Learning from multimedia and hypermedia

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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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P. Gerjets (✉)
Knowledge Media Research Center, University of Tübingen, Tübingen, Germany
e-mail: pgerjet@gwdg.de

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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 rational 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, & Merril, 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 developed 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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