photography and time management.

The design of mobile learning activities should be driven by specific learning objectives. The use of (mobile) technology is not the target but rather a means to enable activities that were otherwise not possible, or to increase the benefits for the learners. Thus, the use of mobile technologies may only be suitable for part of the activity, with other parts being better supported by other technologies, or by no technology at all (as exemplified in our case studies).

A design challenge is to enrich the learning conversations and enhance the learner experience without interfering with it (Beale, 2007). Attention is a key issue. Having to change the focus of attention from the surrounding world to a handheld device can at best be distracting and at worse dangerous (such as the hazard of walking while

gazing at the screen). To counter this, authors report the benefits of short audio presentations to enhance or interpret the surroundings, for instance by telling the story behind a museum exhibit or tourist site (see, e.g. Bradley, Haynes, & Boyle, 2005; Naismith, Sharples, & Ting, 2005).

Technology is not always used for the activities originally intended. Young people are appropriating technology designed for adult work (e.g. SMS messaging and media file sharing) into their social world. This has deep implications for learning, if we consider, for example, why people would need to memorize facts when they can look them up on Google. What are the implications for copyright, authorship and plagiarism when young people can easily capture, share and publish their own experiences, and those of others, as they go about their daily lives? Until recently, instant messaging, file sharing and social networking have been mainly restricted to home computers and Internet cafes; however, countries such as South Korea (Consumer Ease Publishing, 2006) have already adopted mobile networking and the next generation of personal devices will support collaboration and context awareness. An issue for schools is how to accommodate children equipped with powerful personal technologies and new and disruptive skills of informal collaboration and networked learning.

According to Reigeluth (1999), an instructional design theory offers explicit guidance on how to help people learn and develop. Though an instructional design theory for mobile learning is yet to be articulated, the theoretical foundations of mobile learning previously discussed suggest mobile learning instructional design should

- Support learners to reach personal understanding through conversation and exploration;
- Support learners' collaboration in order to construct common knowledge;
- Use technology to enrich learners' collaborative knowledge building with other learners and teachers;
- Support learners' transitions across learning contexts.

Naismith and Corlett (2006) identify five critical success factors for mobile learning projects:

1. *Access to technology*: making mobile technology available where and when needed, either by developing for users' own devices (e.g. phones and media players) or by providing learners with devices they can use at home and on the move.
2. *Ownership*: owning the technology, or treating it *as if* it were our own. Using the technology for entertainment and socializing does not appear to reduce its value as a learning tool, but rather helps to bridge the gap between institutional and personal learning.
3. *Connectivity*: using wireless or mobile phone connectivity, to provide access to learning resources, to link people across contexts and to allow students to capture material that can be sent to a personal media space and then shared or presented.

4. *Integration*: integrating mobile learning projects into the curriculum, the student experience or daily life. Strategies for achieving integration include extending a successful form of learning onto mobile devices (e.g. Frequently Asked Questions, or audio/PowerPoint recordings of lectures) and proving technology that augments the student experience (e.g. “moblogs” (mobile weblogs) to maintain an electronic portfolio or record of learning).
5. *Institutional support*: designing relevant resources in mobile format, training staff and providing technical support.

The above success factors were largely identified from observations of critical incidents in pilot projects. The following section addresses some issues and possible solutions to moving beyond an inventory of successes and failures towards a systemic evaluation of mobile learning.

14.5 Evaluating Mobile Learning

Evaluation is a central activity in the lifecycle of interactive systems design. When performed in the course of design and implementation, formative evaluation informs design. When performed after deployment of a new technology, summative evaluation offers a systematic approach to assess the effectiveness of the system and the learning it enables. Mobile learning poses additional challenges to the evaluation of both technology and learning. This section identifies challenges for mobile learning evaluation, outlines new tools and methods for the collection and analysis of mobile learning data and presents a framework for mobile learning evaluation.

- *Unpredictability of the context of use*: Evaluation methods for static technologies are based on the assumption that the context of use is fixed and well defined. In the case of mobile learning, however, the context of use can vary significantly, for instance, in terms of ergonomics (user posture, lighting and background noise), social context and demands on users’ attention. Moreover, mobile contexts of use are often impromptu and hence difficult to observe, predict or simulate.

The mobile environment is eminently suited to supporting learning outside the context of curricula, institutions and timetables. Our potential subjects of study may be wandering around studying things that interest them, at times that suit themselves, with little or no concern for consistency (Taylor, 2007, p. 26).

- *Unpredictability of the learning process*: Mobile learning blurs the distinction between formal and informal learning. Children have always been able to bring homework into the classroom for assessment or bring in a personal or found object, such as a leaf or a stone, to illustrate a lesson, but now they can systematically capture their experience of learning outside the classroom, through images, notes and audio recordings. Traditional assessment methods are not appropriate for accrediting learning not directly related to the curriculum or done through informal collaboration. Recognizing and assessing the value of non-curriculum learning raises profound issues related to the legitimate scope

of formal education. Where does school end? When can a child just delight in learning for its own sake without having to present the results for school assessment?

- *Unpredictability of the mode of use:* Technology for mobile learning is designed to aid the practice of learning; however, this same technology may also change and affect practice. The way a technology will be used cannot be determined until it is actually used by real people in real settings. Often the way people adopt learning technologies does not coincide with the designer's intent. Tools that enable users to do new activities may change the way users perceive and practice old activities and may give rise to additional unpredicted patterns of learning. An essential task of evaluation is to look at how new tools and services are appropriated by people in their everyday learning practice (Waycott, 2004).
- *Looking beyond the "wow" effect:* Evaluations of mobile learning often report on the users' enjoyment and increased motivation. Through the Kaleidoscope SIG, Jones, Isroff, and Scanlon (2007) have initiated a discussion on the role of affect in mobile learning. They propose that the high affective value of mobile learning is influenced by factors such as control over goals, ownership, fun, communication, learning-in-context and continuity between contexts. Specifying the attributes that make mobile devices "cool" for learning and understanding how best to exploit these also require further investigation. Thus, mobile learning evaluation should attempt to see beyond the initial "wow" factor associated with the technology and investigate how effective is mobile technology in engaging learners over the longer term.

We argued earlier that supporting mobile learning requires supporting people to continue their learning conversations across contexts. Hence, mobile learning evaluation should explore how well these conversations and transitions are supported and their consequences for learning and assess the impact of these technologies on previously established learning contexts and practices.

The challenges mentioned above indicate the difficulties in addressing data collection, analysis and assessment of learning outcomes in mobile learning. Responding to this, researchers are exploring new tools and methods for the collection and analysis of data, research methodologies and approaches suitable for interpreting such data and issues in designing mobile learning research (Vavoula, Kukulska-Hulme, & Pachler, 2007).

New data collection methods include mobile eye tracking (Wessel, Mayr, & Knipfer, 2007), co-design (Spikol, 2007) and data mining of automatically generated data logs (Romero & Ventura, 2007). Combinations of conventional data collection methods are also explored (Smith et al., 2007; Wali, 2007). Theoretical frameworks such as activity theory inform the development of new analysis tools (Papadimitriou, Tselios, & Komis, 2007), while informal learning assessment techniques, like Personal Meaning Mapping (Falk, 2003; Lelliott, 2007) and e-Portfolios (Hartnell-Young & Vetere, 2007), are being considered for assessing mobile learning outcomes.

Evaluation should be a continuous process starting with the inception of a project and continuing on through design, implementation, deployment and beyond. Within the context of the MyArtSpace project (see Section 14.6.1) we have developed a three-level framework for mobile learning evaluation (Centre for Educational Technology and Distance Learning, 2007). It extends the lifecycle evaluation method (Meek, 2006) which places evaluation at the centre of the technology development process from the start of the design process to the final assessment of the technology in a learning context and providing clear routes for feeding evaluation outcomes into (re)design.

The mobile learning evaluation framework structures the evaluation planning around general goals for assessing *usability*, *educational effectiveness* and *overall impact*. More specifically, it comprises three levels:

1. *Micro level*, which examines the individual activities of the technology users so as to identify issues of usability and assess how effective, efficient and satisfying is the user's experience of carrying out the individual activities supported by the technology.
2. *Meso level*, which examines the learning experience as a whole to assess the educational value of the new technology by looking at how it transforms the educational and learning practice in terms of breakthroughs and breakdowns and how well the learning experience integrates with other learning experiences.
3. *Macro level*, which examines the overall, longer-term impact of the new technology on established learning and teaching practices by exploring the extent to which the deployed technology matches initial aspirations, intentions and expectations.

Evaluation activities at each level require a gradual introduction in that, for instance, the meso level requires that the technology is in place and is robust enough to allow assessment of the learning and teaching experience and its educational value. Thus, evaluation activities at the meso level cannot be introduced until well into the implementation phase. Similarly, the macro level requires that the technology is in place and used for long enough to establish its effects on learning practice, so evaluation activities at the macro level cannot be introduced until well into the deployment phase.

14.6 Mobile Learning Exemplars

This section presents three exemplars of mobile learning that show how children can be helped to explore the physical environment, how learning can be supported across contexts, how handheld technology can enable conversations for learning and how new methods of evaluation can reveal the practices and outcomes of learning outside traditional settings.

14.6.1 MyArtSpace: Learning with Phone Technology on Museum Visits

MyArtSpace project was a year-long project funded by the United Kingdom Department for Culture Media and Sport to develop and evaluate mobile technology for school students on field trips to museums and art galleries. It has been deployed in three museums for a year-long trial during which over 3000 school students used the service, on organized visits from local schools. The aim of the project was to address a well-recognized problem (Guisasola, Morentin, & Zuza, 2005) of the lack of connection between the school visit and any preparation and follow-up in the classroom.

MyArtSpace supported learning through explorations and conversations across the contexts of classroom and museum. It enabled students to produce their own interpretation of a visit through pictures, voice recordings and notes that they can share and examine back in the classroom. The activity typically starts with the teacher introducing a “key topic” in a pre-visit classroom lesson to guide and motivate the students in a process of inquiry-led learning during the trip, as they collect and interpret evidence to address the question.

On arriving at the museum, the students are loaned multimedia phones running a Java application that allows them to capture photos, notes and audio recordings. These are sent automatically via the GPRS phone network to a personal web site that provides a multimedia “weblog” of the visit. The students can also view short presentations on museum exhibits by typing in a two-letter code shown beside the exhibit which are also recorded in the weblog. Back in the classroom, they can view the material they collected and produced during the visit, as well as the other students’ collections and further material provided by the museum. They then use a basic presentation tool to add captions to the images and to form the material into individual or shared presentations that form their responses to the key topic.

The evaluation methods included one-to-one interviews with the teachers; focus group interviews with students; video observations of the pre-visit lesson, museum visit and post-visit lesson; attitude surveys; and telephone or e-mail interviews with other stakeholders. Three MyArtSpace visits were observed, of a first prototype and in months 1 and 11 of the year-long deployment. In general, the system worked well, with the phones offering a familiar platform, the two-letter code providing an easy way to activate multimedia in context and the transmission of data taking place unobtrusively after each use of the photo, audio or note tool. The teachers indicated that their students engaged more with the exhibits than in previous visits and had the chance to do meaningful follow-up work.

A significant educational issue was that some students found difficulty in identifying, back in the classroom, pictures and sounds they had recorded. The time-ordered list of activities and objects they had collected provided some cues, but there is a difficult trade-off between structuring the material during the visit to make it easier to manage (for example, by limiting the number of items that can be collected) and stifling creativity and engagement.

Although the system was a success at the technical and educational levels, there is a significant impediment to wider deployment of a system like MyArtSpace. Understandably, museum staff needs to spend their time curating exhibits and guiding visitors rather than maintaining technology. There is also the issue of who pays for the GPRS charges: schools, museums or students and their parents? MyArtSpace may be an indicator of the next generation of mobile technology, when people carry converged phone/camera/media player devices that can capture everyday sights and sounds to a personal weblog. Then, the opportunity for schools will be to exploit these personal devices for learning between the classroom and settings outside school including field trips and museum visits.

14.6.2 The AMULETS Project: Bridging Outdoor and Indoor Classroom Activities Using Smartphones, PDAs and GPS Devices

The AMULETS (Advanced Mobile and Ubiquitous Learning Environments for Teachers and Students) project explored how to design, implement and evaluate innovative educational scenarios combining outdoor and indoor activities supported by mobile and ubiquitous computing. AMULETS is based on the premise that the design of innovative mobile learning activities should be guided by collaborative learning scenarios in context supported by mobile and ubiquitous technologies in authentic settings. The results of two trials conducted with Swedish children since the spring of 2006 illustrate these ideas.

The first trial took place in June of 2006 in an elementary school while the second trial occurred the following December, in the town square with the same school. For these two trials, 55 elementary school children performed remote and co-located activities equipped with smartphones, PDAs, GPS devices and stationary computers in the subjects of natural sciences, history and geography. The educational scenarios consisted of different stages with game-like features. At the end of the learning sessions, all these activities were reconstructed in the classroom using several visualization tools such as digital maps. These types of activity provide new opportunities for children and teachers to review and to continue the learning experience in the classroom, thus supporting different aspects of learning such as exploration, discussion, negotiation, collaboration and reflection.

In the first trial the theme of the scenario was learning about “the forest” and in the second trial “the history of the city square through centuries”. In the forest scenario 26 4th grade students (10–11 years old) took part, working in 7 groups. The activities were conducted over a 2-day period with only one group performing at a time. The active challenges for the children were based on exploring the physical environment, identifying different types of trees and measuring the height and age of trees. Part of the children’s tasks was to record still images and video clips using the smartphones detailing how they solved the problems. This co-created content was automatically encoded with metadata, containing attributes such as GPS

coordinates, time stamp and the phone ID which provided rich contextual information for later use in the classroom. Pedagogical coaches provided the children with practical support in using techniques to measure the height of trees. Additionally, animated characters delivered location-specific content.

In the city square trial 29 5th grade students (11–12 years old) participated. They worked in three groups, with each group divided into two subgroups of five students. One subgroup worked in the local museum and the second group operated outside in the square. For this second trial we introduced collaborative missions to provide the children with challenging problems. In order to solve them, children at the museum and outside were required to collaborate using a number of mobile tools including an instant text messaging system that allowed communication between stationary computers at the museum and the smartphones outside it. A narrative journey backwards in time relating to the square's history was supported by animated characters and video clips delivered to the smartphones, thus providing the contextual information that was needed in order to accomplish the challenges in the different missions.

In order to assess the result of our efforts, we used several techniques for data collection including questionnaires and interviews with the children, students and teachers, as well as observation protocols and data-stored files. The questionnaires were used mostly to evaluate usability aspects, while the interviews with children, students and teachers were used to evaluate the educational aspects of the trial. The results of our trials indicate that children were open and positive when it comes to using mobile and ubiquitous technologies in everyday learning activities, especially when they can be used in playful ways. Another interesting indication from the analysis of our results is that the context in which the learning activity takes place impacts the way children interpret and deal with information. Our results also indicated that innovative learning activities enhanced by ubiquitous technologies should not be regarded as stand-alone activities, as they should be part of a well-developed educational flow that also is combined with traditional ways of teaching and learning. Kurti, Spikol, and Milrad (2008) provide an elaboration of these results.

As mentioned earlier in this chapter, mobile and ubiquitous technologies offer the potential for a new phase in the evolution of technology-enhanced learning, marked by a continuity of the learning experience across different learning contexts. Chan and colleagues (2006) use the term “seamless learning” to describe these new situations. In this section we have presented two examples in which we have implemented seamless learning spaces by augmenting physical spaces with information exchanges as well as using geospatial mappings between the mobile device and the real world that facilitate navigation and context-aware applications.

