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Extending the scaffolding metaphor

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Abstract. A brief overview overview is provided of how the scaffolding metaphor has been defined in educational contexts. This includes a discussion of what theories guide decision-making regarding what to scaffold as well as considerations as to whom or what does the scaffolding (human teachers, peers and tutors or computer tutors or support tools designed for learning environments). The scaffolding construct intersects instruction and assessment in that instructors assess learners to determine what type or level of scaffold is sufficient to help learners reach their potential. Such assessments are dynamic and ongoing and can occur through dialogue and social interactions with or without the use of technology. Hence scaffolds are provided when and where necessary but they are also removed when evidence of learning exists. This article describes how the contributors to this issue have extended the scaffolding metaphor to open-ended technology based environments. Empirical studies are reviewed with regard to how they extend the scaffolding metaphor in terms of the theories that guide the design of scaffolds, the metrics designed to assess how scaffolding affects learning and in terms of teaching scaffolding techniques to others.

Contributors to this issue provide data that support the value of scaffolding in specific instructional situations. Scaffolding is described in two contexts: as performed by human teachers, tutors or peers, and by computers. Most importantly, they define what they mean by a scaffold and they provide guidelines for designing them. The contributors broaden the definitions of scaffolding by describing how a self-regulation framework can provide a more complete representation of scaffolding and consequently enhance the learning experience. Additionally, they provide empirical research that addresses the inter-relatedness and dynamics of self regulated learning (SRL) variables: cognitive, motivational/affective, behavioral, and contextual during the cyclical and iterative phases of planning, monitoring, control, and reflection during learning from hypermedia environments. An additional contribution that these researchers provide is illustrations of scaffolding of individuals as well as communities of learners.

A brief discussion of instructional scaffolding is provided first as a way to contextualize the contributions of this issue.

Defining scaffolding

Scaffolding through human guidance

The use of the word scaffold has different meanings depending on which context one is using the term. A common definition of a scaffold, as found in the Encarta® World English Dictionary (© 1999 Microsoft Corporation) is that a scaffold is a temporary framework of poles and planks that is used to support workers and materials during the construction or modification of a building. Once the job is done the scaffold is removed. If one pushes the scaffold metaphor to an educational context one must assume that a scaffold is also a temporary framework to support learners when assistance is needed and is removed when no longer needed. Determining what to scaffold, when to scaffold, how to scaffold and when to fade scaffolding are core questions. These questions that are determined by the domain in question, the tasks involved, what you want learners to accomplish and the individual differences that need to be addressed in such contexts.

The term scaffolding was used by Jerome Bruner (Wood et al., 1976) to describe the process in which a child or novice could be assisted to achieve a task that they may not be able to achieve if unassisted, until they are able to perform the task on their own. This definition was influenced by Vygotsky's (1978) conception of the zone of proximal development which is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). The implication is that individuals have learning potential that can be reached with scaffolding provided by tutors, parents, teachers, and peers.

A scaffold is, by definition, a temporary entity that is used to reach one's potential and then is removed when learners demonstrate their learning. Support is calibrated for the learner and task and alters as a learner appropriates control and encounters new challenges (Stone, 1998). Collins et al. (1989) articulated the transitory nature of scaffolding when proposing a cognitive apprenticeship model of instruction. There are four parts to their model pertaining to pedagogical content, methods, sequence, and sociology of instruction. The pedagogical methods section of their model is the most pertinent to the discussion of scaffolding. Real world apprenticeship settings provide opportunities for novices to learn from experts by participating in tasks that lead to the overall goals of the setting (see Lave & Wenger, 1991 for a description of a tailoring apprenticeship). An apprenticeship, by nature, takes time and novices acquire skills through scaffolding by experts and deliberate practice. Likewise, a cognitive apprenticeship takes time and the pedagogical methods must model the cognitive skills and strategies for learners, as well as scaffold learners when assistance is needed to reach their goals. Once learners demonstrate competence, hints or scaffolds are removed (or faded gradually) to ensure that learners can independently demonstrate their competence and articulate their knowledge without assistance. Independent learning is the goal of a cognitive apprenticeship and this independence is fostered by providing opportunities for students to reflect on their knowledge as well as to apply their knowledge through explorations in new contexts.

