Education Tech Research Dev (2008) 56:93–100
DOI 10.1007/s11423-007-9064-3

RESEARCH ARTICLE

Advances in scaffolding learning with hypertext and hypermedia: a summary and critical analysis

Roger Azevedo · Michael J. Jacobson

Published online: 28 September 2007

Hypermedia learning environments such as the World Wide Web and CD based multimedia encyclopedias are extensively used in education, frequently with the intent of helping students learn challenging educational subjects. However, we caution educators, instructional designers, and researchers not to be seduced by design approaches for hypermedia environments that allow learners to access, manipulate, or restructure multiple representations of information while receiving little or no scaffolding during learning. As the authors of this special issue demonstrate, learning with hypertext and hypermedia is challenging for learners of all ages and that systematic and carefully designed research is needed in order to contribute to our understanding of how to promote learning with non-linear systems such as these. We further argue that hypermedia design approaches should be informed by empirical research with multiple methodologies from various disciplines rather than adopting ad hoc or intuition-based approaches to designing and evaluating educational hypermedia. Furthermore, our conceptions and formulations of scaffolding have deviated from the original conception (i.e., Wood et al. 1976) of the construct so much that there is some confusion and a general lack of synthesis regarding the nature, role, and effectiveness of scaffolding in learning with hypermedia (see Azevedo and Hadwin 2005; Jacobson, this volume). What we need is a concerted effort by researchers from various fields to conduct theoretically-driven laboratory and classroom research from which to draw scientifically-based principles for the design of hypermedia-based learning environments intended to foster students' learning about complex and challenging topics.

The papers in this special issue hopefully represent principled steps towards addressing such issues. The goal of this article is to summarize the papers in this volume, and to

R. Azevedo (✉)
Department of Psychology, Institute for Intelligent Systems, University of Memphis, 400 Innovation Drive, Memphis, TN 38152, USA
e-mail: razevedo@memphis.edu

M. J. Jacobson
Learning Science Laboratory, National Institute of Education, Nanynag Technological University, Singapore, Singapore
e-mail: mjjacobson@mac.com

provide a brief discussion and critique of issues regarding theoretical, empirical, and educational issues related to scaffolding learning with hypermedia.

Overview and summaries of the articles

The first paper by Jacobson (this volume) describes a set of theory and research issues associated with the use of hypermedia learning environments in problem-based pedagogical environments involving cases. This work is based on Jacobson et al.'s earlier research with hypertext and hypermedia environments (Jacobson and Archodidou 2000; Jacobson et al. 1996; Jacobson and Spiro 1995) as well as seminal research findings from the learning and cognitive sciences (Bransford et al. 2000). He provides an extensive review of the literature related to problem-based learning, knowledge transfer, and conceptual change, and proposes a design framework for a scaffolded hypermedia system intended to support PBL with cases. He provides preliminary results from two studies involving a comparison of several types of scaffolding intended to advance college students and graduate students' scientific knowledge about conceptual perspectives emerging from the study of complex systems.

Shapiro's (this volume) conceptual paper focuses on the role of prior knowledge and metacognition in scaffolding learning with hypermedia. The paper is based on Shapiro's (1999, 2000, 2005) long-standing empirical research using Kintsch's (1988) construction and integration theory in examining the differences between learners' prior knowledge, level of metacognition, and system structure (e.g., linear vs. hierarchical) and the influence of these factors on learning with hypermedia. Shapiro conceptualizes the design of hypermedia-assisted learning (HAL) environments in terms of the interaction between learner characteristics and system features and its influence on hypermedia learning as part of student-centered pedagogical approaches. She proposes several theoretically-driven and empirically-based guidelines for the design of hypermedia learning systems.