14.6.3 The Mobile Digital Narrative: Collaborative Narrative Creation with Mobile Phone Technology

The mobile Digital Narrative (mobileDN) project (Arnedillo-Sánchez & Tangney, 2006) embodies an approach to support collaborative creativity with mobile

technologies. It involves the creation, from idea generation to final production, of a collective multimedia DN shot entirely on mobile telephones by a group of distributed learners.

The project builds on work in digital filmmaking (DFM) in schools (Burden & Kuechel, 2004) and a functional framework for mobile learning which argues for collaborative, constructionist and contextual applications (Patten, Arnedillo-Sánchez, & Tangney, 2006). While DFM facilitates communication, negotiation, decision-making skills (Burn et al., 2001), encourages creativity (Reid, Burn, & Parker, 2002) and draws on students' out-of-school interest (Parker, 2002), access to technology and time investment hinder its adoption in schools (Arnedillo-Sánchez & Tangney, 2006). Furthermore, technology-dependent activities such as filming and editing, which offer the greatest learning benefits (Becta, 2003), become impractical as a whole group activity (Arnedillo-Sánchez & Tangney, 2006).

The mobileDN process was designed and developed iteratively by conducting a series of case studies with 78 users, including teenagers and undergraduates in Ireland and South Africa. It utilizes camera phones, a notebook computer, a concept-mapping tool to scaffold the story creation, a movie editor to assemble the DNs and a portable data projector to enable the collaborative editing process. Our "knapsack lab" provides enormous flexibility in terms of where a mobileDN workshop can take place.

After collaborative face-to-face generation of the story, scaffolded by the concept-mapping tool and a facilitator, the learners are divided into three groups: image (in charge of "shooting"), sound (in charge of recording dialogues and sound effects) and editing (in charge of assembling the "film"). With the "script" (concept-map) in hand, the image and sound groups separately go on location, while the editing group stays at the editing station. As the media is being captured this is transferred via MMS to the editors who start editing shortly after the crews arrive on location. When crew and cast are back in the editing station, the first version of the DN is ready for viewing. The initial shooting and editing phase is followed by additional "targeted" shooting and recording as required. Final editing and production take place face-to-face as a whole group activity.

Over a period of 2 years 36 DN workshops with over 200 participants, including young children, teachers, teenagers, postgraduate students and researchers, have been conducted. Data collection tools used include video recording, observation and interviews. Data sets comprise the video footage, interviews, the researcher's journals, the scripts and media assets created by the learners, the DNs at different stages of production and the final DNs. Findings show that the approach tackles issues of access to technology and time investment reported in traditional DFM projects. All the participating groups have been able to create a DN, from idea generation to final production, in approximately 4 hours. The work flow, structure and labour division designed in the mobileDN methodology, together with the affordances of mobile technologies, enable the parallelization of shooting and editing supporting synchronous collaboration. Participants experience the benefits of lengthier DFM processes, and teachers reported that it is practical, hands-on learning. The activity enables rich conversations across contexts as the participants negotiated how the

images and sounds captured on location could best be assembled together to convey narrative intent.

Technical problems include MMS transfer latency and the cumbersome use of multiple disparate applications. We are addressing these by developing a DN application (Arnedillo-Sánchez & Byrne, 2007) (mobile and PC versions) that seamlessly supports the process and automates media management and transfer. Cost issues are being addressed by providing alternative data transfer mechanisms. We propose the mobileDN method as a viable alternative to DFM in schools. The project, alike others that avail of readily available and affordable mobile technology, presents a cost-effective solution that can contribute towards the democratization of technology-enhanced learning experiences.

14.7 Conclusions

Ten years of research into mobile learning has revealed no single “killer application” for mobile technology in learning, but has offered promising scenarios such as the use of graphing calculators and handheld response systems in classrooms, the use of PDAs to structure small group working, handheld tools for basic learning including foreign language and numeracy skills, handheld tourist guides and those described in the exemplars.

A more general consequence of the research into mobile learning has been an open debate about the nature of learning within and outside the classroom. Focusing on the mobility of learners and learning reveals assumptions and tensions in technology-enhanced learning (TEL). Until now, most research into TEL has assumed that learning occurs in the classroom, mediated by a trained teacher. Even iconoclasts such as Papert saw technology as a means to reform and extend school education (Papert, 1980). Yet, this has implicitly excluded the design of technology for informal and serendipitous learning.

One major opportunity is to support a person through a lifetime of learning, providing young children with tools to capture and organize their everyday experiences, to create and share images of their world and to probe and explore their surroundings. As they mature, these “life blogs” can be extended with tools to support personal projects, such as learning languages, sports and hobbies. In old age, they become storehouses of memories and aids to remembering people and events. Such technology is not only a technical challenge (e.g. maintaining and organizing a useful database of experience over a lifetime) but it also raises deep philosophical, social and ethical issues. Will the technology become a seamless extension of human cognition and memory? What experiences will people want to capture, and how will they erase them? What is the legitimate sphere of parents, formal education and the state in managing and assessing children’s mobile learning?

Tensions are already arising between the two spheres of traditional context-bound education and informal mobile learning. A future scenario portrays schools being unable, or unwilling, to adapt to the new patterns of learning and social interaction

outside the classroom and young people seeing school learning as irrelevant to their skills and interests. At the heart of the conflict is the technology. Schools currently ban powerful tools for personal learning and social networking while they struggle to provide computers that deliver an outdated form of didactic teaching. A very different future scenario depicts formal education adapting to the new technologies and opportunities, with children learning how to adapt their social networking practices to the school environment, supported by tools for teamwork and collaborative learning. Schools will save costs by allowing students to bring their own technologies and will gain from building on students' skills of networked learning. As converged computer/phones become standard consumer products they will bridge the "digital divide" and schools will be able to afford additional devices for children who do not own them.

These future scenarios should not be determined solely by commercial or social forces. The mobile learning research community has already played a major role in defining the scope of the field and providing exemplars of successful, and unsuccessful, applications of learning with mobile technology. Kaleidoscope has set an agenda for research into the co-evolution of learning and technology that is not merely a response to the pressures of society, governments and the technology industry, but an attempt to shape a more expansive and inclusive landscape of learning.

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Chapter 15

Learning from Multimedia and Hypermedia

Peter Gerjets and Paul Kirschner

Abstract Computer-based multimedia and hypermedia resources (e.g., the world wide web) have become one of the primary sources of academic information for a majority of pupils and students. In line with this expansion in the field of education, the scientific study of learning from multimedia and hypermedia has become a very active field of research. In this chapter we provide a short overview with regard to research on learning with multimedia and hypermedia. In two review sections, we describe the educational benefits of multiple representations and of learner control, as these are the two defining characteristics of hypermedia. In a third review section we describe recent scientific trends in the field of multimedia/hypermedia learning. In all three review sections we will point to relevant European work on multimedia/hypermedia carried out within the last 5 years, and often carried out within the Kaleidoscope Network of Excellence. According to the interdisciplinary nature of the field this work might come not only from psychology, but also from technology or pedagogy. Comparing the different research activities on multimedia and hypermedia that have dominated the international scientific discourse in the last decade reveals some important differences. Most important, a gap seems to exist between researchers mainly interested in a “serious” educational use of multimedia/hypermedia and researchers mainly interested in “serious” experimental research on learning with multimedia/hypermedia. Recent discussions about the pros and cons of “design-based research” or “use-inspired basic research” can be seen as a direct consequence of an increasing awareness of the tensions within these two different cultures of research on education.

Keywords Multimedia · Hypermedia · Learner control · Use-inspired basic research · Design research

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15.1 Introduction

Multimedia, both as “thing” and as “term”, is not really new. The *Velvet Underground*, an avant-garde group formed by Andy Warhol, first used the term in 1965 to describe a combination of live music, cinema, experimental lighting, and performance art. Multimedia is generally defined as a set of external representations using multiple forms of coding (e.g., text and pictures) and/or modality (e.g., visual and auditory) to inform (e.g., in education and/or training), and/or to entertain (e.g., in art and theater) an audience (cf. Mayer, 2005). In the context of this chapter, multimedia will refer to the use of electronic tools and media to store, present, transmit, and experience multimedia content such as when a computer is used to represent and present information through audio, graphics, image, video, and animation in addition to traditional media (printed text and graphics).

Hypermedia can be considered to be a specific multimedia application. This term, too, finds its origin in 1965 when Nelson used it as an extension of the term hypertext to denote a situation where

graphics, audio, video, plain text and hyperlinks intertwine to create a generally non-linear medium of information. This contrasts with the broader term multimedia, used to describe non-interactive linear presentations as well as hypermedia (<http://en.wikipedia.org/wiki/Hypermedia>).

Thus, the term hypermedia refers to the idea that multimedia materials are organized as network-like information structures, where fragments of information are stored in nodes that are interconnected and can be accessed by electronic hyperlinks (Conklin, 1987; Rouet, Levonen, Dillon, & Spiro, 1996). According to the definitions used in this chapter, control over the order and selection of information in multimedia learning environments is mainly established by the system, whereas hypermedia environments are capable of being explored (and thus controlled) by learners in multiple ways.

At the time of this writing, multimedia and hypermedia have permeated our culture. Many websites, especially those sites making use of Web 2.0 applications such as the blogsite *MySpace*® and the video sharing site *YouTube*®, allow their users to upload, view, share and use graphics, audio, video, plain text, and hyperlinks to other sites and contents to create enormous communities of users. Most websites for commercial enterprises use multimedia and hypermedia to advertise their products and services. Education, too, is making increasing use of multimedia. Today, computer-based multimedia resources, and particularly the world wide web (WWW), are one of the primary sources of academic information for a majority of pupils and students (Lenhart, Simon, & Graziano, 2001). In line with this expansion in the field of education, the scientific study of learning from multimedia and hypermedia has become a very active field of research for scholars interested in cognition and instruction (for overviews see Mayer, 2005; Rouet, 2006; Scheiter & Gerjets, 2007).

The aim of this chapter is to discuss recent developments and trends in research on multimedia and hypermedia learning. Here we distinguish between work that

directly focuses on learning from multimedia or hypermedia, from a psychological, pedagogical, technological, or even practical perspective, and other work in which this is important but not the core focus of research. The latter type of work uses multimedia and hypermedia environments as a technological context to investigate their pivotal issues such as collaborative learning, participatory design, or educational formats.

The remainder of this chapter comprises three related review sections. In the first two sections, we review the educational benefits of multiple representations and of learner control, as these are the two defining characteristics of hypermedia. In the third section, we describe recent scientific trends in the field of multimedia/hypermedia learning. Within the review sections we will point to relevant European work on multimedia/hypermedia carried out in the context of the Kaleidoscope Network of Excellence. According to the interdisciplinary nature of the network this work might come not only from psychology but also from technology or pedagogy. Our overview will focus on contributions made to the community in the last 5 years and will discuss how these contributions relate to cognitive-instructional research activities on multimedia and hypermedia that have dominated the international scientific discourse in the last decade. In doing so, we propose comparisons with regard to research issues and research methods as well as with regard to their concern for serious educational settings and valid research outcomes.

15.2 Multimedia Learning and the Benefits of Multiple Representations

Research on learning from multimedia has its roots in experimental studies of human memory and cognition and in research on the use of adjunct aids for learning and instruction, both starting in the 1960s and 1970s. The classical model of memory developed in the 1960s assumed that all memories pass from a short-term, working memory to a long-term store after a small period of time. External stimuli enter a sensory memory and if they are attended to, they are encoded and “passed on” to short-term memory (Atkinson & Shiffrin, 1968). Most cognitive scientists believe that the storage capacity of the long-term memory is unlimited and is a permanent record of everything that you have learnt.

A problem, especially for instructional purposes, is that the working memory is limited to holding about seven items or elements of information (Miller, 1956) at any one time for about a maximum of about 20 seconds. However, working memory is seen not as a monolithic structure, but rather as a system embodying at least two code-specific sub-components: a visuo-spatial sketchpad for pictorial information and a phonological loop for verbal information, both of which are coordinated by a central executive (Baddeley, 1999). This distinction provides a theoretical rationale for using different ways of coding multimedia instruction. Both assumptions, namely the severe limitation of working memory and the code-specific substructures of working memory are the core of many accounts on how to improve

multimedia instruction. The most prominent examples are Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2001) and Sweller's Cognitive Load Theory (Sweller, 1999; Sweller, van Merriënboer, & Paas, 1998).

Research on the use of adjunct aids for learning and instruction also has its roots in the 1960s and 1970s and roughly coincides with the paradigm shift in psychology from behaviorism to cognitivism. One of the first researchers in this respect was Ausubel (1962, 1968) who advanced a theory contrasting meaningful learning with rote learning. To support meaningful learning he proposed using advance organizers that can be used by the learner to actively tie new knowledge to their existing cognitive schemas. Shortly thereafter, Rothkopf (1970) advocated the idea that learning depends less on what teachers or instructional designers plan or want to happen in learning situations than on what the learners themselves actually do. Central to this idea is that what actually occurs is

a matter of choice on the part of the student. In relevant circumstances, students choose whether they will pay attention in lectures, read assignments, or review what has previously been read; rarely are these activities the only ones available (Rhodes, 1993, p. 6).

These two strands of research paved the way for modern-day research on multimedia in education and learning. For instance, it is usually assumed that the major advantages of multimedia environments over materials that use only a single representational format (e.g., text) relate to the fact that these environments allow learners to pool cognitive resources for learning (i.e., cognitive structures and processes) and that they facilitate and/or afford suitable learner activities. Based on memory research, many authors claim that verbal and non-verbal representations are encoded and stored in different subsystems of short-term, working memory, and long-term memory (Baddeley, 1999; Kosslyn, 1994; Paivio, 1991). Whereas verbal representations result in a propositional representation, non-verbal representations such as visualizations are encoded and stored in an analogical format. Thus, multimedia materials allow addressing different memory systems thereby potentially enhancing learning. With regard to learner activities, it has been suggested that visualizations compared to verbal representations facilitate specific cognitive processes and are thus more computationally efficient for accomplishing tasks that make use of these processes (Larkin & Simon, 1987; see also cognitive offloading, Scaife & Rogers, 1996). Thus, combining verbal and pictorial information increases the available set of cognitive processes that can be brought to bear for learning. Additionally, as has been emphasized by Ainsworth (1999) in her functional taxonomy of multiple representations, the combination of different types of representations may serve different roles that may be essential for knowledge acquisition – even if the representations used are informationally equivalent. She categorizes these roles into three groups: Visual and verbal representations may fulfill complementary roles in instruction (e.g., by facilitating different cognitive processes). Additionally, they can constrain interpretation and guide learners' reasoning about a domain. Finally, visual and verbal representations might be suited to foster a deeper understanding than could be achieved by means of just one representational format. Thus, whenever any of these functional roles can contribute to learning, representing redundant

information visually as well as verbally may be advised according to Ainsworth's taxonomy. In sum, there are some clear arguments and guidelines describing how to use multimedia materials for instruction that can be based on cognitive analyses.