Scaffolding provided through computer guidance

The above definitions of scaffolding also apply to the notion of computer scaffolding and feedback, which has its own history in the areas of artificial intelligence and education and intelligent tutoring systems.[1] There is an extensive literature on intelligent tutoring systems, that includes the process of scaffolding, that cannot be summarized in this paper but that should be considered when investigating scaffolding (see Sleeman & Brown, 1982; Anderson et al., 1985; Psotka et al., 1988; Merrill et al., 1992; Corbett et al., 1997; Koedinger et al., 1997; Shute & Psotka, 1996). Intelligent tutoring systems are designed based on cognitive task analyses of the domains or tasks in question which result in: the determination of an underlying model of the curriculum and problems to be solved; an expert model(s) of performance on such problems, and; a student model of performance that is updated dynamically as individuals solve problems. The intelligent tutoring system uses the student model to assess what a student knows and needs to know and provides scaffolds based on this model and fades assistance accordingly.

Another relevant area that explores the different types of scaffolds that can be provided by computers is the one pertaining to computers as cognitive tools (Pea, 1985; Perkins, 1985; Salomon et al., 1991; Derry & Lajoie, 1993, Jonassen & Reeves, 1996; Lajoie, 2000, 2005). Researchers in the cognitive tools area cover a wide spectrum of scaffolding approaches that include modeling and scaffolding by computer and human tutors or by the structure of the tools embedded within the computer based learning environment. Some cognitive tools lead to deeper understanding by helping individuals actively reorganize their knowledge (Pea, 1985), or reflect on their own problem solving processes, such as hypothesis generation and data collection.

Computer technology can also serve as a matching service that can link the right type of expert to scaffold a particular student's learning. Greer et al. (1998, 2000) designed a peer help system for students in computer science who needed assistance with their programming skills. The system would be able to provide links to peers and tutors who would be "ready, willing, and able" to help students who requested help. Once a helper was found, the student needing help and the helper would interact on-line to help solve the student's problem. Greer et al. created an economy around the help system: getting help had a cost. Helpers were paid in "credit units" that were internally maintained by the students needing help (who had bank accounts stocked by the system with an appropriate number of credit units). Students needing help would negotiate with potential helpers as to the cost of the help. The economy served two purposes. One purpose was to limit the number of helpers sought by students needing help (since there was a cost to getting help) and the other purpose was to motivate peers and tutors to make themselves available to provide help (since help was paid for). The system had natural constraints. For instance, if a student wanted the most skilled expert to answer a question and the expert was busy he/she might charge more than a less busy but less skilled helper would charge. The student thus determines if it is worth it to go for the best advice or to settle for hopefully "good enough" advice. In the long run, it was hoped that this economy would naturally evolve to reflect in credit units the real costs of helping, such as the time a helper took to give help, and would stimulate appropriate decision making by the student needing help, such as the seriousness of the problem the student was facing.

The role of assessment

When students do not request help a mechanism needs to be in place for when to provide scaffolding. Cognitive apprenticeship models in the area of reading, writing and mathematics (Collins et al., 1989) speak to the issue of dynamic assessment in the sense that decisions are made on what and when to scaffold as well as when to fade (see Palinscar & Brown, 1984; Scardamalia & Bereiter, 1985; Schoenfeld, 1985). Dynamic assessment can be described as the moment-by moment assessment of learners while they are in the process of problem solving for the purpose of making informed decisions about feedback (Lajoie & Lesgold, 1992; Pellegrino et al., 2001; Lajoie, 2003). Dynamic assessment implies that human or computer tutors can evaluate transitions in knowledge representations and performance while learners are in the process of solving problems, rather than after they have completed a problem. Immediate feedback in the form of scaffolding can then be provided to learners during problem solving, when and where they need assistance. The purpose of assessment in these situations is to improve learning in the context of problem solving, while the task is carried out. The advantage of dynamic assessment by computers is that information relevant to domain learning can be captured in a continuous record of changes in knowledge, skill, and understanding as students encounter problems of increasing complexity (Frederiksen, 1990).