Azevedo et al. (this volume) report on an experimental study involving the comparison between a human tutor condition (external regulating agent) and a control condition (no human agent) on college students learning about the circulatory system with hypermedia. Their multi-method experimental study investigated several learning outcome measures (e.g., declarative knowledge and mental models) as well as employed think-aloud process data to examine the deployment of self-regulatory processes during learning. Their study is based on theoretical frameworks and models of self-regulated learning (SRL; Azevedo 2005, in press; Pintrich 2000; Winne 2001) and is part of a series of empirical studies aimed at testing the effectiveness of adaptive and non-adaptive scaffolding in hypermedia to foster learners' understanding of science topics. The results reported in their paper provide evidence of the superiority of adaptive scaffolding during learning about the circulatory system and documents the deployment of key self-regulatory planning, monitoring, and learning strategies needed to develop conceptual understanding of science topics.

The final paper in the special issue, by Gerjets et al. (this volume), presents a set of studies designed to empirically assess the instructional potential of hypermedia environments for improving schema acquisition from worked-out examples. Their work is informed by extensive research from cognitive science on schema acquisition, problem solving, cognitive load, and transfer of skills (Catrambone 1998; VanLehn 1989) and their own extensive research program on cognitive issues related to learning with multimedia and hypermedia (Gerjets and Hesse 2004; Gerjets et al. 2000). More specifically, they

tested two methods for enhancing comparisons between elaboration prompts and an interactive comparison tool on learners' problem solving performance and near-transfer problems.

Theoretical, empirical, and research issues

The overall quality of research on learning with hypermedia and hypertext has frequently been criticized on theoretical, research, and analytical grounds (e.g., Azevedo 2005, in press; Dillon and Gabbard 1998; Dillon and Jobst 2005; Jacobson et al. 1996, this volume; Shapiro and Neiderhauser 2004; Tergan 1997a, 1997b). The first major issue is that the majority of the research is atheoretical and based on intuition regarding the design of hypermedia system features. Many of the published studies fail to adopt a theoretical framework to guide the research questions, to determine the types of data collection methods and corresponding analyses, and to draw appropriate inferences from which to inform scientifically based design guidelines (see Jacobson and Archodidou 2000 for an example of theoretically-based guidelines). It is also surprising to see how many published studies merely prescriptively mention cognitive flexibility theory (Spiro et al. 1992; Spiro and Jehng 1990) or Mayer's (2005) multimedia learning theory without empirically testing the underlying assumptions or the design recommendations of these two leading theories. In addition, a majority of the quantitative studies lack methodological rigor, employ inadequate research designs, use incomparable conditions, fail to control for confounding variables, misuse statistical analyses, and often violate statistical assumptions (e.g., small cell sizes).

In contrast, the studies presented in this special issue are theoretically-driven and based on research traditions from the learning and cognitive sciences. The authors examine learning with hypertext and hypermedia by using existing theoretical frameworks, and hopefully their corresponding methods and analytical approaches will contribute to our evolving scientific understanding of learning with hypermedia. For example, contributors to this special issue have used theory and research on conceptual change, text comprehension, schema theory, problem solving research, analogical encoding, and self-regulated learning to guide their investigations into learning with hypermedia. It is clear from the articles in this special issue that each adopted theory has its own assumptions, conceptions of learning, research methods, and analytical approaches that in turn have implications for learning. The theoretical plurality of these approaches contributes to the knowledge base of the research literature and also models alternatives to atheoretical research on hypermedia, which we hope will encourage other researchers to explicitly adopt theoretical frameworks to guide their research on learning with hypermedia.

In addition to theoretical plurality, the papers in this special issue exemplify a variety of research questions, methodologies, and analytical approaches in their investigations of learning with hypertext and hypermedia. The majority of research studies presented in this special issue used random assignment of learners into treatment conditions where the experimental group received some form of scaffolding (e.g., ontological, adaptive). Three of the papers employed pretest assessments of the content knowledge to be studied or learned (Azevedo et al., Jacobson and Shapiro, this volume), with collection of process data in the form of think-alouds during task performance or learning (Azevedo et al.). Subsequently, participants were post-tested to assess the construction of new knowledge from learning activities or task performance. In addition, the studies comprise a range of learners from adolescents (including middle-school and high-school students;

see Azevedo et al., this volume; Gerjets et al., this volume) to college students (Jacobson, this volume; Shapiro, this volume; Gerjets et al., this volume), and graduate students (Jacobson, this volume).