In recent years the interaction between a learner's internal and external representations in multimedia environments has become an active field of research addressing how learners develop their internal knowledge representations in cases where they (a) perceive external multimedia representations of knowledge, (b) interact with technological artefacts, and/or (c) collaborate to co-construct knowledge (cf. Demetriadis, 2004; see also Chapter 9). These research activities go beyond the issue of finding taxonomies for representations and their interrelationships such as Ainsworth's (1999) taxonomy based on the claim that multiple representations can complement and constrain each other and that they can be used to construct deeper knowledge or the approach of de Vries (2006) who provided classifications from a semiotic perspective. For instance, Demetriadis and Papadopoulos (2004) introduced the notion of representational density to reflect the fact that certain representations can contain more information compared to others and are, thus, denser. Their claim is that experienced learners can work and learn in environments with denser representations because they have developed adequate mental schemata that enable them to handle information from external representations in clusters, thus reducing the number of independent items that they need to process at each time in their limited working memory. Practically, this concept can be used to postulate that designing representations in an adaptable format may allow instructors to achieve an optimal coupling between the learner's internal abilities and the representational density in any specific context of instruction. Other researchers address the issue of using multiple representations in simulation environments (van der Meij & de Jong, 2004), and of investigating the interplay between internally and externally represented collaboration scripts (Kollar & Fischer, 2004; see also Chapter 10). There is also research that focuses on the idea that students' attitudes concerning the use of different media for learning vary and that information about these various stances should be taken into account by designers and educators to better integrate and use multiple representations (cf. Gerjets & Hesse, 2004).

15.3 Hypermedia Learning and the Benefits of Learner Control

Whereas multimedia environments are characterized by a system-controlled linear structure, hypermedia environments offer non-linear information access, where learners can select and sequence information according to their personal needs and preferences. When it comes to the additional instructional benefits of these learner-control options offered by hypermedia learning, the research literature is much more ambiguous (for an overview, see Scheiter & Gerjets, 2007). For instance, Kinzie, Sullivan, and Berdel (1988) found that by transferring the locus of control from the teacher to the student, intrinsic motivation to learn increased and more satisfaction was derived from the learning experience, ultimately leading

to improved academic performance. This finding has been backed up by other researchers who proposed that learner control might be an essential aspect of effective learning (Hannafin, 1984, Kohn, 1993; Lawless & Brown, 1997; Lou, Abrami, & d'Apollonia, 2001). Therefore, learner control is seen as a major advantage of hypermedia compared to more traditional forms of learning environments and is often seen as the defining feature of hypermedia (Shapiro & Niederhauser, 2004).

However, beyond the potential benefits, this representational and navigational freedom may cause problems when learners select suboptimal information diets (cf. Pirolli & Card, 1999) or become disoriented and cognitively overloaded (Conklin, 1987). Accordingly, there is a body of research (for an excellent review, see Williams, 1996) which shows that not all learners prefer nor profit from controlling the tasks (Carrier, 1984; Milheim & Martin, 1991), and that forcing such control on them can even hinder learning (Snow, 1980; Rasmussen & Davidson-Shivers, 1998). Merrill (1980), for example, concludes that college-level students generally do not make good use of learner-control options, a position also taken by Carrier (1984). And Snow (1980), a pioneer in Aptitude–Treatment Interaction research argued that far from eliminating the effects of individual differences on learning, providing learner control may actually exacerbate the differences. Finally, Salomon (1998; Salomon & Almog, 1998) refers to the “butterfly defect” of hypermedia in which the learner flits like a butterfly from hyperlink to hyperlink without either processing the information in depth or developing a proper search strategy.

That learner-control options provided by hypermedia might lead to more problems than benefits has also been demonstrated in our own research. We investigated in a series of experiments what degree of learner control is most beneficial for different types of learners (Gerjets, Scheiter, Opfermann, Hesse, & Eysink, in press). Most learners benefited from a rather structured learning environment. In another study we investigated the impact of learner characteristics on information utilization strategies, cognitive load, and learning outcomes in a hypermedia environment by means of a cluster analysis. The results showed that only learners with specific characteristics (i.e., higher prior knowledge, more complex epistemological beliefs, more positive attitudes toward mathematics, better cognitive, and metacognitive strategy use) displayed adaptive strategies of information utilization within the hypermedia environment.

However, it has to be kept in mind that “learner control is not unidimensional, but depends fundamentally on the nature of the decisions to be made” (Gall & Hannafin, 1994, p. 218). Thus, several aspects of learner control can be distinguished that might differ in how helpful or harmful they are for learning (cf. Lunts, 2002; Merrill, 1980). First, learners may be allowed to determine the order in which they would like to access different information units (i.e., sequencing). Second, learners may decide on which learning materials to receive (i.e., selection or content control) and third, they may decide on how a specific content should be displayed, for instance, by determining whether to represent it in a verbal or in a pictorial format (i.e., representation control). In addition to these three aspects of learner-control characteristic for hypermedia, a basic level of learner control can

be established by having learners decide over the pace of information presentation (pacing) such as by allowing learners to play, pause, stop, or replay dynamic representations (Wouters, Paas, & van Merriënboer, 2007). Pacing, however, is not limited to hypermedia, but can be found in many multimedia environments as well.

Beyond distinguishing between different types of learner control it has to be kept in mind that learner characteristics such as prior knowledge and metacognitive skills will likely play a moderating role with regard to the effectiveness of learner control in hypermedia environments (Azevedo, Cromley, & Seibert, 2004). For instance, there is accumulating evidence that learners with low levels of prior knowledge in comparison to learners with more favorable learning prerequisites have more difficulties in navigating hypermedia systems (e.g., Kelly, 1993; Last, O'Donnell, & Kelly, 2001; Lawless & Kulikowich, 1996; McDonald & Stevenson, 1998a; Mills, Paper, Lawless, & Kulikowich, 2002), apply superficial processing strategies (Chen & Ford, 1998), produce worse learning outcomes (Alexander, Kulikowich, & Jetton, 1994; Kraus, Reed, & Fitzgerald, 2001; Lawless & Brown, 1997; Lee & Lee, 1991; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Potelle & Rouet, 2003; Shin, Schallert, & Savenye, 1994; Shyu & Brown, 1992, 1995), and require more instructional support (Barab, Bowdish, & Lawless, 1997; Calisir & Gurel, 2003; de Jong & van der Hulst, 2002; McDonald & Stevenson, 1998a, b; Potelle & Rouet, 2003; Shapiro, 1999; Shin et al., 1994). A comprehensive overview on the different studies investigating the relationship between prior knowledge and hypermedia effectiveness is provided by Chen, Fan, and Macredie (2006).

15.4 Recent Trends in Multimedia/Hypermedia Learning

In this final review section we point to some more recent scientific trends in the field of multimedia/hypermedia learning. The nature of this work is very interdisciplinary therefore we will discuss trends that originated from psychology as well as developments that focus on issues from technology and pedagogy.

15.4.1 Developing Process-Oriented Models of Multimedia Learning

From a cognitive-psychology perspective, an important theoretical issue of recent concern is related to going beyond the currently dominant cognitive theories of instructional design for multimedia learning such as the Cognitive Theory of Multimedia Learning (Mayer, 2001) or the Cognitive Load Theory (Sweller, 1999). These theories emphasize the role of the human cognitive system and its architectural and resource limitations (e.g., limitations in processing channels, working memory, attention) and derive multimedia-design principles that describe in detail how different representational codes and sensory modalities may be effectively combined to foster media-based learning. These principles are usually tested

experimentally under typical laboratory conditions (i.e., system-controlled pacing of materials, low text complexity, homogenous group of students, immediate retention as performance measure), but rarely under conditions that are more akin to natural learning situations (e.g., classrooms, self-directed learning). It may be that some of the principles are less valid or might even reverse under more natural conditions (cf. Rummer, Schweppe, Scheiter, & Gerjets, 2008). This would occur because other variables, such as adaptive strategies or collaboration, become more important.

To overcome this, many theoretical attempts currently try to augment resource-oriented and principle-oriented approaches by developing more process-oriented models of how multiple external representations can be used to construct coherent mental models of learning contents. Research in this direction comprises the development of taxonomies for different representations and their relations as well as the use of eye tracking and neuroimaging to capture in detail what external stimuli learners pay attention to and what neural structures are involved in processing these different materials. By using the latter method a theoretical controversy has been developed on whether long-term memory structures can be characterized as non-modal and abstract representations (e.g., Anderson et al., 2005) or whether they essentially depend on the modality of the information presentation (e.g., Barsalou, Simmons, Barbey, & Wilson, 2003). Thus, the issue is whether multimedia learning merely affects the learning processes involved in acquiring a novel cognitive structure or whether multimedia also influences the type of cognitive structure acquired (cf. Kiefer & Spitzer, 2001).

15.4.2 Extending Multimedia Theories to Hypermedia

While theory-based design recommendations exist with regard to multimedia learning, there is hardly any such advice for hypermedia environments. We addressed this issue in our research by developing a conceptual extension of Cognitive Load Theory (Sweller, 1999) that focuses on the role of learner activities and allows the application of this theory to learner-controlled hypermedia environments (Gerjets & Scheiter, 2003; Gerjets & Hesse, 2004). Gerjets and Scheiter (2003) suggested that due to the fact that learners may exert control over instruction, the relationship between instructional design, cognitive load, and learning outcomes becomes far less deterministic in hypermedia learning as is assumed in Cognitive Load Theory (Sweller et al., 1998). To account for that, the augmented version of Cognitive Load Theory includes information utilization strategies as moderators; a recent update of this version by Gerjets and Hesse (2004) also incorporated learner characteristics as factors that may influence strategy selection. Empirical evidence for this enhanced version of the augmented Cognitive Load Theory was reported by Scheiter, Gerjets, Vollmann, and Catrambone (in press); the role of information utilization strategies was also demonstrated by Gerjets, Scheiter, and Schuh (2008). Finally, Gerjets et al. (in press) directly tested the assumption whether multimedia-design guidelines hold

for hypermedia and showed empirically that this is not the case. Therefore, it does not seem advisable to simply equate hypermedia with multimedia learning as suggested by Dillon and Jobst (2005), as both may comprise very different information utilization and processing strategies and require very different research agendas (cf. Scheiter & Gerjets, 2007).

15.4.3 Learning from Animations/Dynamic Visualizations

In recent years, instructional animations and other dynamic visualizations (e.g., digital video) have become a ubiquitous part of many hypermedia and multimedia environments. In line with that development, many researchers have suggested that embellishing textual instructional explanations with animations should lead to better outcomes than learning from text alone (cf. multimedia principle; Mayer, 2005). However, there is not much empirical evidence for that claim (for a review, see Tversky, Bauer Morrison, & Betrancourt, 2002). Therefore, several researchers have begun to investigate important design features of instructional animations (e.g., de Koning, Tabbers, Rikers, & Paas, 2007; Jeung, Chandler, & Sweller, 1997; Mautone & Mayer, 2001; Mayer & Chandler, 2001; Weiss, Knowlton, & Morrison, 2002; Wouters et al., 2007). In our own research we investigated several possible presentation formats for instructional animation. First, we investigated how verbal explanations that accompany animations should be designed with respect to the modality they are processed with. We found that auditory explanations are not always superior to written explanations as postulated by the so-called modality principle (cf. Mayer, 2005). According to our findings, the modality effect can only be observed for simultaneous text–picture presentations, but not for sequential presentations once longer text segments are used as experimental materials (Schüler, Scheiter, Gerjets, & Rummer, 2008). Second, we investigated whether to use a male or a female speaker for auditory explanations accompanying animations in a math domain. The results showed that learners achieved better learning outcomes when the explanations were presented by a female speaker rather than a male speaker irrespective of the learner's gender (so-called speaker/gender effect). Being given the choice, learners' preferred female speakers, but this individual preference had no direct impact on learning outcomes. As these results can be best explained based on gender stereotyping and processing of schema incongruent information, we suggest augmenting purely cognitive approaches to multimedia design by social-motivational assumptions (Linek, Gerjets, & Scheiter, 2008). Third, we studied in a biology domain whether the degree of realism may be a moderating factor with regard to the instructional effectiveness of animations. Contrary to our initial expectation that learning materials that are close to realistic situations should foster some aspects of learning we found that students learning from the realistic visualizations had worse outcomes on almost all measures and irrespective of their prior knowledge. This suggests that learners had been overwhelmed by the visual complexity of these visualizations (Scheiter, Gerjets, & Catrambone, 2006; Scheiter, Gerjets, Huk, Imhof,

& Kammerer, 2008). Fourth and in line with the latter argument we found in a math domain that so-called hybrid animations are particularly efficient learning aids. Hybrid animations start with an iconic representation of a concrete problem situation described in a word problem and subsequently morph the icons continuously into symbols, thereby excluding irrelevant surface features from the representation and highlighting the problem's structural features at the same time. Thereby, they reduce visual complexity and allow learners to understand mathematical operations and to induce abstract problem schemas (Scheiter, Gerjets, & Schuh, 2008). Based on these and other research findings, Scheiter and Gerjets (2008) conclude that design recommendations for the instructional use of animations need to be much more subtle and have to take into account more moderating variables than they currently do within the dominating theories of multimedia learning.

15.4.4 Multimedia/Hypermedia Environments for Users with Special Needs

Another strand of research with regard to hypermedia and adaptation is related to the concern for making hypermedia environments accessible for user groups with special needs (e.g., blind people or people with reading and/or writing disabilities). Web-based multimedia and hypermedia environments allow the combination of different representational codes and the addressing of different sensory modalities, which might be especially beneficial for users with special needs. Initiatives that try to pave the way onto the web for users with learning disabilities can be distinguished into two main approaches. The first tries to avoid inappropriate representational formats (e.g., written text as the only information source) by designing special websites dedicated to the specific needs of people with learning disabilities. The second aims at using remedial actions to make existing website contents accessible for users with learning disabilities. Exemplary solutions are automatic displaying of contents with symbols or using text to speech software. For instance, in our own research group we investigated which representational formats are beneficial to foster recognition and understanding for users with learning disabilities. Manipulating the modality and codality of the information presentation yielded that learners benefit most from auditory-presented information (as compared to written text) accompanied by symbols (as compared to text only). This is in line with our assumption that only few learners with learning disabilities are able to process written language alone in a sufficiently meaningful way (Zentel, Opfermann, & Krewinkel, 2007).

15.4.5 Integration of Socio-cognitive and Socio-motivational Variables

Socio-cognitive and socio-motivational theories have become increasingly important for analyzing how social constraints influence cognitive processes of multimedia learning. An example of this is research on the effects of animated pedagogical

agents on learning (e.g., Atkinson, 2002; Atkinson, Mayer, & Merrill, 2005; Moreno, Mayer, Spires, & Lester, 2001).

Socio-motivational issues have recently been addressed by Dettori, Giannetti, Paiva, and Vaz (2006; see also Chapter 4). The aim of this work is to use narrative techniques for learning in multimedia systems, where narrative can be used as organizing principles of the content knowledge presented. Usually, narrative learning environments are heavily dependent on advanced multimedia technologies such as 3D-animation, virtual environments, and pedagogical agents. A focus of the research on narrative learning environments is on the socio-motivational and emotional issues in the context of multimedia learning. For instance, the building of empathy between a learner and an animated character is often seen as a way of creating a novel educational experience. On the other hand, it has been pointed out that the purely motivational role that narrative plays in many currently diffused environments needs to be overcome (e.g., Dettori et al., 2006). Accordingly, an important challenge in designing narrative learning environments is to provide cognitive support in the construction of meanings by exploiting the potential of technological means such as high level graphics and intelligent agents. Up to now, this work is mostly characterized by a general educational interest in designing and evaluating narrative learning environments, although it addresses the important and timely issue of augmenting the cognitive perspective by socio-cognitive and socio-motivational theories in order to analyze how social constraints influence cognitive processes in multimedia learning (cf. Linek et al., 2008).