Integrating scaffolding provided by humans and computers

The role of dialogue and social interaction play a large role in educational scaffolding (Lajoie & Azevedo, in press). Evidence of this role was demonstrated in research investigating: (a) comprehension and monitoring activities (e.g., Palinscar & Brown, 1984), (b) student-generated self-explanations (e.g., Chi et al., 1994; Chi, 2000), (c) instruction (e.g., telling the student a fact), (d) cognitive scaffolding that helps the student solve a problem on his or her own (e.g., hinting) (e.g., Merrill et al., 1995), (e) motivational scaffolding (e.g., feedback on student performance) (Lepper et al., 1997), and (f) tutor question-asking (e.g., Graesser et al., 1997). In addition to the social aspects of scaffolding, technology itself when designed to provide cognitive tools, can also serve to scaffold learning (Pea, 1985; 2004).

Recently, there have been two special issues dedicated to discussions about scaffolding, one in the Journal of the Learning Sciences (2004) and this issue. In the former issue Pea (2004) reports on the need for mixed initiative designs (Carbonell, 1970) that include human and computer support for learning. The suggestion is that this mix would result in more ideal learner outcomes given that the human touch affords more opportunities for building on student affect and motivation. Lepper (1988) has long proposed the need to bring the heart (motivation) and brain (cognition) together when considering student learning. He has systematically studied such issues as student interest, learner control, personal identity, personal challenge and affect in his research on learning. Similarly, Snow (1989) proposed an assessment model that considered individual differences in cognitive and conative structures and their relationship to learning. Finally, Pea (2004) reminded us that scaffolding must consider both cognitive and motivational aspects of learning.

This special issue edited by Azevedo & Hadwin raises another scaffolding dimension that should be considered, namely, metacognition and the components of self-regulation. The contributions found in this issue are described below.

Taken together the papers in this special issue demonstrate how theories can guide the design of both human and computer scaffolds. Theories of self regulated learning, metacognition, expertise, mental models and personal epistemologies drive the systematic assessment of change in each of the complex settings described by the authors. Secondly, there are new methodologies documented in these papers for coding complex learning situations within computer based learning environments as well as for plotting trajectories of learning over time. Lastly, computer based environments are described in multiple ways, for instance, simulations, hypermedia, hypertext, web based distributed learning and so forth. Each contributor addresses how theories of SRL drive the design of scaffolding.

Why scaffolding?

The premise of these papers is that learning in open ended technology-based environments, i.e., hypermedia environments, is difficult and that there is a greater chance of learners becoming disengaged if they do not receive adequate assistance. For example, Winne and Hadwin's (1998) model of self-regulation has been used by Azevedo and colleagues to examine students' learning with hypermedia because it defines the interplay between learner characteristics, the hypermedia environment and the mediating self-regulatory processes. Learning with hypermedia environments requires learners to regulate their learning, to make decisions about what and how to learn, how much time to spend on a task, how to access other instructional material, when to abandon or modify plans and strategies, and when to increase effort (Winne 2001).

The papers by Azevedo et al. (2005) and Hadwin et al. (2005) speak directly to the need for scaffolds in hypermedia environments that foster SRL. In particular, they analyze human scaffolding in such contexts as a precursor to developing models that can inform the future design of computer scaffolds in hypermedia environments.

Azevedo et al. (2005) examine the effects of scaffolding in a hypermedia environment designed to inform adolescents about the circulatory system. Scaffolds were defined as tools, strategies and guides to support students in regulating their learning. The effects of three scaffolding conditions (adaptive, fixed and no scaffolding) were investigated to determine their effectiveness in facilitating changes in students' mental models of the circulatory system and whether or not they demonstrate SRL (planning, monitoring, strategy use, task difficulties and demands) in each condition.

In the adaptive scaffolding condition a human tutor provides individualized support based on ongoing diagnosis of a student's level of understanding. Adaptive scaffolding, as described in the paper, matches current definitions of dynamic assessment in that scaffolding is individualized and based on assessing what a student knows and understands to ensure that the student has the ability to learn with tutorial assistance. Additionally, the adaptive scaffolds are designed to guide students' understanding by helping them plan their learning through activation of prior knowledge; monitoring emerging understanding by having them engage in a feeling of knowing and judgment of learning. In contrast, the fixed scaffolds consisted of instructions to use a list of 10 domain specific sub-goals to guide their learning about the circulatory system.