The hypermedia environments used in the special issue papers included researcher-developed systems and commercial packages. The learning sessions tend to be longer than what is typically found in the literature. The studies in this special issue range from a 40-minute learning session to approximately five hours and one month in Jacobson's paper (this volume). Dependent variables used in the four research projects included problem solving performance, time spent on studying examples, time spent on retrieved examples, declarative knowledge, and mental models. Lastly, Azevedo et al.'s paper also captured process data from think-alouds to analyze the deployment of self-regulatory processes used by both the learners and the human tutor during leaning with hypermedia. In sum, the papers presented in this special issue present well-articulated, theoretically-based, and empirically-driven studies on learning with hypertext and hypermedia.

Scaffolding issues: what, when, how, and by whom or what

Another major issue in this volume is the role of scaffolding in learning with hypermedia. Scaffolding may be viewed as dealing with four major questions: what, when, how, and whom or what. Each question will be described below along with an analysis of how they pertain to the studies in this special issue. The issue of scaffolding learning with hypertext and hypermedia has recently received some criticism and has been a source of continuing debate (see Azevedo and Hadwin 2005; Jacobson, in press; Pea 2004; Putanbmbekar and Hubscher 2005). The major criticism has been a lack of adherence to the original conception of scaffolding as proposed by Wood et al. (1976), which includes assumptions of dynamic assessment, graded support during learning, and fading of all support once the student demonstrated competency in problem solving (see Pea 2004 for an extensive review of the issues and the historical perspective). Puntambekar and Hubscher (2005) outline the major differences between the original conception and the current conception of scaffolding as used by educational and learning science researchers in learning with computer-based learning environments such as hypertext and hypermedia.

What to scaffold?

In general, this question asks whether to focus on the topic or domain (e.g., circulatory system, complex systems) or the learning processes underlying domain learning (e.g., metacognitive processes, problem solving, and self-regulatory processes) or both content and processes. The four studies in this special issue focused on different aspects of these three possible combinations of *what* to scaffold. Determining what to scaffold is a difficult issue that researchers need to consider carefully when designing their studies on learning with hypermedia. The answer relates not only to the theoretical approach and research questions but also learner characteristics such as the learner's level of prior knowledge, developmental level, and domain expertise. Research suggests that learners who have low prior knowledge, are younger students, and lack domain expertise necessitate both content and process scaffolding. In contrast, high prior knowledge learners and those with domain expertise may need process scaffolding rather than content scaffolding. In addition, the content scaffolding needed to support high prior knowledge learners is also shown to

qualitatively differ from the process scaffolding for low prior knowledge students (e.g., Azevedo 2005; Shapiro and Neiderhauser 2004). This particular issue was not explicitly explored in the papers in the special issue, but is an area that future research should further investigate.

When and how to scaffold?