15.4.6 Technological Trends: Interactivity and Personalization

Important research trends in learning from multimedia and hypermedia are related not only to psychology but also to technology (and pedagogy). We will point to some of the important trends without going into many of the details.

Recent technological developments include the increasing importance of dynamic and interactive representations in multimedia environments (e.g., the use of animations, simulations, serious games, or interactive videos) and the use of mobile and ubiquitous devices for displaying and integrating these materials (e.g., PDAs, smartphones, or tablet PCs; see also Chapter 14). Furthermore, the personalization and individualization of multimedia environments has also become increasingly important (e.g., the use of pedagogical agents, context awareness, adaptive hypermedia systems, social footprinting).

According to de Jong (2006; see also Chapter 2), scientific inquiry learning involves the processes of orientation, hypothesis generation, experimentation, conclusion, and evaluation. An important ingredient of a computer-based inquiry enactment for orientation and experimentation is a source (or sources) of information. These sources usually comprise multimedia materials such as simulations and microworlds, virtual (remote) labs, interactive videodiscs, hypermedia-based or web-based databases. Thus, research in this line relies heavily on technologically advanced multimedia and/or hypermedia materials. A number of landmark systems have been devel-

oped that provide learners with information sources as well as with other tools and cognitive scaffolds, such as *WISE* (Web-based Inquiry Science Environment; Slotta, 2004), *ThinkerTools* (White, 1993), *SimQuest* (van Joolingen & de Jong, 2003), and *Co-Lab* (van Joolingen, de Jong, Lazonder, Savelsbergh, & Manlove, 2005). For example, a WISE application on thermodynamics would be a collection of simulations, texts, images that runs within the WISE environment, which turns out to be a multimedia learning environment which is used for the specific instructional approach of inquiry learning. Although this work is mostly characterized by a general educational interest in designing and evaluating inquiry-based learning environments there are also very specific cognitive processes addressed. An example is the issue of comparing how learning processes differ across several instructional approaches when they are based on exactly the same type of external representation (Eysink et al., 2008).

ActiveMath (cf. Melis, Büdenbender, Goguadze, Libbrecht, & Ullrich, 2003) is an example of a multimedia application that aims at assembling a rich, web-based learning environment for mathematics that integrates several multimedia tools such as a function plotter, computer algebra systems for exploratory learning, a semantic search, notes, and an interactive concept map tool. ActiveMath permanently records and assesses the performance of a student by means of exercises, and uses this information to construct a student model that can be inspected by the learner. Thus, the projects aim at combining the main features of e-Learning environments and intelligent tutoring systems. Artificial intelligence techniques (e.g., personalization, user modeling) are used to provide learners with adaptive instruction, for instance with different types of information (e.g., explanations, visualizations) or representations (e.g., spoken text instead of printed text) depending on performance levels, prior knowledge, preferences, and other learner characteristics.

ELEKTRA is another exemplary research project that aimed at designing a game-based virtual learning environment by combining state-of-the-art research in cognitive science, pedagogical theory, and neuroscience with best industrial practice in computer game and e-learning software design (Kickmeier-Rust et al., 2006). ELEKTRA uses advanced visualization techniques such as appealing 3D graphics and animation, an intuitive navigation in a 3D environment, dynamic game play, simulation, and interactivity to overcome traditional problems of game-based learning such as ineffectiveness, lack of motivation, lack of immersion and coherence, and lack of classroom applicability.

As these examples demonstrate, recent technological trends often comprise the attempt to combine different advanced technologies like dynamic and interactive representations, personalization and feedback, user modeling and tutoring, as well as virtual reality and gaming into coherent complex learning environments. This approach seems to be fruitful in order to develop stimulating and realistic real-world learning scenarios. One caveat, however, is related to the question of using these environments for research on technology-enhanced learning. Due to the integration of different tools and technologies, it is often quite unclear how the relative importance of the individual components of these complex learning environments can be investigated and evaluated in isolation.

15.4.7 Issues from Pedagogy: Scaling up Laboratory Research

Recent trends within pedagogy comprise issues that can be characterized as scaling up laboratory research. These issues concern the collaborative use of multimedia design for learning, and the integration and orchestration of multimedia materials in larger-scale formal and informal instructional settings (e.g., classrooms, museums, workplaces).

One example that relates to the collaborative use of multimedia materials is an experimental study on the collaborative use of animations by Rebetez, Bétrancourt, Sangin, Dillenbourg, and Mollinari (2006). This research is based on the assumption that learners in collaborative scenarios can use animations to ground their mutual understanding. However, up to now empirical studies have not confirmed the benefits that one might intuitively expect from the collaborative use of animations (Schnotz, Böckheler, & Grondziel, 1998). However, this lack of positive results can be explained by the fact that processing animations induce a heavy perceptual and memory load on learners. Accordingly, the cognitive benefits of collaborative use of animation appear only if delivery features decrease this cognitive load, for instance by breaking down the continuous flow of the animation into small chunks, by decreasing the interaction demands or information learners should maintain in working memory. If these considerations are taken into account, the collaborative learning setting proved efficient for taking advantage of the potential of dynamic visualizations. This work fits well into more basic research activities addressing the instructional use of animations, not only with regard to the research issues addressed but also with regard to the research methods applied.

Recent work on multimedia-based mathematics learning addresses the important pedagogical issue of how to integrate and orchestrate multimedia materials in realistic large-scale instructional settings (e.g., concrete classrooms; see also Chapters 5 and 13). While mathematics is traditionally perceived as abstract and formal, this work investigates how ICT can facilitate access to mathematical concepts by means of the manipulation of concrete representations. One of the main goals in this context is to explore representational issues in mathematics learning (cf. Morgan, 2006). In particular, it is investigated how different systems to construct and represent mathematical objects and relations provide new ways to give meaning to mathematical concepts. This approach is based on the assumption that mathematical knowledge can be acquired through the exploration and manipulation of various representation forms (e.g., visual, motor, perceptive, etc.) and that representations are keys to abstract knowledge. One of the most obvious ways in which representations provided by technological tools may differ from those available in traditional media is that they enable the dynamic manipulation of either geometric or symbolic objects. In addition to dynamic representations, technological tools also have the potential to offer multiple representations of the “same” mathematical object and to allow users to make connections between these representations, either simply by juxtaposition or by manipulating one representation and causing a corresponding change in another. These ideas are very closely related to basic cognitive-psychology research on multimedia learning (e.g., Bodemer, Plötzner, Feuerlein, &

Spada, 2004), but also to issues of simulation-based inquiry learning as discussed in de Jong (2006; see Chapter 2).

Different types of computational environments for real-world settings have been used to support math learning. Examples are *ARI-LAB* which is a multiple-tools system that combines hypermedia and network communication technologies to support learning in the domain of arithmetic problem solving (cf. Bottino & Chiappini, 1995, 2002; Bottino, Chiappini, & Ferrari, 1994), *E-slate* which is a programmable authoring system for multi-domain exploratory software (cf. Kynigos, 2004) and *Aplusix*, which is a learning environment for algebra (cf. Nicaud, Bouhineau, & Chaachoua, 2004). These environments have been tested in a variety of concrete classroom settings by using an innovative methodology called *cross-experimentation* (cf. Morgan, 2006). In this methodology, each research team tests, in real classroom settings, an ICT-based tool that was developed by one of the other research teams. These cross-experimentations were carried out according to jointly developed guidelines and were aimed at facilitating common understanding across research teams with diverse practices and cultures to progress toward integrated views of technology use in education.

This way of integrating and orchestrating multimedia materials in realistic large-scale instructional settings is a good example to demonstrate that a certain gap seems to exist within research on technology-enhanced learning. When we compare this “serious” educational use of multimedia/hypermedia and the “serious” experimental research on learning with multimedia/hypermedia reviewed in Sections 15.2 and 15.3 it seems that the latter communities also address research issues of educational relevance but – in many cases – seem to be more concerned with yielding valid research findings than investigating realistic contexts of applications. Within Kaleidoscope several initiatives seem to be more concerned with addressing complex and serious educational and technological scenarios than with engaging in more basic and valid research on specific effects of the multimedia features embedded in the environments used. We will further elaborate on this “two cultures” issue in the next section.

15.5 Summary and Discussion

In this chapter we provided an overview of recent research on learning with multimedia and hypermedia. In Sections 15.2 and 15.3, we outlined some mainstream approaches to the study of multimedia/hypermedia from a cognitive-instructional perspective. In Section 15.4, more recent scientific trends in the field of multimedia/hypermedia learning were outlined from a broader perspective including not only psychology but also technology and pedagogy. In these review sections, we pointed to relevant European work on multimedia/hypermedia mainly carried out within Kaleidoscope.

Juxtaposing the cognitive-instructional research activities on multimedia and hypermedia that have dominated the international scientific discourse in the last

decade with contributions from Kaleidoscope related to multimedia/hypermedia learning yields some interesting results. It is immediately obvious that the Kaleidoscope work is broader in scope as it addresses not only psychological issues but also issues of technology and education. However, there are several other conclusions that can be derived from this juxtaposition.

Most important, there is only a surprisingly small overlap between the cognitive-instructional mainstream community and the Kaleidoscope community. On the one hand, mainstream cognitive psychologists who investigate learning from multimedia and hypermedia may not have the same inclination to address complex technological and educational contexts that has been visible within Kaleidoscope. In line with this reasoning, they do not seem to focus scientifically on the problems prevalent at that level of analysis. On the other hand, portions of the educational and technological work conducted within Kaleidoscope seem to have been less reliant on research findings from psychology. Many researchers within Kaleidoscope are motivated by an interest in designing and evaluating technology-based learning environments. This focus may mean that less attention is directed to investigating a particular low level, but very important process occurring during learning from multimedia/hypermedia. Thus, the review presented in this paper reveals a noteworthy gap between researchers who seem to be mainly interested in “serious” educational uses of multimedia/hypermedia and those researchers that mainly focus on conducting “serious” experimental research on learning with multimedia/hypermedia.

Making salient these “two cultures” of research in technology-enhanced learning is a major accomplishment of Kaleidoscope that could lead to two quite critical conclusions. On the one hand, researchers working in scenarios and environments with realistic complexity and “educational value” might want to increase their efforts to ensure that their design decisions and instructional assumptions can be justified in a straightforward way from valid research findings. On the other hand, researchers who are mainly concerned with valid research outcomes and sound experimental designs might want to increase their efforts to avoid the potential danger of focusing on research issues and variables that are less important when it comes to realistic educational contexts.

Burkhardt and Schoenfeld (2003) have noted that researchers committed to laboratory studies often do not feel responsible for turning scientific insight into educational impact. Accordingly, an alternative path has been suggested by proposing to conduct so-called use-inspired research to create “useable knowledge in education” (Design-Based Research Collective, 2003; Lagemann, 2002). According to proponents of this approach, laboratory research

is detached from practice [and] may not account for the influence of contexts, the emergent and complex nature of outcomes, and the incompleteness of knowledge about which factors are relevant for prediction (Design-Based Research Collective, 2003, p. 5).

According to Stokes (1997), use-inspired basic research, on the other hand, combines a strong commitment to considerations of use and a strong orientation toward goals of scientific understanding. Use-inspired research can take different forms from rapid prototyping case studies to implementations that try to blend laboratory

and experimental research. This blending approach usually start with an analysis of an educational problem as it occurs in the real-world context, which is then taken to the laboratory to subject it to a more detailed analysis with the aim of generating a solution to the problem under controlled conditions. In the last step, the most effective solution to a problem according to the laboratory results is then evaluated in the real-world context. Most likely, the solution needs to be further modified, thereby required multiple iterations between the laboratory and the real-world context. This way of blending laboratory and applied context has the advantage that “real” educational problems are addressed rather than making up problems in the laboratory that play only a very small role in the real-world context. Moreover, because evaluations in the real-world context are explicitly part of the research agenda, the complexities of the context will have to be considered, as otherwise the solution will fail.

Applying this reasoning more specifically to the research on learning from multimedia and hypermedia reviewed in this paper yields the advice to try to take the best from both worlds by means of combining scientific approaches:

Thus, researchers predominantly interested in valid and sound experiments might try to extend their work beyond studying how to design small pieces of instruction delivered under artificial conditions. It seems clear that the issue whether the rich set of findings obtained in the laboratory on multimedia learning can be scaled up and used to inform instructional design in real-world instructional contexts has to be considered a serious scientific question. For instance, the research that has been conducted against the background of the Cognitive Theory of Multimedia Learning is characterized by only very small variations in terms of the domains, sample, material layout, and learning outcome measures used. In particular, the multimedia messages investigated by Mayer (2001, 2005) conveyed knowledge on the functioning of biological and mechanical systems, whereby their length has been restricted to 3 minutes at a maximum, with short verbal materials and only very little control left to the subjects, which have been mostly psychology students. It is an open question whether the respective findings concerning retention and transfer can be simply transferred to the classroom, where the content domains are much more comprehensive in terms of topic (e.g., including history, language, mathematics) and complexity, the learners may show a larger variability with regard to their learning prerequisites, and where the sustainability of students’ achievements is of much more importance. The fact that there are so many differences between the laboratory and the real-world setting warrants some caution that multimedia-design principles are applicable without any modification. Thus, considering moderating variables that distinguish the laboratory from realistic environments should be a topic of major importance for research (e.g., learner pacing, distracting environments, collaborative situations, motivational configurations).

On the other hand, researchers mainly interested in designing and evaluating technology-based learning environments of realistic complexity should be encouraged not to confine themselves to study merely overall instructional effects of complex environments, but to try to go into more detailed analyses at a fine-grained level by taking relevant processes into the laboratory. This can be done by obtaining specific process data (e.g., by means of eye tracking, log file analyses, verbal

protocols) and by using experimental variations of complex environments that differ with regard to certain features in order to find out which of them are crucial for the processes under consideration. From a scientific perspective, it is important not to take instructional design as in art but to specify a theoretical rationale for instructional decisions, including detailed design decisions. This could be done, for instance, by using the small instructional units investigated in laboratory research as building blocks for more comprehensive environments. Additionally, one could compare effects of similar variations in the laboratory and in realistic setting. At the current moment, only very few (successful) examples of such an approach exist for multimedia learning. One has been documented by Stephen Reed (2005), who describes the interaction between research and practice in designing animations in algebra in a paper entitled “From research to practice and back: The Animation Tutor project”. Nevertheless, in order to achieve a more comprehensive body of knowledge on learning from multimedia and hypermedia, it seems necessary that the two research communities reviewed in this paper will continue to take notice of each other and to inspire each others theoretical and methodological approaches.

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Part V
Postface

Chapter 16

A Computer Science Perspective on Technology-Enhanced Learning Research

Pierre Tchounikine, Anders I. Mørch and Liam J. Bannon

Abstract In this chapter we examine the role of computer science (CS) in the field of technology-enhanced learning (TEL). CS encompasses a number of distinct intellectual traditions, generating debates about the nature of the CS field. Given the diversity of views within CS and within TEL, our aim in this chapter is to highlight a number of important CS-related issues that impact on the TEL domain. We first note that taking a computational/technological perspective on TEL does not imply a privileging of this perspective, but can be used as a lens to highlight certain issues of importance for the whole TEL field. We then examine three distinct ways in which computer scientists can be involved in TEL research: creating novel forms of computational mechanisms and infrastructures that afford new possibilities for studying and enhancing learning and teaching processes; contributing to the elaboration of powerful abstractions; and implementing specific TEL models and processes on computer systems. We finally discuss several TEL issues in the light of this analysis.