The coding scheme developed for the data analysis in this paper is worthy of replication since it allows researchers to examine whether or not students demonstrate SRL in each condition. Furthermore, mental model progression was also coded to note knowledge changes over time. Students in the adaptive and non-scaffolded conditions demonstrated more increases in declarative knowledge outcomes than the fixed scaffolding condition. One might predict that any scaffolding is better then none. However, it could be possible that the students in the non-scaffolded condition had to work harder in constructing their knowledge and hence recalled information more readily. Those who received adaptive scaffolds outperformed students in all conditions in that they demonstrated greater shifts in mental models, increase activation of their prior knowledge more, engaged in more frequent and regulated planning, monitored their cognitive activities and progress toward learning goals, and engaged in help seeking and effective strategy usage. The fixed scaffold condition demonstrated the least change from pre to post assessment.

Based on their analyses Azevedo et al. will design a database of computer scaffolds for SRL based on how human tutors responded to student questions across different age groups. Given that this database is based on an analysis of human tutoring of SRL it will be an interesting test of whether human tutoring can be translated into computer scaffolds in open-ended environments. The results of such work across different age groups will be a solid test of the model they derived (see Azevedo et al., 2004). It might be possible that simple prompting of SRL components and processes can make a difference if in fact there is a way to assess the level of the students' prior knowledge with technology prior to scaffolding in this fashion. However, the type of learning tasks and outcomes should influence the effectiveness of different types of scaffolding. Thus, the question remains if the same SRL scaffolds would be effective across tasks, for example, problem based, recall, comprehension, model building and testing of models through simulations. Furthermore, if SR is situation specific (Schunk, 2001) then can general SRL prompts really be effective or does each task need the type of in-depth analysis demonstrated in Azevedo et al. research.

Whereas the Azevedo research describe situations where tutors directly scaffolded SRL learning the Hadwin et al. (2005) research examined a naturalistic setting to see how SRL was appropriated over time within a graduate course. Hadwin et al. examine each phase of SRL as a complex interplay between learner and the social context that frames and supports the task. In particular, they examined teacher-student discourse within the context of a research methods course to provide evidence that students can appropriate the SR language of their instructors over the course of the year. A theory driven discourse analysis consisted of coding the teacher-student dialogue with regard to the presence of scaffolding and fading in the context of phases (task definition, goal setting and planning, enacting, evaluating/adapting,) and facets (cognition, motivation, behavior and metacognition) of SRL (Pintrich, 2000; Zimmerman & Schunk, 2001).

Hadwin et al. describe scaffolding as a mechanism for relinquishing control of SRL to students once they develop competence and mastery in a specific context. They describe scaffolding as a gradual withdrawal of help while others describe scaffolding as a mechanism for providing assistance. As stated above, the withdrawal of assistance is usually referred to as fading support (Collins et al., 1989; Pea, 2004; Puntambeker & Hübscher, 2005). McCaslin and Hickey (2001) describe teacher-student interactions as commencing with the co-regulation of learning and transitioning toward SRL. Hadwin et al. build on this analysis in their own research describing teacher-directed regulation, co-regulation and student directed regulation to see when co-regulation stops and self-regulation takes over. This coding paradigm speaks to the socio-cultural aspects of SRL in that they are looking at the teacher-student dialogues to see when SRL is appropiated. However, it would have been interesting to code their data using a cognitive apprenticeship approach, examining what was modeled, scaffolded and faded in the context of teaching graduate students to be independent producers and critiques of research methods.

To summarize, Hadwin and colleagues found evidence of sociocultural perspectives of SRL transitions from teacher to student in both facets and phases of SRL. Through their coding schemes they were able to document scaffolding of SRL components and phases as well as when fading occurred and SRL commenced. Students appropriated SR across phases by adopting strategies and techniques used by teachers when directly regulating the same phases. Documenting such transitions is an important methodological step that could be replicable in other domains. As with the Azevedo research this study demonstrates that scaffolds are not static but dynamic entities that change to fit student needs and are taken away when there is evidence that assistance is no longer needed.