This question deals with the timing of administering or making scaffolding available to the student during learning. It also relates to whether the scaffolding is always, selectively, or adaptively available as well as the delivery method (e.g., embedded as part of the interface, provided by an adaptive agent). Adaptively varying the scaffolding is based on the assumption that someone (e.g., human agent, teacher, peer) or something (e.g., adaptive pedagogical agent, intelligent tutoring system) is monitoring the learner's progress during learning and determines when to administer the scaffold to facilitate learning. The majority of the studies presented in this special issue have experimentally manipulated students' access to scaffolding that is built-in to the experimental manipulation and presented as an interface element. As such, some researchers have used embedded scaffolds that are ever-present and available to the student throughout the instructional episode or learning session and it is the students' responsibility to determine when to access and use the scaffolds. These scaffolds are usually designed to facilitate metacognitive monitoring, present lists of sub-tasks or sub-skills to facilitate the procedural sequencing through the task, provide problem-solving or conceptual support, and so on. Some approaches to scaffolding simply focus on one specific process (e.g., Azevedo's metacognitive monitoring), whereas others might focus on different types or levels, such as Jacobson's (this volume) use three levels of scaffolding related to concepts, ontologies, and problem solving to foster learning about complex systems. Shapiro (this volume) employed a design that embedded the scaffolding into the interface design of a system, by contrast, Azevedo et al.'s (this volume) used a human agent who followed a human tutoring script and deployed process scaffolding during learning, with each scaffold specifically aimed at particular content (e.g., after reading the introduction to the circulatory system the learner was prompted by the human tutor to summarize what they had just read). A related issue of concern in the field relates to the fading of scaffolding. None of the special issue papers explicitly dealt with this issue since the scaffolding was not faded during the respective studies, although the use of human-aided scaffolding by Azevedo's group allowed a certain degree of fading to occur. The fading issue is a critical one to be addressed as researchers start to conduct longitudinal studies involving both macro-level and micro-level analyses of domain understanding (e.g., Jacobson, this volume) and emerging skills and regulatory processes (e.g., Gerjets et al., this volume) that increase the time-scale of learning from hours to more extended duration periods of use over days and weeks. It should also be noted that the computational fading of scaffolding will probably require the utilization of intelligent or adaptive agent technologies in conjunction with the hypermedia functionality (Azevedo et al. 2005; Brusilovsky 2001; Jacobson 2006).

Whom or what scaffolds?

This question is related to the delivery system. Should a human, teacher, or peer provide the scaffolding or does an agent in the hypermedia system provide it? The issue of delivery

has regained attention as some researchers have begun to focus on artificial agents to scaffold learning (see Kim and Baylor 2006). The majority of studies in hypertext and hypermedia use embedded system features to deliver the scaffolds or scaffolding through interface elements. The set of studies in this special issue exemplify this ladder approach to providing scaffolding. For example, Jacobson's (this volume) hypermedia environment used hyperlink provided scaffolds embedded in the hypermedia cases and problem solving activities for student to access and Shapiro (this volume) used system features such as site maps, annotations capabilities, and navigational prompts to scaffold students' learning. An important unanswered research question is whether the additional technological machinery that would be necessary to create intelligent adaptive hypermedia that machine controlled the fading of scaffolding would in fact be superior to current non-adaptive designs in which the learner metacognitively assumes control over utilizing scaffolds by accessing them when needed and "fading" (i.e., not using) when they are not needed.

In sum, the area of scaffolding in hypermedia and learning technologies remains a viable area of research that should be approached empirically. Many theoretical and conceptual questions remain to be addressed and models to be tested related to the *when, how, when, and by whom or what* of scaffolds and scaffolding. Increasing technological advances make it easier to test some of these issues but they should not be based on intuition or technology-only approaches.

Summary

In this special issue we have presented exemplars of current research on learning with hypertext and hypermedia. The focus of each paper has been on examining the different roles for the use of scaffolding to enhance learning with hypermedia. The papers discuss various laboratory and classroom studies involving learners of all ages (from middle school to graduate school), learning about several topics and domains, and learning with both researcher developed and commercially available hypertext and hypermedia environments. The research presented in each paper is based on existing theoretical models and that manipulated aspects of hypermedia scaffolding, including the amount and types of scaffolding, the delivery of the scaffolds or scaffolding, on students' learning about complex and challenging topics. The studies used a combination of product data (e.g., learning outcomes from pretest-posttest measures) and one study converged product and processes data (based on think-aloud protocol analysis). In general, the results of these studies indicate that scaffolding learning with hypermedia is critical for sustaining and fostering learning with these systems and that several learner characteristics (e.g., developmental level, domain expertise, prior knowledge), system features (site maps, navigational support), scaffolds (static versus dynamic, human versus artificial, ever-present interface elements versus delivered by a human agent based on content covered), and learning processes (problem solving, reasoning, metacognitive monitoring, self-regulatory processes) interact in a complex manner that affect students' learning as assessed by a several measures (e.g., declarative knowledge, mental models, transfer tasks, comprehension tests). Overall, it is important to emphasize that the design of viable and effective hypermedia environments that employ appropriate scaffolding techniques for the level of the learner and the content knowledge must be based on theoretical and research based principles. Further, given the ubiquity of globally distributed hypermedia such as the World Wide Web, it will also be important to find ways to make these research based