Keywords Computer science · Technology · Technology-enhanced learning

16.1 Introduction

Technology-enhanced learning (TEL) is a research arena where different disciplines such as computer science, education, psychology, philosophy, pedagogy and communication intersect. In this chapter, we examine more critically the role of just one of these disciplines, namely, computer science, (hereafter abbreviated to CS), in the field of TEL.

Despite narrowing down to this single discipline, this is still not an easy task, as the field of CS encompasses a number of distinct intellectual traditions, leading to debates about the nature of the CS field. The field of CS has a legacy from at least two different academic disciplines, along with one more applied

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tradition – logic/mathematics, electrical engineering and systems analysis and programming activities at computing centres. For those CS departments that have emerged from mathematics, the emphasis in CS is on studies of computation, complexity and formalisms – what is often termed “theoretical” CS today. The “Electrical Engineering” tradition is evident in the number of “Computing Departments” that are called EECS Departments (especially in the US) – namely, Electrical Engineering and Computer Science – where there is more of an emphasis on hardware and software development, software engineering, etc. Many CS departments emerged from the activities of people working in mainframe computing centres in research and industrial organizations in the late 1960s and early 1970s. Such departments often showed more of an interest in such areas as software applications for specific domains, business computing, systems analysis and design, and information systems studies more generally. These different legacies, while no longer so apparent today, still have an effect on how we conceive of the discipline of CS. For instance, if one refers to the Wikipedia definition of CS, it is defined as “the study of the theoretical foundations of information and computation and their implementation and application in computer systems”. Wikipedia also claims “Computer science searches for concepts and formal proofs to explain and describe computational systems of interest”. Here, the more formal academic tradition is being presented. In the context of TEL this may be somewhat misleading as very little TEL research or practice can be considered as contributing to theoretical foundations of CS. Just to complicate the matter further, in recent years the term CS has often been supplanted by the term “Informatics”, and this latter term often privileges the human and social aspect of computer systems design, use and evaluation more than is evident in the CS field. Wikipedia states that informatics “. . . has computational, cognitive and social aspects, including study of the social impact of information technologies”, but this term is itself the subject of much debate as to its meaning (Bannon, 2005; Dahlbom, 1996).

What the above paragraph does at least demonstrate is that any perspective that purports to represent “a CS viewpoint” will itself be at best partial and incomplete. The science and techniques related to the building of computer-based artefacts is a broad and not clearly defined area. It can be conceptualized and broken into different sub-domains in different ways and is subject to different definitions, interpretations and misunderstandings. What we must accept is that there is presently no shared understanding of CS with respect to TEL. This is not only a matter of language, but of conceptualization of what, in fact, is the field of CS.

Thus, when we bring together researchers from the computing area with researchers from the education sphere, there are many opportunities for misunderstandings. One dimension is the focus of the TEL activity and the emphasis on CS, technological innovation and/or perceived value of an application to the targeted learner or teacher. There is also some confusion and misunderstanding with respect to the role of computer scientists in the field and what can be classified as “research in CS” as opposed to “engineering work”. These difficulties have a historical and cultural dimension, as they relate to how TEL researchers coming from CS or technology have been educated and see the world; and also to how learning scientists have been educated, use computers and see the world.

Given the diversity of views within TEL, our aim in this chapter is to highlight a number of important CS-related issues that impact on the TEL domain. We first note that taking a computational/technological perspective on TEL does not imply a privileging of this perspective, but can be used as a lens to highlight certain issues that we believe are of importance for the whole TEL field. We then examine three distinct ways in which computer scientists can be involved in TEL research: creating novel forms of computational mechanisms and infrastructures that afford new possibilities for studying and enhancing learning and teaching processes; contributing to the elaboration of powerful abstractions; and implementing specific TEL models and processes on computer systems. We finally discuss different issues in the light of this analysis.

16.2 Computers as Support for Human Learning

It is now widely accepted, even by many computer scientists and technologists, that one of the problems with many early attempts at TEL was that an over-emphasis was placed on the technology *per se*, rather than the learning outcomes for the person. Although technologies are indeed used more and more, and success stories related to TEL research can be highlighted, the results have, however, often been less than overwhelming. Practical problems of institutional acceptance and the “fit” of these systems into ongoing educational practices have also hindered the acceptance of these technologies into the educational mainstream. The area has also suffered from an over-hyping of technological possibilities, with relatively meagre evidence of successful implementations outside of very limited field trials and highly resourced experimental sessions. In recent years, there has been an increasing acceptance within the TEL community that the focus should be on supporting the learning process through the medium of the technology and more modest claims as to the purported benefits of such systems. As highlighted in the different chapters of this book, there is now a general agreement that, when considering the TEL domain, focus should not be put on the technology alone.

Acknowledging the necessity of human-centred approaches does not, however, mean that computational dimensions are secondary. First, analysing TEL systems from the point of view of the technology on which they are based does provide a perspective on the analysed system and on the evolution of the field. Second, analysing the nature of the computational dimension involved in the systems also provides a perspective on the nature of the role of computer scientists (and CS) in the field. Finally, acknowledging the necessity of human-centred approaches does not mean that technologically driven projects should be discarded. There are many different approaches to the design of technology (e.g. empirically based, theory driven or evolutionary) that differ from purely technology-driven approaches. Although the latter approach has well-known drawbacks, it may also contribute to TEL advances. A clear understanding of the roles of computer scientists (and, therefore, CS) is thus important.

16.3 The Role of Computer Scientists in TEL Research

Computer scientists are involved in different ways in TEL research projects. In order to make clearer the different ways in which CS impacts the field, three prototypical (non-orthogonal) roles for CS can be disentangled:

1. Building new technologies or further developing existing technologies to create novel possibilities for supporting human activities.
2. Elaborating powerful abstractions.
3. Enabling specified models and processes to be run on computers (algorithm development and implementation).

In this section we explore these three different roles and then conclude with some general considerations on the role of CS in TEL.

16.3.1 *Creating New Possibilities for Learning*

As highlighted in the Introduction, CS is a broad field that includes work on the creation of new computer-based technologies (i.e. hardware, software and user interfaces). Computer scientists are naturally at the forefront of this activity, which has a spin-off effect in that it opens new possibilities, – creating software or hardware that allows innovative interactions to take place.

The evolution of the TEL field can naturally be linked to technological advances in CS. The very first computer-based instructional systems, often referred to as behaviour-inspired systems (cf. Suppes, 1990), can be seen as involving the direct application of algorithmic techniques. The Intelligent Tutoring System (ITS) movement that followed was based on the evolution of symbolic Artificial Intelligence towards knowledge-based systems (Wenger, 1987) and so-called expert systems (ITS researchers applied this in order to model two aspects of teaching: domain-expertise and pedagogy-expertise). Computer-Supported Collaborative Learning (CSCL) is inspired by both a cognitive and a socio-cultural view of learning (cf. Chapter 1; Stahl, Koschmann, & Suthers, 2006; Chapter 3) on the one hand, but is also inspired by the technological advances in computer-supported cooperative work and groupware (cf. Grudin, 1994). Technical developments in networked computing (basic exchange of data between two computers, speed rate improvements, graphic interfaces, permissions or dead-locks management allowing the creation of advanced systems such as Wikis or Workflows) allowed for explorations in new forms of computer-mediated learning and distance education. In a similar way, Web-based learning approaches rely on Web-based technology. More recently we can discern new trends in TEL such as Grid-learning (based on Grid-technologies) or e-learning 2.0 (based on Web 2.0 technologies) which, while the jury is still out on their efficacy, at the very least clearly demonstrate the influence of technological (CS) developments on the field of TEL.

Seen from this perspective, if we consider technology-driven educational applications, a recurrent pattern can be identified. First, new technology stirs up a wave of excitement among certain people – technologically-oriented TEL researchers and early adopters in educational fields (Rogers, 1995). This is often followed by a period of disappointment among many people when the expected pedagogical benefits do not immediately materialize. The simple but core principle that technology is not the answer to a question that must be found, but rather a potential means to address well-defined educational problem again resurfaces. A period usually follows where the importance of pedagogy over technology is stressed, and the technology-driven development stalls. At this stage, some researchers skip to a novel technology *El Dorado*: the advent of a new wave of computing innovation. So, once again, technologically-inspired visions come to the fore and take centre stage for a period. This cycle seems to repeat endlessly. However, other more learning-centred projects, where the role of the technology is to support learners in solving problems, are also feasible. When considering this more interesting and pragmatic perspective on TEL research, a core issue for the field is whether the project involves a significant element of novel CS research-content, as some TEL projects may have an innovative pedagogical frame, yet utilize only standard technology platforms, thus omitting any CS-research element to the project. A current prototypical example of a TEL sub-field that builds on a technological advance (and its dissemination) is mobile learning, which is a direct spin-off of mobile technologies. At this stage of research, the literature provides examples of research that prioritizes the technology and explores innovative uses of it (technologically driven works) and research that implements ideas anchored in learning theories via these new technologies (cf. Chapter 14).

Exploring technological innovation on its own merits is indeed a vector for TEL research advances. This is not in contradiction with the principle that TEL must be focused on educational issues. Educational problems can be addressed with existing technologies or wholly new technologies created from learning-centred work, and also by tailoring and customizing new technologies. The latter end of this scale identifies a bottom-up dimension to development and can lead to user-driven innovation. Technology and education do act as bottom-up and top-down approaches to address a set of related (TEL) issues. Their interplay is the core of the field.

When attempting to clarify TEL subfields that are heavily linked to a specific technology, an interesting question to ask is: what is the specific educational advance that is related to the fact that this technology is being used? For instance, a large portion of research in the areas of mobile learning or grid-learning uses an underlying innovative technology, but fails to demonstrate how this technology leads to educational advances that would not be possible without it (typically, presenting on a phone or a PDA what could be presented on a classic screen without any contextual advantage of using a mobile device, or using a grid where basic Websites would be sufficient). While we share an interest in applying novel technology to educational issues, we are insistent that the pedagogical validity of the research should be established in parallel with the creation of technological novelty. Only with such an approach will the TEL field advance and will the contributions of CS research to TEL be fully appreciated.

16.3.2 *Elaborating Powerful Abstractions*

Building software requires programming, that is, writing code in a general purpose programming language such as C++ and Java. More recently, CS and in particular software engineering has evolved towards processes and methods based on higher level abstractions such as models and software components. Modelling is a core issue in CS. From a basic technical viewpoint, it is now possible to generate code or program interfaces (e.g. APIs) from abstract descriptions represented in conceptual modelling languages. This allows one to consider software at the level of abstract notions and processes rather than at the symbolic level of a programming language (e.g. variables, control structures, procedures, classes or objects). From a pragmatic point of view it has been demonstrated that working at the level of models rather than at a symbolic level facilitates and ameliorates software construction. It also appears to be the only way to address the complexity of today's software and architectures. Advanced software engineering practices (such as the Model-Driven Architecture approach; Miller & Mukerji, 2003) argue for the use of models to direct the course of understanding, design, construction, deployment, operation, maintenance and modification of systems' computational implementation, that is, building software by automated transformations of models. Similarly, software components, that is, high-level building blocks that hide their internal parts (code) and expose their external interface (connection points) also facilitate and ameliorate software construction by addressing it at a higher level of abstraction than general programming languages allow.

Models and components support the tendency of application developers to act at a level that is closer to that of the domain-expert users. For instance, considering the design of software for a bank, some issues will be addressed at a purely technical level (e.g. networking issues), but some computer scientists will also be involved, along with domain (bank) experts, to help in modelling the notions to be considered (e.g. monetary transactions), and the processes to be operationalized.

TEL is a typical area where building models that involve software issues is a key dimension. Typically, the issue to be addressed is the modelling of a learning-setting, modelling that includes the role of the computer-based system in this setting. Given this situation, two prototypical cases can be distinguished. In the basic case, the overall modelling can take place as: design and model the learning-setting, the different actors, their roles, etc.; specify the computer-based system properties and functionalities according to the learning-setting model; implement the computer-based system; conduct usage or impact analyses; re-engineer as needed. Such a process can be seen as multidisciplinary if considered at a coarse grained level of granularity, but in fact it corresponds to a sequence of disciplinary actions. A second case is when the overall modelling may not be addressable by segmenting it into disciplinary phases. This is the case when the general conceptualization of the setting, and/or the models required to operationalize the setting, cannot be tackled by learning sciences *and then* CS. Such situations require conceptualizing and addressing the problem as a trans-disciplinary TEL problem, "trans-disciplinary" here implying that one must transcend the boundaries of conventional academic disciplines.

Elaborating (with learning scientists) powerful abstractions is arguably computer scientists' core contribution to TEL. Different examples have been presented in this book:

- Sharing and operationalizing CSCL scripts, for instance, requires building (different but connected) models (cf. Chapter 10);
- Making didactic decisions requires building, representing and making operational some didactic knowledge (cf. Chapter 5 and Chapter 7);
- Adapting and personalizing programs to the context and/or learner (as suggested in different projects, e.g. Chapter 5) require building the underlying required adaptation tools and transformation models;
- Building models of scientific phenomena by learners in the context of inquiry learning tasks requires quantitative and qualitative models that can be simulated (cf. Chapter 2).

Computer scientists are key actors in this type of work. They provide conceptual languages and notations (XML-based formalisms, UML-based formalisms, Petri-nets, System Dynamics, etc.), tools (design tools such as graphical modellers, visualization or simulation tools), and their modelling competence and skills. Here again, all of these are to be used in the context of a common project involving computer scientists and learning scientists.

It should be noted that such modelling activities have a value in and of themselves, and not only when used as a base for implementing procedures or processes. Very often, the objective of the work is to elaborate a model that allows one to understand or design the setting, even if no computer implementation is planned or the model is not implemented as such in the computer (Baker, 2000). For instance, it is now very common to address learning scenarios via some given Educational Modelling Language and the associated conceptual notions, predefined conceptual map or manipulation tools. This modelling is often not used further, for example, to generate some code or tune a technical architecture, but it is still a valuable pedagogical tool.

16.3.3 Implementing Specified Models and Processes on Computers

Finally, the most obvious way for computer scientists to be involved in TEL research is to be in charge of writing the code and implementing a working model on a computer system. At this level, whatever the research issues were at the previous stage and whether the model was specified by learning scientists or together with learning scientists, the TEL problem is transformed into a computational problem and tackled accordingly.

When considering this type of work, two cases can be distinguished. If the operationalization process is difficult, it requires the computer scientist to act as a CS researcher. If the operationalization process is not difficult and is only technical

(i.e. it may be complex but requires only already known techniques), then it requires the computer scientist to act more as an engineer.

A very prototypical example of a TEL project that requires well-elaborated programs, but basically engineering tasks, is the simulation software used in inquiry learning projects such as those presented by van Joolingen & Zacharia (Chapter 2). The software implementation is constrained by very detailed specifications, but does not raise CS research questions as such. An example of a TEL problem that does entail CS research issues involves the difficulties encountered in creating knowledge-based systems that can solve problems while respecting educational constraints (e.g. Chapter 5; Chapter 7) or Natural-Language understanding (e.g. Chapter 6).

In the context of the search for integration of research projects and products, an interesting example of a CS problem that is arising from the concatenation of components and other software building blocks is *interoperability*. The need to interoperate data (e.g. linking track-analysis output or textual-communication outputs and learning scenarios; see for example Chapter 9) requires difficult CS issues to be tackled, such as elaborating data-exchange formats, parsers or models-weaving and models-transformations processes.