Hadwin et al. suggest that their research on SRL could lead to the effective design of pedagogical agents that can support learners. They recognize the challenge in designing adaptive scaffolds for metacognition and SRL since more research is needed to determine what scaffolds are effective, when to scaffold, and how to scaffold. Eslinger et al. (2004) made some advances in this regard, examining how a community of pedagogical advisors or agents can assist learners over time in the context of software designed to promote science inquiry. Their strategy was to integrate self-assessments with pedagogical agent support. The agents could adapt feedback based on students' self-assessment and needs. Computer scaffolding can be linked to students' own determination of needs (see Greer et al., 1998, 2000). However, students are not always aware of what they know or do not understand.

The Avededo & Hadwin papers provided evidence of human scaffolding of SRL with conclusions as to how such evidence could inform future computer design decisions. Puntambekar and Stylianou (2005) describe how the computer environment itself can or can not scaffold learning. Hypermedia environments can enhance learning or produce cognitive overload. The cognitive advantage of such environments is that viewing materials from multiple perspectives increases cognitive flexibility and interconnections (Spiro et al., 1991) however it could also lead to cognitive disorientation (Marchionini, 1988). Puntambekar & Stylianou designed two studies to examine learning in hypermedia contexts, to see whether learning in hypermedia environments was more effective with scaffolding.

CoMPASS (Puntambekar & Stylianou, 2002) is an environment designed to promote learning about force and motion through multiple representations for learning that include concept mapping, hypertext and text help. Study 1 was designed to examine students' navigation patterns using CoMPASS as a way to determine the influence of concept maps on learning. Students were involved in design-based projects and were to make connections between hands on activities and the conceptual information that they read in CoMPASS. Student navigation patterns were analyzed to determine their influence on learning and to classify paths into clusters so that support could be presented based on a specific decision path. They defined four types of meta-navigation support based on their cluster analysis and defined support to help them monitor and regulate these processes in order to accomplish their learning goals.

Study 2 examined the effectiveness of scaffolding based on the path analysis in study 1. One group received navigational scaffolds based on mapping an individual's response to a specific navigational path and the control group did not receive support. Students in the support group performed better than the control group on the concept mapping task. Puntambekar & Stylianou designed a Pathfinder algorithm that is used to compare navigational paths, analyze the proximity of nodes visited, as well as the trajectories. Through this methodology they were able to identify both frequency of concepts visited, as well as the depth of the node structure. They defined richness and depth ratios for this purpose. The richness ratio was the ratio of number of connections made to the number of concepts visited. The depth ratio was the ratio of scores for explanation of connections with the number of connections. The scaffolded map version led to more expert-like performance in that knowledge is more tightly interconnected, deeper and richer. They conclude that scaffolding knowledge structure through these types of tools can lead to better understanding.

The results of these two studies prompt interesting questions, such as when is the right time to provide support for monitoring navigation behavior, how much exploration time should students have before providing support, do all learners need support? In essence, the need for adaptive scaffolding in hypertext environments is supported by this research as well since specific problem solving paths were scaffolded with different types of assistance. The richness and depth ratios introduced in this research provide good tools for assessing learner growth in the hypermedia environments. These metrics combined with the pathway trajectories start to define learning in context and how and when SRL components change over time.

In addition to the hypermedia and hypertext environments described above, Dabbagh and Kitsantas (2005) state web-based pedagogical tools (WBPT), i.e., WebCT, add another layer of complexity to learning that requires a higher demand for SRL. They report that achievers in face-to-face learning situations are goal oriented, use various task strategies to accomplish goals, self monitor their progress, self evaluate, help seek and manage time efficiently (Zimmerman and Kitsantas, 1999; Kitsantas et al., 2004). They voice concern that even these students may not be prepared for the high level of SRL and control required in web based or distributed courses (Whipp & Chiarelli, 2005). They describe both the opportunities and the complexities of distributed course events. While these opportunities are motivating they require SRL to achieve student goals.

Dabbagh & Kitsantas describe scaffolding and fading of SRL in the context of WBPT. In particular they describe how different categories of WBPT support different SR processes. That is, collaborative and communication tools support goal setting, help seeking, time management and planning; content creation and delivery tools support self evaluation, task strategies and goal setting; hypermedia tools support task strategies; and administrative tools support self monitoring and help seeking. These results were determined by examining student perceptions of the usefulness of WBPT in supporting completion of course assignments and the SRL processes activated when different WBPT were used.