principles more widely known to a wider range of researchers and commercial developers of learning technologies that employ hypermedia functionality.

References

Azevedo, R. (in press). The role of self-regulation in learning about science with hypermedia. In D. Robinson & G. Schraw (Eds.), *Current perspectives on cognition, learning, and instruction.*

Azevedo, R. (2005). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist, 40*(4), 199–209.

Azevedo, R., Cromley, J. G., Winters, F. I., Moos, D. C., & Greene, J. A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional Science, 33*, 381–412.

Azevedo, R., & Hadwin, A. F., (2005). Scaffolding self-regulated learning and metacognition: Implications for the design of computer-based scaffolds. *Instructional Science, 33*, 367–379.

Azevedo, R., Moos, D. C., Greene, J. A., & Winters, F. I. (this volume). Why is externally-facilitated learning more effective than self-regulated learning with hypermedia? *Educational Technology Research & Development*, doi: 10.1007/s11423-007-9067-0.

Bransford, J. D., Brown, A. L., Cocking, R. R., & Donovan, S. (Eds.). (2000). *How people learn: Brain, mind, experience, and school (expanded edition).* Washington, DC: National Academy Press.

Brusilovsky, P. (2001). Adaptive hypermedia. *User Modeling and User Adapted Interaction, 6*(2–3), 87–110.

Catrambone, R. (1998). The subgoal learning model: Creating better examples to improve transfer to novel problems. *Journal of Experimental Psychology: General, 127*, 355–376.

Dillon, A., & Gabbard, R. (1998). Hypermedia as educational technology: A review of the quantitative research literature on learner comprehension, control, and style. *Review of Educational Research, 68*(3), 322–349.

Dillon, A., & Jobst, J. (2005). Multimedia learning with hypermedia. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 569–588). Cambridge, MA: Cambridge University Press.

Gerjets, P. H., & Hesse, F. W. (2004). When are powerful learning environments effective? The role of learning activities and of students" conceptions of educational technology. *International Journal of Educational Research, 41*, 445–465.

Gerjets, P., Scheiter, K., & Schuh, J. (this volume). Information comparisons in example-based hypermedia environments: Supporting learners with processing prompts and an interactive comparison tool. *Educational Technology Research & Development*, doi: 10.1007/s11423-007-9068-z.

Gerjets, P., Scheiter, K., & Tack, W. H. (2000). Resource-adaptive selection of strategies in learning from worked-out examples. In L. R. Gleitman & A. K. Joshi (Eds.), *Proceedings of the 22nd annual conference from the cognitive science society* (pp. 166–171). Mahwah, NJ: Erlbaum.

Jacobson, M. J. (2006). From non-adaptive to adaptive educational hypermedia: Theory, research, and design issues. In G. Magoulas & S. Chen (Eds.), *Advances in web-based education: Personalized learning environments* (pp. 302–330). Hershey, PA: Idea Group.

Jacobson, M. J. (this volume). A design framework for educational hypermedia systems: Theory, research, and learning emerging scientific conceptual structures. *Educational Technology Research & Development*, doi: 10.1007/s11423-007-9065-2.

Jacobson, M., & Archodidou, A. (2000). The design of hypermedia tools for learning: Fostering conceptual change and transfer of complex scientific knowledge. *Journal of the Learning Sciences, 9*(2), 149–199.