From the perspective of CS, TEL can thus also be seen as a field that creates interesting instances of general CS issues and provides an interesting context in which to address them. Interoperability is just one example. Another example is “tailorability”. In CS, a system is said to be “tailorable” if it provides its users with integrated support for modifying the system in the context of its use (Mørch, 1997). In TEL, “tailorability” appears as a potential means to combine the two objectives of (1) providing learners with software designed to guide and support them, this design being based on pedagogical decisions, while (2) providing learners with built-in flexibility features to adapt software to their needs, in context. Introducing tailorability in TEL software, however, raises major issues (Tchounikine, 2008): tailorability for learners ought to be studied with respect to the intentionality behind the computer-based system (i.e. if the system has been designed to reify some pedagogic principles, its potential flexibility must be studied with respect to these principles and constraints; (Dillenbourg & Tchounikine, 2007). Furthermore, tailoring must be technically easy to achieve. And tailoring is, with respect to the learners’ activity as related to the script, another activity: the risk of causing a breakdown in the activity flow should not be underestimated. In summary, TEL defines a context where some CS issues (here, tailorability) are core issues, have a particular instantiation and are subject to specific constraints.

16.3.4 CS in TEL

In this chapter we have disentangled different potential roles for computer scientists involved in TEL. These roles are not orthogonal to each other. They may be difficult to disentangle in the context of a given project, as computer scientists may act at

different levels, and on different planes. Their separation, however, provides a basis for clarifying the nature of computer scientists' actions.

From a general point of view, basic sciences are driven by the objective of understanding (e.g. understanding how people learn). Design-oriented sciences are differently driven by the objective of solving a problem through building artefacts (e.g. software). In the context of TEL, CS is design-oriented. However, for a CS researcher, the objective is not simply to build software programs, but also to elaborate notions, principles, models, theories, tools or processes allowing a better understanding of how to build software.

Does TEL software engineering present specific issues of more general CS interest, and if so what are the specifics? The answer might be that TEL as such does not require software engineering methods specific to TEL, but specific to human-centred software design and implementation. There are different approaches to TEL design such as technology-driven, participatory design (involving future users in design), empirically based design (prototyping with user testing), theory-based design (basing a design on a theory or conceptual framework originating outside of the technology domain) or evolutionary (incremental) design. These approaches are, however, used in different application domains and are thus not specific to TEL. However, TEL probably requires actors with computational skills (researchers, engineers) who have TEL expertise and can thus understand TEL concerns. This is the case when exploring innovations based on new technologies, if only to avoid meaningless projects. It is, of course, particularly the case when elaborating abstractions with learning scientists. Finally, it is also important when implementing specified models and processes: software engineering has demonstrated that complex software such as TEL systems cannot be built successfully based on a one-off specification process – they require iterative development with users.

16.4 Discussion

16.4.1 Technological Dimensions and Evolution of the Field

We believe that TEL research and, thus, TEL software, can be interestingly examined in terms of the underlying theory about learning or teaching that they embody, as well as in terms of the computational techniques on which they are based. For instance, Intelligent Tutoring Systems (cf. for example, Chapter 7) are based on representation of knowledge and expertise, decision making, Artificial Intelligence and knowledge engineering techniques. Microworlds or simulations (e.g. Chapter 2) are based on modelling and visualization (2D, 3D) techniques. Critiquing systems and design environments (Cheung et al., 2007) combine aspects of ITS (task-specific feedback) with microworlds (modelling and simulation). Hypertext and multimedia (e.g. Chapter 15) are based on representation, structuring and conditional/dynamic access techniques. Many CSCL systems (e.g. Chapter 1; Chapter 10)

are based on social interaction, pedagogical models (e.g. knowledge building) and HCI techniques. As highlighted previously, mobile learning or Web-based learning are anchored in their corresponding technologies (cf. for example the emergence of Web 2.0). Data analysis systems (e.g. Chapter 12) are based on log-analysis and pattern-based communication analysis.

How the technology is used also provides an interesting view of the field's evolution. For instance, computer-enabled communication facilities have been a basis for the development of first, Web-based learning, then CSCL, and now mobile learning. Patterns, which originated from Alexander's work in architecture (Alexander et al., 1977) but are now an established technique in programming design (programming patterns), have recently expanded their scope of application, as in knowledge-capitalization patterns or data-interpretation patterns, etc.

All researchers (from CS and from education) acknowledge that technology is not the entry point, and technologies should be considered rather as a potential means to respond to educational questions. However, as a matter of fact, every new wave of techniques generates a new type of system and often tends to replace the preceding one. This is an issue that should be analysed. Is it that these new technologies allow us to solve better the educational problems that were already the subject of work with the preceding technologies or does the target (the educational question) move with the means (the technology)? And, if the latter, what does this denote? Is it the case that educational projects taking advantage of this new technology allow a better understanding of the educational objectives that should be addressed or do they just generate false hopes?

Let's consider for instance the ITS/CSCL shift, – the fact that while ITS (based on Artificial Intelligence techniques) was a predominant paradigm in the 1980s, it has now been replaced (as a predominant paradigm) by CSCL, which has been made possible by the emergence of networked communication (Koschmann, 1996).

In the 1970s and 1980s there were many attempts to develop what was termed Intelligent Tutoring Systems (ITSs). Their emphasis was on modelling of the user and of the task domain, in order to provide feedback on the learners' actions at each stage of problem-solving. The computer was meant to play the role of a human tutor. What has been learned from this work is the difficulty of being able to adequately model aspects of the task, setting and user. Except in very delimited domains, this approach has not led to any substantial change in educational practice, although a few systems inheriting from this work have been successfully implemented (e.g. Koedinger, Anderson, Hadley, & Mark, 1997). An alternative approach is one where the computer is seen as a mediating artefact between learners and teachers or other learners, providing a support medium that augments the learning space for the student, but without any attempt to necessarily model substantive aspects of the users. Rather, the learners are provided with resources for action through the computer medium, allowing flexibility and control to be in the hands of the users, not the system. This is the approach adopted in much of the work within the CSCL area. The change is manifest from a subject matter perspective, in that the ITS paradigm is associated with teaching and learning domain-specific skills (physics, mathematics, English, etc.), whereas CSCL is often about general

skills (communication, working in teams, knowledge building). The demands for skills in collaboration and knowledge integration (e.g. to critically evaluate information resources found on the World Wide Web) have come to the foreground over the past 10 years, making the teaching of general (also referred to as knowledge-based) skills more important than ever. CSCL is about teaching and learning the knowledge and skills required for participation in the knowledge-based society in concert with the basic skills they rely upon.

From a computational perspective, the evolution from ITS to CSCL corresponds to a deep change of concerns. ITS raises issues such as the understanding by the computer-based system of learners' activity and production, problem-solving and interaction control. All these are difficult and not yet solved Artificial Intelligence problems. On the other hand, most CSCL work (not all, but most) does not address these issues. CSCL also raises difficult CS issues (e.g. HCI issues), but these are less binary and non-contingent problems than in ITS (i.e. the problem is solved or not, the software can be programmed or not).

Although there are indeed educational rationales to the ITS/CSCL shift, many ITS-related questions remain core TEL questions (and, by the way, also make sense in CSCL, for example, understanding learners' activity). Their disregard by a part of the research community is also a matter of computational difficulty.

Dissemination and usability of technologies are also important factors. If some CSCL work requires difficult CS issues to be solved, on the other hand, many projects are based on simple, stable, well disseminated and almost freely available technologies. Teachers are unlikely to customize AI-based systems, but often have no difficulty in using basic CSCL or Web technologies for their courses.

To summarize, the technological dimension and the extent to which the field's evolution is related to educational issues and/or technological issues is an open issue for further investigation.

16.4.2 Levels of Granularity and Concerns of Educationalists and Technologists

All TEL systems are, by definition, based on some computer-based system. Computer scientists' focus is on the detailed properties of these systems, which is not the case for most educationalists.

Let's consider for instance a computer-based system designed to run a CSCL script (cf. Chapter 10). Computer scientists will focus on issues such as the functionalities that the system presents to learners involved in the script (communication tools, task-specific tools, etc.), the detailed specificities of these functionalities (e.g. the HCI details or the way functionalities are integrated within a common interface dedicated to the task at hand), data flow and workflow issues, etc. (Tchounikine, 2008). These dimensions are rarely taken into account in educationalists' work. Many, however, consider issues at a much higher level of granularity. Typically, the

technological dimension of the work will consist in taking care that students access a general Learning Management System and its generic tools, without considering their specificities. Rather, an issue will be the fact the software is easily available or that learners are familiar with it.

The possible difference in the levels of granularity of computer scientists' and educationalists' matters of concern is an issue, as it may create confusion that makes multidisciplinary work difficult. A recurrent pattern in research work is a detailed design of a computer-based system that provides very specific functionalities, functionalities that, independently of their potential positive, negative or neutral possible impact, are just not matters of concern for educationalists. This typically leads computer scientists to abandon the field or return to more delimited technical domains. From another perspective, an open question is the extent to which CS researchers working on specific computational issues are useful to the TEL field, given the widespread dissemination and use of free and easy-to-use software (instant messengers, Moodle, wikis, blogs, etc.).

16.4.3 How Should CS Projects in TEL be Evaluated?

Evaluation is a difficult question for many fields. We can find a wide variety of both quantitative and qualitative methods in the educational and psychological projects in TEL. In CS, the evaluation question is very different depending on the type of work. For instance, a project related to the building of an algorithm can be examined by means of a quantitative evaluation: the algorithm works or not (given some input, it provides the expected output or not) and/or can be analysed with respect to some metrics (e.g. given a benchmark, it provides the output in less time, or with more precision, than a comparative algorithm). Evaluating a model or a process/method is much more of a qualitative issue. Given a model or a method that is supposed to help in the design of computer-based systems, it is just not possible to create experimental conditions, for example, to have a set of modelling teams (not to say companies) that solve the same problem and for which the support provided by the model or method is the only impacting factor.

How should CS projects in TEL be evaluated? Considering purely CS methodological, technical or technological issues, the obvious *wrong* answer is with respect to the fact that learners learn using the TEL system. When the overall project includes a sub-project that consists in developing a given computer-based system on the basis of well-defined specifications originating from the pedagogical analysis (cf. *supra*), the CS dimension can be evaluated as such. The CS work can be perfectly successful from the point of view of the CS objective addressed, independently of the fact that the underlying learning hypothesis makes sense or that the produced software has the expected impact on students. The argument here is that the success of the CS work can be disentangled from the success of the project it is part of (which of course nonetheless remains the general important objective). This is very different for the type of work we have referred to as "elaborating (with

learning scientists) powerful abstractions”. Interdisciplinary artefacts such as TEL models require interdisciplinary evaluations, which are problematic to design and implement.

16.5 Conclusions

If we were to characterize the work that has been done in the Kaleidoscope Network of Excellence, we would say it exemplifies the diversity of the field as well as its evolution. Most projects undertaken in the context of Kaleidoscope are based on using already existing technologies and/or specifying systems to be subsequently built by engineers (although, unfortunately, this is sometimes done by researchers!). Few projects address complex architectural issues (large interrelated repositories of learning objects, building complete Learning Management Systems, TEL application generators, etc.) which relate more directly to CS concerns (ontologies, database, network issues, etc.). There is a strong emphasis on human activity and learning. A characteristic of many of the projects undertaken is, however, to use and promote the use of CS methods and processes such as modelling approaches (UML, Petri networks, design patterns, etc.). Computer scientists play a key role in these projects by working together with learning scientists on the elaboration of these models. These modelling exercises do not necessarily relate to programming new software and are often conducted for the intrinsic value of the elaborated model. This shows the rising interest in the role of explicit semi-formal models and may be a sign of a move towards the generalization in TEL of model-based approaches as developed in software engineering. Elaborated models are often challenged by the building of proofs of concept, such as, for example, the models elaborated for interoperable systems. Finally, by the fact that projects focus on, and are driven by, educational principles/theories, they *incidentally* define problems for CS researchers (examples include technological challenges in mobile learning; Artificial Intelligence issues in ITS; Human-Computer Interfaces; model-transformations and model-weaving; tailorability; etc.). The term “incidentally” is used here to stress that the project is not built as a way to justify some CS research as a solution to a potential learning problem that will be found, but that the entry point is (or quickly becomes, in the case of initially technology-driven works) human activity and learning, and not the CS difficulty. The research leads to CS issues that may be purely engineering issues or may be research issues. From the perspective of CS research, this is very positive, as it creates a context in which classical techniques and methods (in Artificial Intelligence, software engineering, HCI, networking, etc.) can be analysed and improved with respect to *externally defined* explicit constraints.

To summarize, this chapter has noted that while TEL should not be driven by a technological agenda per se, that is, the focus should be on the learning and not on the technology, there are ample ways in which the CS discipline can contribute to the TEL research agenda, and we have outlined three such ways.

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Chapter 17

Implementing Technology-Enhanced Learning

Diana Laurillard, Martin Oliver, Barbara Wasson and Ulrich Hoppe

Abstract In this chapter, we look at the implementation perspective from the starting point of the fundamental educational aims that unite the academic community. We argue that interactive and cooperative digital media have an inherent educational value as a new means of intellectual expression. Our primary concern is not the optimisation of knowledge transmission but the use of digital technologies to enhance intellectual expressiveness and creativity: helping the students in their appropriation of the world with a special emphasis on their intellectual development, it is essential for the education system to incorporate new digital media as tools for intellectual expression and production. We outline the main issues relevant to the implementation of technology-enhanced learning (TEL) – the link to overall educational aims, the relationship between innovation and practice, the importance of user engagement, the nature of TEL research, and the characteristics of the local context, and the nature of TEL as a catalyst for change. The chapter concludes with some of the key lessons learned in recent research and development projects that will help to develop more successful ways of ensuring that the technology achieves its potential to enhance learning.

Keywords Technology-enhanced learning (TEL) · Implementation · Higher education · User engagement · Pedagogy

17.1 Introduction

This chapter will discuss and summarise strategies and successful approaches to delivering innovative technology to different learning settings and fostering innovation through technology. Our perspective, however, is not focused on “efficiency” in terms of using technology to accelerate learning processes by faster delivery and distribution of learning materials. It is rather oriented towards the role of technology

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to enable new types of learning experiences and to enrich existing learning scenarios. To do this successfully, we have to understand not just teaching and learning, but also the context in which the implementation of technology-enhanced learning (TEL) has to take place.

One of the strongest arguments for bringing new digital technologies into schools and other educational institutions is that, by doing so, we would trigger pedagogical innovation. This argument can be explained in a system-theoretic perspective on education. One analysis has identified a basic “technology deficit” in pedagogy and education (Luhmann & Schorr, 1982).

Although Luhmann & Schorr argue for more “technological” approaches in education, they emphasise that the constraints inherent in the system have to be understood and considered in any attempt to foster serious change. Essentially, we cannot re-engineer or adapt the system from outside, it has to adapt itself. On the surface level, this is happening: computers and Internet connections are now widely distributed and available in many schools in Europe and even in supposedly less developed parts of the world. However, the consequences in terms of curriculum revision, in terms redefinition of the basic professional skills of teachers or in terms of classroom orchestration remain largely unsolved.