Although there is no doubt of the potential of WBPT, one must keep in mind that it is the instructors' use of the tools that is pedagogical rather than the tool itself. It is quite possible that what Dabbagh & Kitsantas describe could be viewed as best pedagogical practice rather than the WBPTs themselves. Availability of tools alone is not enough. Such tools need to be embedded in the instructors' pedagogical goals and made transparent to students for engagement to occur. In order for a tool to support SRL in this context there has to be the pedagogical goal of promoting SRL. Perhaps a more extensive discussion of the theories behind the instructors choice of web-based learning activities, the emphasis on problem solving and inquiry, and exploration could reflect the promotion of SRL rather than the distributed learning event or the WBPTs themselves.

On-line courses often encourage small group discussions about course content. Choi et al. (2005) look at ways of scaffolding small group discussions by providing peer-questioning strategies to facilitate metacognition while learning about turf-management. Three types of peer questioning strategies were created – clarification or elaboration questions, counter arguments and perspective-oriented questions. The data analysis consisted of scoring both the frequency of questions posed and rubrics for identifying the quality of questions. Choi et al. report that the frequency of questions increased and clarification questions were the most dominant type of question posed. However, no differences were found in initial answers, final answers, or gains across discussion sessions. Although students were scaffolded in the types of questions to ask, the quality of the discourse did not improve. When students had sufficient domain knowledge they were able to construct appropriate questions. However, those with less knowledge had difficulty constructing effective questions. Questions alone were not enough to prompt deeper thinking.

Choi et al. conclude that explicit modeling and training of the discussion prompts prior to the study may have produced better results. However, it seems that the questioners could have benefited from more adaptive scaffolding of how to scaffold others. Choi et al. suggest that automatic windows for prompting questions on the types of scaffold may be more beneficial in the future. However, given that prior knowledge is an issue in constructing appropriate questions there may be a limitation in a menu driven approach to computer scaffolding.

Extending the scaffolding metaphor through empirical research

Pea (2004) points out that computer mediation provides an opportunity for empirically testing the effectiveness of whether computer scaffolds are effective as well as determining rules for when to scaffold and when to fade assistance. This issue points to the relevance of scaffolding in technology rich environments that are used in an open ended manner, such as hypermedia, hyper-navigation tools, internet resource tools, and web-based pedagogical tools.

Contributors in this issue have started to extend the scaffolding metaphor by elaborating the theoretical frameworks for defining scaffolding. Early discussions about what to scaffold used to center around cognitive skills and strategies but, as reviewed earlier, there has been a trend toward including more conative, affective and motivational scaffolds to enhance learning. John Self at a panel discussion in 1997[2] boldly stated that what we need are computers that care. Pea (2004) reaffirmed this message by stating that mixed methods of human and computer scaffolds will more likely have the human touch. The theoretical expansion to scaffolding presented in these papers deal with SRL which more broadly speak inclusively to scaffolds pertaining to cognition, behavior, motivation and metacognition.

In addition to theoretical considerations researchers conducted empirical studies to test their predictions about scaffolding. Their findings inform our understanding about scaffolding, how it effects learning across age groups, the appropriation of SRL over time in naturalistic settings, peer-questioning strategies, and the effectiveness of WBPT in distributed learning events.

An additional benefit that these papers present are methodologies that can be used to document the presence and effectiveness of scaffolding. Theory-driven discourse methodologies were designed to investigate the use of scaffolds in developing and appropriating SRL over time, and their influence in transitions in mental models, conceptual understanding, and quality of question-posing. Path analysis, metrics and rubrics were all informative in this regard.

To conclude, theory and research are extending our definitions of scaffolding, what it is, what we should scaffold, how we should scaffold, who or what should do the scaffolding and how we determine the effectiveness of such scaffolds. Given the complexity of the issue, and the confluence of terminology that informs scaffolding (tutoring, feedback, scaffolding, assistance, embedded assessment, dynamic assessment, diagnostic monitoring) progress is slow but steady.