Jacobson, M. J., & Azevedo, R. (this volume). Advances in scaffolding learning with hypertext and hypermedia: Theoretical, empirical, and design issues. *Educational Technology Research & Development*, doi: 10.1007/s11423-007-9066-1.

Jacobson, M. J., Maouri, C., Mishra, P., & Kolar, C. (1996). Learning with hypertext learning environments: Theory, design, and research. *Journal of Educational Multimedia and Hypermedia, 5*(3/4), 239–281.

Jacobson, M. J., & Spiro, R. J. (1995). Hypertext learning environments, cognitive flexibility, and the transfer of complex knowledge: An empirical investigation. *Journal of Educational Computing Research, 12*(5), 301–333.

Kim, Y., & Baylor, A. L. (2006). A social-cognitive framework for pedagogical agents as learning companions. *Educational Technology Research & Development, 54*(6), 569–590.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction integration model. *Psychological Review, 95*, 163–182.

Mayer, R. (2005). Cognitive theory of multimedia learning. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31–48). NY: Cambridge University Press.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *Journal of the Learning Sciences, 13*, 423–451.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451–502). San Diego, CA: Academic Press.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist, 40*(1), 1–12.

Shapiro, A. (1999). The relationship between prior knowledge and interactive overviews during hypermedia-aided learning. *Journal of Educational Computing Research, 20*(2), 143–167.

Shapiro, A. (2000). The effect of interactive overviews on the development of conceptual structure in novices learning from hypermedia. *Journal of Educational Multimedia & Hypermedia, 9*, 57–78.

Shapiro, A. M. (2005). Site map principle. In R. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 313–324). London, UK: Cambridge University Press.

Shapiro, A. (this volume). Hypermedia design as learner scaffolding. *Educational Technology Research & Development*, doi: 10.1007/s11423-007-9063-4.

Shapiro, A., & Niederhauser, D. (2004). Learning from hypertext: Research issues and findings. In D. H. Jonassen (Ed.), *Handbook of research for education communications and technology* (2nd ed). Mahwah, NJ: Erlbaum.

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1992). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. M. Duffy & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 57–75). Hillsdale, NJ: Lawrence Erlbaum Associates.

Spiro, R. J., & Jehng, J. C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix & R. Spiro (Eds.), *Cognition, education, and multimedia* (pp. 163–205). Hillsdale, NJ: Lawrence Erlbaum Associates.

Tergan, S. (1997a). Conceptual and methodological shortcomings in hypertext/hypermedia design and research. *Journal of Educational Computing Research, 16*(3), 209–235.

Tergan, S. (1997b). Misleading theoretical assumptions in hypertext/hypermedia research. *Journal of Educational Multimedia and Hypermedia, 6*(3–4), 257–283.

VanLehn, K. (1989). Problem solving and cognitive skill acquisition. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 527–579). Cambridge, MA: MIT Press.

Winne, P. H. (2001). Self-regulated learning viewed from models of information processing. In B. Zimmerman & D. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 153–189). Mawah, NJ: Erlbaum.

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 17*(2), 89–102.

Roge Azevedo is an Associate Professor in the Department of Psychology at the University of Memphis. His research interests include the role of self-regulated learning about challenging science topics with open-ended learning environments and using computers as metacognitive tools for enhancing learning.

Michael J. Jacobson is a Faculty Researcher at the Singapore Learning Sciences Laboratory and an Associate Professor in the Learning Sciences and Technology Academic Group at the National Institute of Education (NIE), Nanyang Technological University in Singapore. His research has focused on the design of learning technologies such as 3D multi-user virtual environments and hypermedia to foster deep conceptual understanding, conceptual change, and knowledge transfer in challenging conceptual domains. Most recently, his work has explored cognitive and learning issues related to the design of learning technologies to help students understand new scientific perspectives emerging from the study of complex and dynamical systems.