In this chapter we look at the implementation perspective from the starting point of the fundamental educational aims that unite the academic community. We argue that interactive and cooperative digital media have an inherent educational value as a new means of intellectual expression. Our primary concern is not the optimisation of knowledge transmission but the use of digital technologies to enhance intellectual expressiveness and creativity: helping the students in their appropriation of the world with a special emphasis on their intellectual development, it is essential for the education system to incorporate new digital media as tools for intellectual expression and production.

We outline the main issues relevant to the implementation of TEL – the link to overall educational aims, the relationship between innovation and practice, the importance of user engagement, the nature of TEL research, and the characteristics of the local context, and the nature of TEL as a catalyst for change.

17.2 The Relationship Between General Educational Aims and TEL Research

The European Union is united in the aspirations recorded in the Lisbon Agreement 2000, to make the EU the world’s most competitive and dynamic knowledge-based economy by 2010. The focus must now be on training people for the knowledge economy, not just to acquire ICT skills, but also to be able to cope with the higher level skills of knowledge management and technical analysis required from the majority of professionals in an ICT-literate workplace.

The same point arises within individual partner states. For example, a major study of skills for the workforce set a similar agenda, and this is now influencing UK

education policy (Leitch, 2006). Within the Kaleidoscope Network of Excellence programme the studies of learning at work provide telling evidence of this by showing that the knowledge and skill level of most working people now has to be much higher than was traditionally needed, in order to take account of the complex information handling that has been driven by the spread of technology in the workplace (Chapter 5). However, technology is also the means by which these skills can be enhanced. The identification of the need for “techno-mathematical skills” makes it possible then to use this diagnosis to develop the technology-based interventions that make explicit the models underlying the kinds of technological representations being used in many workplaces, such as finance products and statistical processes (Hoyles, Noss, Kent, & Baker, 2006).

Education has a role in preparing people for work – traditionally for the industrial environment, but now for the knowledge economy, and that must affect both what and how students learn. European educational policy aims are ambitious, which means that education has to learn to adapt faster, in line with the rate of change in the worlds of work and leisure.

Technology-based environments can provide alternative ways of offering a more authentic learning context. One critique of current education argues that students are rarely involved in a context in which they need to develop or modify knowledge (Grabinger & Dunlap, 1995). This is poor preparation for a role in the knowledge economy. Part of the point of specialist disciplinary training is to prepare people to contribute to that discipline. Universities are comfortable with teaching specialist knowledge produced by experts, but practitioner knowledge and the skill to develop it, which is what the knowledge industry needs, are not a natural part of university curricula. Michael Gibbons and others suggest that universities should move into this area at the undergraduate level, and not just leave it to the postgraduate, or post-experience programmes within the private sector (Gibbons et al., 1994). Adequate preparation must therefore include the development of expertise in the skills of knowledge negotiation, taking the skills of inquiry, critique, evaluation and debate beyond the understanding of ideas to the development and representation of the new knowledge that comes from being a practitioner in a field. For example, the study of chemistry will be preparing at least some students for the role of being a professional chemist, that is, entering a community of practice (Wenger, 1999). It is therefore extremely important to understand what chemists actually do. The same point is valid for science in general, where learners need to experience authentic environments for the study of science, both to excite their interest and to enhance their understanding (Braund & Reiss, 2006), but the conventional field trip will always be occasional whereas a virtual field trip, simulated through technology, could achieve at least some of the same motivation and understanding. Thus TEL offers new ways to present and study domain content and domain-related skills and competencies.

This is why research in TEL can be of particular value. It necessarily focuses on the aims of education, but it also has to act as a catalyst for rethinking the instantiation of those aims in curriculum development. Because very little is known about the ways in which the professions actually develop knowledge, there may be an important role to be played by the field of science and technology studies (Kuhn, 1970;

Chapter 8; Latour & Woolgar, 1979). In addition, the socio-cultural approach to TEL offers a view of learning that is situated in human social practice; existing practice forms the foundation for the design of the future use of new technological tools (Bannon & Bødker, 1991).

The context of implementation for TEL research is an education system that is changing, but not changing fast enough. Learners are being prepared for a world in which technology is increasing the speed of innovation and change, but they are being prepared by an education system that is not oriented towards rapid change in the way it is managed and operated. TEL systems could help education adapt to a world that is rapidly changing in response to technology.

17.3 Disseminating TEL Research and Innovation

Although many positive developments in the use of TEL have been identified, the relationship between these and wider educational practice often remains aspirational. Even when taken up in policy, the effects on practice can be unpredictable and erratic (Conole, White, & Oliver, 2006).

Attempts to explain this situation often focus on the social contexts in which these innovations are developed and shared. Greater rationality in the process of fostering adoption may help, but does not solve the problems. For example, using policy to encourage change is often ineffective because many practitioners see these as disconnected from their own experiences, so that the contrast between the policy “hype” and the challenges that characterise their own use of TEL can increase rather than reduce their scepticism (Price et al., 2005). It has long been recognised that this is no simple case of technophobia (Cuban, 2001) – indeed, this can be seen as a sensible response by teachers to a situation that seems to threaten their sense of professional identity.

The situation can be quite different, however, where the process of implementation is treated as a research endeavour in its own right, rather than as a known, controllable and largely technical problem. Studies have shown that teachers persevere even with difficult developments where these support or enhance the professional values they hold, but are more likely to reject or adapt an innovation that fails to accord with these values, rather than abandon that in which they believe (Price et al., 2005). An analysis of the relative success of different approaches to changing academics’ practices identified a series of factors that make change more likely (Sharpe & Oliver, 2007). They suggest that a scholarly approach to implementing innovation can be more successful with academics. TEL requires a more structured approach to designing learning, giving rise to much greater thoughtfulness about what learners need, and to further reflection on their beliefs about learning and teaching. Sadly, time and space for reflection of this kind is often marginalised by outcomes-oriented funding or accountability regimes.

Less common, but perhaps most successful, are initiatives that permit co-development. Where developers brought a part-finished artefact, for example a “half-baked microworld” (Kynigos, 2007) to an existing community, and then

worked with those community members to tailor it to address their own interests and preoccupations, a sense of ownership and engagement resulted that made adoption of the innovation a much more plausible outcome. This approach has clear resonances with processes of action research, and with models of design research that involve iterative and participative practices (Barab & Squire, 2004). Importantly, the artefacts produced are not just given to intended users, but are jointly negotiated. Wenger proposed that when any group is given an artefact produced by others, they have to engage in a process of making sense of how this relates to what they already do as they start trying to use it (Wenger, 1999). If the purpose of the artefact is obscure to them, then what it may come to mean for the group is that they are marginal, unimportant in determining the agenda for their work. If this is the case, then the resistance of many teachers to innovations that they were not involved in developing becomes much less surprising.

This certainly happens with TEL developments. Falconer's analysis of the LADiE project (Falconer, 2007) reveals how, even when teachers, researchers and developers are committed to working together, communication can break down and difficulties arise. Here, each community failed to understand the representations that the others used to specify design features and requests for information failed to be met simply because the recipients could not understand what was needed of them. Eventually, "mediating representations" had to be developed to support design discussions. Similarly, when the British Educational Communication Technology Agency sought to develop a model of e-learning to guide its work with teaching practitioners, teachers only wanted to make use of it once they had the opportunity to adapt the model so that it reflected their assumptions and values rather than those of a central agency (de Freitas, Oliver, Mee, & Mayes, 2007). Simplistic models of research "dissemination" are unlikely to lead to widespread change. Unsurprisingly, the transmissive pedagogy so broadly criticised by TEL researchers in relation to student learning is not particularly effective when educating our peers either.

This has implications for the way in which researchers and developers work with teachers. Directive approaches, such as a mandated series of workshops, do less to help teachers make sense of these innovations than dialogic approaches (Price et al., 2005). Such negotiation is certainly possible to achieve through conventional approaches such as workshops or training programmes, if these are conducted responsively, but were most clearly exemplified by "shepherding" – a consultative approach to supporting innovation in which a centrally based specialist works with disciplinary academics so support their curriculum work (Oliver et al., 2005). In the UK, such individuals might be referred to as Learning Technologists, but terminology around this role is currently inconsistent – and the idea of shepherding is evocative and informative. Such support is resource intensive, but this scaffolded development of teachers' expertise embodies some important principles of effective adoption.

Thus, dissemination, in the simple sense of "transmission" of innovation, does not work. Resources and approaches from other contexts can be offered to the teacher for consideration, but are adopted or adapted in the service of addressing immediate, meaningful concerns. The intensive nature of this kind of work means

that it is unlikely to be the sole approach adopted for disseminating innovation, but its documented success suggests that it could play an important role as part of a repertoire of dissemination approaches.

17.4 The Importance of User Engagement in TEL Research

If we cannot simply “transmit” research results through conventional dissemination processes, how are we to effect the adoption of TEL? In this section we build on the previous section and argue for the importance of user engagement in TEL as a design science that is attempting to affect human behaviour, where “users” are students and teachers, as well as policy-makers and stakeholders. Involvement of the key stakeholders in the design and creation of learning technologies is crucial to the success of TEL research because it concerns the changing behaviour of the users of that research.

This is an unfamiliar way of working in education, which has traditionally been a relatively private exchange between a teacher and their learners. In the context of a modern educational environment, a wide range of stakeholders believe they have a role to play, and the teacher has to play their part in a team, an institution and beyond the institution, a community. The teacher no longer acts alone, but must expect to build on others’ knowledge, and share their own knowledge of teaching and learning.

TEL research can be directed at supporting this new form of professionalism. One recent study proposes ways of supporting communication and knowledge sharing between key stakeholders – educators, researchers, practitioners, designers and software developers (Chapter 13). By developing a set of design patterns, they provide the basis for deep collaboration between the various stakeholders when designing and deploying educational resources.

This kind of approach is essential if we are to succeed in the form of user engagement where research begins with practice and builds its aims and methodologies from that (Ludvigsen & Rasmussen, 2005; Rasmussen & Ludvigsen, 2009). The general approach to research is to use the methodology of “design research”, which typically involves users right from the beginning of the project, as “practitioner informants” or “action researchers”, testing, trialling and critiquing the digital tools and resources being developed within the research. This is a key condition for the success of implementation. As our study showed, teachers need to be involved in the design phase and have the main responsibility for execution in the learning environment. This is critical to the success of the project, so one does not create an implementation problem (Wasson & Ludvigsen, 2003).

The European SEED project took exactly this participatory approach and included teachers in the design of interactive and cooperative tools for the classroom (Lingnau, Harrer, Kuhn, & Hoppe, 2007). SEED did not strive for curricular reform but operated on the basis of the given curriculum with a focus on “maintaining, possibly enriching each teacher’s grown teaching style and preferences” (Hoppe, 2009), that is, the “active appropriation” of these new media in the everyday classroom.

This was achieved though a balance between the teacher's articulation of their ideas for transforming their practice with new media and the researcher's illumination of the possibilities of the new media. The collaborative modelling platform Cool Modes (Pinkwart, Hoppe, Bollen, & Fuhlrott, 2002) provided general shared workspace enabling extensions to be suggested and defined by teachers. These extensions have been successfully used in several practical trials in real school settings with positive effects on the teacher's role as non-directive learning coach, and on students' intrinsic motivation and capabilities in autonomous collaborative problem solving (Lingnau et al., 2007).

The design-based research approach used in TEL has highlighted the importance of the interaction between educational aims and TEL research outputs, with the latter acting as a spur to challenge curriculum development. Rich, ethnographic descriptions of professional and working practice contexts will be required if learning objectives are to be rethought and re-written. Although such investigations might be thought to fall more naturally into the fields of educational or sociological research, their relevance here is as a foundation for the TEL work that follows. Furthermore, Barab and colleagues argue that design-based researchers

can instantiate a critical stance in different aspects of their design work and at different levels of its implementation, including transforming the curriculum, the student, the teacher, and the socio-cultural contexts in which their designs are being realized (Barab, Dodge, Thomas, Jackson, & Tuzun, 2007, p. 265).

Thus, TEL researchers need to work closely with those researchers who can help to illuminate the practice contexts of users and practitioners, if adoption and successful implementation is to be feasible.

We can exemplify this argument by detailing some of the skills required for professional practice, such as in medicine). However, medical education seeks to change practice, not just improve it; the patient safety agenda, for example, means that policy must also be considered, since it serves to critique current practice, not just sustain it. How a TEL project is positioned in relation to this will determine whether it sustains or develops the existing educational system.

The symbiotic relationship between research and practice, for TEL research, therefore means that implementation will only be successful when this relationship is reflected in the way research is conducted. User engagement, from the earliest opportunity, is important for the relevance of the innovation to users, and for the authenticity of the learning at its core.

17.5 The Characteristics of TEL Research that Adversely Affect Adoption

17.5.1 The Different Goals of Researchers and Practitioners

As we discussed in the earlier section, there is a difficult relationship between the innovative developments in TEL research and their implementation in practice. This

breach between researchers and practitioners clearly affects adoption (see as an example Chapter 6). Natural language processing technologies are often unreliable and expensive to develop; it would not be a sensible use of educational resources to try to adopt such a system, as it might lead to erroneous feedback to learners. Consequently, it tends to be established technologies, which are less interesting as a focus for research, that tend to be most useful to practice. In the case of language learning, the teacher would want tools that assist morphosyntactic analysis for text enrichment or learning production analysis (Chapter 6), neither of which would excite TEL researchers. However, although the accuracy of tools such as natural language processing may not be foolproof as direct feedback to learners, nonetheless they can be important tools for giving the teacher an easy way of checking learners' outputs.

Funding for TEL research does not typically begin by analysing the most critical problems in education that could be solved using technology. Funding is generated either for research on new technologies as speculative solutions or for researching educational problems. For the two to come together research funding has to identify the enhancement of learning through technology as a unified research field, and not rely simply on the happy coincidence that disparate research funding traditions might some day find each other. From the work done within the Scientific Quality Committee in Kaleidoscope, which used an international committee of experts to identify research funding sources for TEL, both national and international, it was clear that there were very few such calls that bring together education and technology as an interdisciplinary field. When research funding sources recognise the importance of TEL research that is targeted on user requirements and policy aims (see for example, www.tlrp.org/e-learning) the field is able to progress as it should, with users and practitioners closely involved.

17.5.2 A Disruptive Technology

TEL research provides both opportunities and threats to the teacher. The opportunities lie in the new forms of learning and teaching opened up to them. The threats lie in the disruptive nature of digital technology. This is probably the most important factor that tends to inhibit adoption of TEL. It is not a simple addition to a classroom or educational process. The opportunities it offers for more flexible, adaptive and learner-centred ways of learning require a fundamental rethink of teaching and learning. Without this, the technology can simply be an inconvenience or can even reduce learning effectiveness if it is used inappropriately.

It is well recognised that teachers' practices tend to change slowly, particular if the values they hold seem to be threatened by the innovation. One recent study offers the example of the teacher role as being to "orchestrate" learning through the use of a collaborative tool, and this is disruptive of the classroom and so affects adoption (Chapter 10). Where things do change they are often brought into the service of existing approaches rather than being allowed to overturn them (Cuban, 2001). It is less risky to use technology simply to improve current practice. This may be a

sensible response – the concerns in medical education around patient safety have an echo in concerns about the well-being of students (Luengo et al., 2008). There are ethical implications for carrying out research in education where, by definition, the outcome of the process is unknown. Teachers may wish to avoid taking such risks themselves, until something they find persuasive convinces them that it is a risk worth taking. The problem with this is that low risk usually means sub-optimal outcomes. Technology is not being exploited for what it can do best and is not serving the reform the educational system needs.