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Notes

1. For those interested in these areas there are regular international conference proceedings for the Artificial Intelligence and Education (IAIED)and for Intelligent Tutoring Systems.

2. IAIED conference in Kobe. Volume 13, 2003 of the International Journal of Artificial Intelligence and Education has a special issue that pursues the issue of caring for the learner in honour of John Self.

References

Anderson, J.R., Boyle, C. & Reiser, B. (1985). Intelligent tutoring systems. *Science* 228: 456–462.

Azevedo, R., Cromley, J.G. & Seibert, D. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of Educational Psychology* 96(3): 523–535.

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* (5–6): 381–412 (this issue).

Carbonell, J.R. (1970). AI in CAI: An artificial intelligence approach to computer-assisted intstruction. *IEEE Transactions on Man-Machine Systems* 11(4): 190–202.

Chi, M.T.H., de Leeuw, N., Chiu, M.-H. & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science* 18: 439–477.

Chi, M.T.H. (2000). Self-explaining: The dual processes of generating inference and repairing mental models. In R. Glaser, eds, *Advances in Instructional Psychology: Educational Design and Cognitive Science*, Vol. 5, pp. 161–238. Mahwah, NJ: Erlbaum.

Choi, I., Land, S.M. & Turgeon, A.J. (2005). Scaffolding peer-questioning strategies to facilitate metacognition during online small group discussion. *Instructional Science* 33 (5–6): 483–511 (this issue).

Collins, A., Brown, J.S. & Newman, S.E. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L.B. Resnick, eds, *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*, Vol. 5, pp. 453–494. Hillsdale, NJ: Erlbaum.

Corbett, A.T., Koedinger, K.R. & Anderson, J.R. (1997). Intelligent tutoring systems. In M.G. Helander, T.K. Landauer and P. Prabhu, eds, *Handbook of Human-Computer Interaction*, Vol. 5, pp. 849–874. 2nd edition, Amsterdam, The Netherlands: Elsevier Science.

Dabbagh, N. & Kitsantas, A. (2005). Using web-based pedagogical tools as scaffolds for self-regulated learning. Instructional Science 33 (5–6): 513–540 (this issue).

Derry, S.J. & Lajoie, S.P. (1993). A middle camp for (un)intelligent computing. In S.P. Lajoie and S.J. Derry, eds, *Computers as Cognitive Tools*, Vol. 5, pp. 1–11. Hillsdale, NJ: Erlbaum.

Eslinger, E., White, B., Frederiksen, J. & Bush, K. (2004, April). A software tool for scaffolding inquiry science learning. paper presented at the Annual American Educational research Association Conference, San Diego.

Frederiksen, N. (1990). Introduction. In N. Frederiksen, R. Glaser, A. Lesgold and M. Shafto, eds, *Diagnostic Monitoring of Skill and Knowledge Acquisition.*, Vol. 5, pp. ix–xvii. Hillsdale, NJ: Erlbaum.

Graesser, A.C., Bowers, C.A., Hacker, D.J. & Person, N.K. (1997). An anatomy of naturalistic tutoring. In K. Hogan and M. Pressley, eds, *Effective Scaffolding of Instruction*. Brookline Books.

Greer, J.E., McCalla, G.I., Cooke, J.E., Collins, J.A., Kumar, V.S., Bishop, A.S. & Vassileva, J.I. (1998). The Intelligent HelpDesk: Supporting Peer Help in a University Course. In *Proceedings for the Intelligent Tutoring Conference,* San Antonio, Texas, LNCS No1452, pp. 494–503. Springer Verlag: Berlin.

Greer, J.E., McCalla, G.I., Cooke, J.E., Collins, J.A., Kumar, V.S., Bishop, A.S. & Vassileva, J.I. (2000). Integrating cognitive tools for peer help: The intelligent intraNet peer help-desk project. In S.P. Lajoie, eds, *Computers as Cognitive Tools (Vol.2): No More Walls*, Vol. 5, pp. 69–96. Mahwah, NJ: Erlbaum.

Hadwin, A.F., Wozney, L. & Pontin, O. (2005). Scaffolding the appropriation of self-regulatory activity: A socio-cultural analysis of changes in student-teacher discourse about a graduate research portfolio. *Instructional Science* 33 (5–6): 413–450 (this issue).