New technology is also disruptive because of the new skills it requires of teachers, as for all professionals. The e-literacy skills demanded by the spread of new technology are being acquired by teachers, as they are by students, to meet their personal requirements. The majority of teachers in European countries are by now probably familiar with the skills required for word-processing, e-mail, web-searching and Internet transactions, by virtue of their leisure and domestic transactions. This reduces the hurdle for using new technology in teaching and shows how quickly new technology can be adopted when it fits the requirements for personal value, utility and usability. The design issue for TEL, therefore, is to reduce the disruption entailed by new technology by creating tools and services that fit teachers' and learners' requirements as well as commercial and leisure technology does. Meanwhile, the optimal implementation model being adopted by most institutions is gradualist and incremental, bringing in e-mail, websites for information about courses, VLEs for the dissemination of lecture slides and for discussion forums, interactive whiteboards for presentation – all the technologies that enhance existing teaching methods and are therefore neither risky, nor disruptive, and therefore not transformational.

17.5.3 The Role of Assessment

Assessment is one of the teachers' responsibilities that creates most stress; and rightly, because the design and deployment of assessment activities profoundly affect students' lives. TEL can be highly beneficial, if used well, but, for good or ill, it unquestionably changes assessment.

By changing the nature of the learning process, and what can be learned, TEL outputs inevitably challenge conventional forms of assessment and lead to requirements for different kinds of assessment (Schoonenboom & Levene, 2007). A similar example comes from inquiry-based learning (IBL), which enables learners to create their own representations of knowledge as models, animations and diagrams (Chapter 2). As learners become creative participants in a knowledge-building process they are acquiring skills and knowledge in a different way, matching the demands of the world of work, but it means they need to be assessed in a different way. It is not sufficient to assess what they know, as this does not represent their skills. In the transmission model of teaching the skills developed by learners were revision skills of recall and re-representation of the knowledge

taught. The unseen exam was an appropriate assessment method, and success clearly measured those skills. The same unseen exam for students who use IBL will measure what they know, but cannot represent the different possible ways of *coming to know*. It would be possible to recall and re-represent a very clear account of a concept that looks little different from that of a student who has built their own account of it. An employer who wants someone to be able to précis a report will be content with the former assessment; an employer who wants someone to research a local issue will need the applicant with the latter skills and therefore needs an assessment method that is capable of identifying them.

The workplace in a knowledge economy needs people who can think for themselves; TEL provides the means to rehearse learners in these skills. The education system cannot escape the responsibility of embracing those two facts in a programme of assessment reform. It is difficult, and risky, however, to change so much – what is learned, how it is learned and how it is assessed. TEL does not demand this change, it is an enabler. It is the effect of knowledge technologies on the world of work and leisure that makes the demand, and our job in education is to respond to that. It is not a task that can be shouldered by the individual teacher. In the final section we consider how it might be addressed.

17.6 Characteristics of the Local Implementation Context that Affect Adoption

17.6.1 Senior Management Support

The successful implementation of learning technology requires a fundamental re-think of the organisation of teaching and learning within an institution because it affects not just the transactions between teachers and learners, but the distribution of resources and support for teaching as well. These changes are so fundamental that full implementation cannot be carried out within one part of the system – it has to be systemic. This puts the onus on senior managers in an institution to lead and promote the change process.

One recent study of enterprise-wide e-learning in a telecom company found that the support the training administrator received from their senior manager was crucial to a unit's successful adoption of e-learning (Netteland, Wasson, & Mørch, 2007).

The bottom-up change that teachers could effect themselves is likely to be slow in education systems that more commonly operate top-down:

Education systems change slowly because they tend to be hierarchical command-control systems, rather than devolved-power adaptive systems. Teachers and lecturers are given neither the power nor the means to improve the nature and quality of the teaching-learning process through technology (Laurillard, 2008a: 324).

This has long been argued as an aspect of our quality assurance systems that needs to change if education is to adapt to its environment within a reasonable timescale (Elton, 1999).

The hierarchical organisation of education is therefore also one of the reasons that institutions have been slow to implement technology-enhanced learning:

The education system is run by leaders who are not comfortable with either the detail or the implications of the technology potential, and those who are, are not powerful enough within the system. There has been radical change in some institutions, demonstrating the importance of leadership. Institution leaders need the direction to be set at national level, and they need more support for the changes they must direct within their own institutions (Laurillard, 2008a: 324).

For this reason, the UK national strategy for e-learning in education made support for leadership as one of the main priorities (Department for Education and Skills, 2005).

17.6.2 Multiple Contexts

The introduction of new technologies into the management of educational institutions has already had a disruptive effect on the way they operate: the boundaries break down between home and work, and across departments and staff, as a result of the open networking now made possible. Networking and access to mobile devices necessarily creates multiple contexts for working (see Chapter 14). The same is true for students. Teachers designing online learning experiences must recognise that the Internet is not easily bounded, and their students are expert navigators within that world. They cannot ignore it, but they can make a virtue of it. Students are enthusiastic users of online networking, and with careful design of an educational equivalent, they can be nurtured into using their skills effectively for learning. Similarly, the easy mobility afforded by mobile devices makes it easier to access different learning contexts.

For teachers, this means orchestrating learning across multiple contexts. The learning system can reach beyond the classroom into more authentic contexts for learning, and for applying theoretical concepts. An online collaborative learning system can collect and manage data from several groups of students and compile the results in a meaningful way for the teacher (Chapter 1), enabling them to adjust and differentiate the kind of scaffolding they offer to individuals and groups. For teachers to maintain some degree of control over these multiple contexts in which their students are working, it will be important for them to have appropriate monitoring tools, as in the context of learners using “trails” in exploration of a real-world environment (Chapter 12).

Similarly, it has been shown that the design of collaborative learning systems (both the technological and the pedagogical aspects) needs to address the extent to which the instructors and tutors can get feedback on the student’s collaboration process during the deployment of the learning activity (Wasson, Guribye, &

Mørch, 2000). For example, Wake (2002) found that the facilitators (instructors and tutors) felt that their ability to follow the students' progress in the learning activity was difficult and thus their ability to give feedback was limited. In the DoCTA project, pedagogical agents were added to a collaborative learning tool that provided the teacher with information on the students' collaboration and suggested ways in which teacher might want to respond (Chen & Wasson, 2003, 2004). Intelligent agents of this kind will be essential features of support tools for teachers, as the multiple online courses they are tutoring each foster a multiplicity of learner contexts of engagement. The complexity of these parallel social worlds of teacher–learner encounters can only become more elaborate in future, so digital management tools will be essential.

The value of multiple contexts made possible through networking is also demonstrated in research projects that build links between educational institutions. It is difficult for any one educational institution to provide the kind of flexibility in curriculum and teaching methods that personalisation requires, so collaboration across institutions is an important way of achieving this. Each contributes to the other and benefits by more than they contribute, if the collaboration is managed sensitively. The DoCTA study shows that a learning environment that is shared across distributed learning spaces, such as two schools, requires careful adjustment and greater flexibility of timetables in the two schools (Wasson & Ludvigsen, 2003). Inevitably, this involves institutional managers in the collaboration, which underlines the importance of their involvement in the change process. It cannot be done by teachers alone.

There is also growing interest in the way that particular pedagogic approaches can operate in multiple contexts. For example, storytelling is a powerful approach for education, both for its motivational value and for the structure it provides (Chapter 4). It enables the learner to organise concepts and relations, and thereby internalise them more easily. Some TEL resources, as may be expected, are particularly well suited to a small number of disciplinary contexts. Technology-enhanced language learning approaches will be of obvious benefit for language-related subjects, and also to any TEL learning activity where learners need to learn how to use language carefully, which is relevant to any discipline (Chapter 6). However, all disciplines develop their own languages and technical terms, and so resources such as intelligent glossaries – because they relate to the *process* of doing work in a discipline, not just the subjects under study – may be of value across disciplinary contexts.

17.6.3 Summary

The common recommendation to enable implementation is to combine “top-down” and “bottom-up” approaches. This mantra is hard to disagree with, but really says very little. Of course managers need to promote and support change and teachers need to work to incorporate this into their practices. What is often ignored, however, are the innumerable structural changes that accompany this and the ongoing

discussions needed in order to make these changes. These discussions will be much easier when the alterations required make sense to those involved and accord with their own beliefs and values.

17.7 TEL as a Catalyst for Changes in Pedagogy

17.7.1 *The Teacher as Facilitator*

Because digital technologies embody such a wide range of media and services they can be used to provide an elaborated virtual learning environment that works alongside the physical and social educational environments to support the full range of relationships within the learning process. One such example is “situated multi-environment learning tools”, an open learning system that supports visualisation, communication and re-elaboration, creative exploration of problem-solving, representation and justification of knowledge, and the social relations between teachers and learners (Chapter 5).

If the teacher is able to decide the level of control they exert on their learners’ use of such an environment, it becomes a highly flexible tool for their learning design, enabling them to adjust the learning process to the needs of individual and groups of learners. The teacher is therefore a kind of “conductor” of the learning process – or “orchestrator” (Chapter 1) or “narrator” (Chapter 4).

This kind of innovation makes the setting into which TEL is introduced very significant, as it will inhibit adoption unless it is adapted to the capabilities of the new system. The learning objectives, the content, and the roles of teachers, all need to be examined with respect to how they need to change (Chapter 5). The teacher is sometimes offered what sounds like an unexciting role of “facilitator” in this new world. But if this term means anything, it is not simply someone who marshals resources and organises students into learner-focused self-help groups. Taking into account the kinds of arguments made throughout this book, the teacher becomes “a facilitator of the learning process”, which means they take responsibility for what and how a student learns, and set up the learning environment within which it becomes possible for every learner to achieve their learning potential. In their study of collaborative knowledge-building in middle school, Wasson and Ludvigsen (2003) saw evidence that the teacher is extremely important in *supporting, stimulating and motivating* the students *to integrate previous knowledge* with their new knowledge.

Not all TEL research, nor its implementation in practice, attends very much to the needs of the teacher. There is a danger that the increasingly common idea of the teacher as facilitator could effectively de-skill teachers if it were misinterpreted as a low-level skill. In fact teachers should be seen as centre stage – enabling learners to learn by marshalling a much greater variety of learning experiences and opportunities. This is a highly skilled role that makes teachers more like reflective practitioners in the practice of their profession – perhaps we should even regard teaching as a form of “design science”?

17.7.2 The Teacher as a Designer of Learning

With this kind of development TEL research helps to professionalise the teacher, giving them the opportunity to create the ideal learning environment for all their students, and greatly extending their practice beyond the capability of conventional methods. This is significant shift in the role of the teacher, and teachers will need supportive systems to help them build the skills and orientation to this new way of working (Chapter 3). Fortunately, while TEL research is building support for learner collaboration, the same tools and environments can be used to support teachers in the discovery and development of their new capabilities as “designers of learning” and “educational innovators”.

Systems that offer collaborative learning environments could be used to support collaborative learning among teachers, in their discovery of how best to use TEL (Laurillard, 2007). Online communities developing around authoring environments such as LAMS (Learning Activity Management System¹), and learning object repositories such as MERLOT (Multimedia Education Resources for Learning and Teaching OnLine²) are the early stages of the kind of collaboration that could enable teachers to work together as “reflective practitioners”, progressing their field, as researchers do (Laurillard, 2008b; Schön, 1987).

We know from TEL research on computer supported collaboration scripts that external scripts scaffold learner participation in collaborative learning activities and engage them in high-level collaboration processes. We can apply that same result to the teacher “as learner”. One recent study argues that external scripts can be seen as part of the learning environment (Chapter 10). By scaffolding the collaborative learning process, there is evidence that learners are able to work on tasks and engage in activities that they normally would not, and that their expectations change. They give an example where the expectation of having to present their results to peers leads to better elaboration of the learning material and to more knowledge construction. In the same way, we could imagine that a collaborative learning design tool for teachers, scaffolding their decision-making about learning design, could help them think more constructively and more innovatively, as they work together on learning design. How external scripts are integrated into wider social environments such as classrooms is one of the challenging issues related to the instructional design of computer supported collaboration scripts. They also point to a need to learn more about how to facilitate the teacher’s authoring of such scripts. One way would surely be to provide a collaborative tool that fosters a teaching community in developing this knowledge for themselves (Laurillard, 2008a).

If teachers do eventually become TEL designers, it will be important for them to be able to share their designs and to build on models generated by others. Such models must include representations of knowledge, diagnosis and didactic decision-making, which can help the teacher develop a well-designed educational interven-

¹ created at Macquarie University – <http://www.lamsinternational.com/>

² based in North America – <http://www.merlot.org/>

tion. There is a continuing interest in the idea of shareable learning designs, going beyond what is envisaged in the IMS LD specification (IMS-LD, 2003), and the projects continuing in this area will continue to challenge that specification.

17.7.3 New Relationships with Knowledge

The knowledge economy, fuelled by knowledge technologies, is changing what we know, and how we come to know it. At several points in our discussion, notably in relation to curriculum pedagogy, and assessment, we have seen how our relationship with knowledge and its representation is changing due to new technology. Bottino and colleagues summarise the main factors that make TEL in the workplace successful as follows: authenticity, visibility and complexity (Chapter 5). However, the authors argue that this conclusion would be valid across other educational sectors as well. The interesting outcome from this work is the reciprocal relationship between knowledge and pedagogy – each opens up new possibilities for the other. This is certainly a principle that will travel across educational sectors. New kinds of knowledge, such as the modelling of an organisational system, require new kinds of pedagogy, which focus on the construction and sharing of models. New kinds of high-level cognitive skill, such as the distillation of critical information from many diverse information sources, require new kinds of pedagogy, which rehearse students in searching, identifying, evaluating and selecting, with appropriate feedback on those processes. Conversely, the use of new technology in the workplace means that learners can experience authenticity through digital tools because they are the same tools as those used in the workplace. This is not a “virtual” work experience; it is the real experience of the digital world of the worker.

17.8 Concluding Points: Strategic Approaches to the Implementation of TEL Research

The discussion set out in the sections of this chapter demonstrates a need for a holistic, systemic approach to TEL adoption and implementation, whether at national, institutional or departmental level. TEL implementation has to be carried out with an awareness of national strategies for educational reform and an EU-wide approach to educational collaboration. Technology makes its best contribution when it is implemented in the service of high-level strategic ambitions, less so when we use it “because it’s there”. Educational policy has been clearly defined within the EU and its nation states, and given the scale of its ambition, it needs the assistance of technology, used well. We have tried to set out some of the requirements for implementation to succeed.

We conclude that the route from research to innovation, then to practice, through to mainstream implementation requires the following:

- An understanding of the authentic professional contexts that will influence the curriculum, pedagogy and assessment practices that need technology enhancement.
- Congruence between innovation and teacher values.
- Teachers having time to reflect on their beliefs about learning and teaching because TEL requires a more structured and analytical approach to pedagogy.
- Teachers and practitioners need a sense of ownership through their involvement in co-development of the TEL products and environments.
- TEL research must be conducted to reflect the interdependence between researchers and users.
- Education leaders need more support for the radical change of institutional teaching and learning models needed, if technology is to be exploited effectively.
- Teachers need to be more closely engaged in the design of teaching that uses technology, collaborating with peers and exchanging ideas and practices.

Education systems in all the EU countries are still in the relatively early stages of mainstream implementation of digital technologies for enhancing learning. We have assembled some of the key lessons learned in recent research and development projects. Through building and sharing this knowledge, we will develop gradually more successful ways of ensuring the technology achieves its potential to enhance learning.

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