Jonassen, D.H. & Reeves, T.C. (1996). Learning with technology: Using computers as cognitive tools. In Jonassen D.H., eds, *Handbook of Research for Educational Communications and Technology*, Vol. 5, pp. 693–719. New York: Simon and Schuster.

Kitsantas, A., Reiser, B. & Doster, J. (2004). Goal setting, cues, and evaluation during acquisition of procedural skills: Empowering students' learning during independent practice. *Journal of Experimental Education* 72(4): 269–287.

Koedinger, K.R., Anderson, J.R., Hadley, W.H. & Mark, M. (1997). Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education* 8: 30–43.

Lajoie, S.P. (2000). Breaking camp to find new summits. In S.P. Lajoie, eds, *Computers as Cognitive Tools (Vol.2): No More Walls*, Vol. 5, pp. xv–xxxii. Mahwah, NJ: Erlbaum.

Lajoie, S.P. (2003). Transitions and trajectories for studies of expertise. *Educational Researcher* 32(8): 21–25.

Lajoie, S.P. (2005). Cognitive tools for the mind: The promises of technology: Cognitive amplifiers or bionic prosthetics?. In R.J. Sternberg and D. Preiss, eds, *Intelligence and Technology: Impact of Tools on the Nature and Development of Human Skills*, Vol. 5, pp. 87–102. Erlbaum: Mahwah, NJ.

Lajoie, S.P., Azevedo, R. (in press). Teaching and learning in technology-rich environments. In P. Alexander and P. Winne, eds, *Handbook of Educational Psychology* (2nd ed.). Erlbaum: Mahwah NJ.

Lajoie, S.P. & Lesgold, A. (1992). Dynamic assessment of proficiency for solving procedural knowledge tasks. *Educational psychologist* 27(3): 365–384.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lepper, M. (1988). Motivational considerations in the study of instruction. *Cognition and Instruction* 5(4): 289–309.

Lepper, M.R., Drake, M. & O'Donnell-Johnson, T.M. (1997). Scaffolding techniques of expert human tutors. In K. Hogan and M. Pressley, eds, *Scaffolding Student Learning: Instructional Approaches and Issues*, Vol. 5, pp. 108–144. New York: Brookline Books.

Marchionini, G. (1988). Hypermedia and learning: Freedom and chaos. *Educational Technology* 28(11): 8–12.

McCaslin, M. & Hickey, D.T. (2001). Self-regulated learning and academic achievement: A Vygotskian view. In B.J. Zimmerman and D.H. Schunk, eds, *Self-regulated Learning and Academic Achievement*, Vol. 5, pp. 227–252. Mahwah, NJ: Lawrence Erlbaum Associates.

Merrill, D.C., Reiser, B.J., Ranney, M. & Trafton, J.G. (1992). Effective tutoring techniques: A comparison of human tutors and intelligent tutoring systems. *The Journal for the Learning Sciences* 2(3): 277–305.

Merrill, D.C., Reiser, B.J., Merrill, S.K. & Landes, S. (1995). Tutoring: Guided learning by doing. *Cognition and Instruction* 13(3): 315–372.

Palinscar, A.S. & Brown, A.L. (1984). Reciprocal teaching of comprehension – fostering and monitoring activities. *Cognition and Instruction* 1: 117–175.

Pea, R.D. (1985). Beyond amplification: Using the computer to reorganize mental functioning. *Educational Psychologist* 20: 167–182.

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.

Pellegrino, J., Chudowsky, N. & Glaser, R. (2001). *Knowing what students know*. National Academy of Science.

Perkins, D.N. (1985). The fingertip effect: How information processing technology shapes thinking. *Educational Researcher* 14: 11–17.

Pintrich, P.R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. Pintrich and M. Zeidner, eds, *Handbook of Self-regulation*, Vol. 5, pp. 451–502. Academic Press: San Diego, CA.

Psotka, J., Massey, L.D. & Mutter, S.A. (1988). *Intelligent tutoring systems: Lessons learned*. Hillsdale, NJ: Erlbaum.

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

Puntambeker, S. & Stylianou, A. (2002). Students' use of external representations in science learning. In P. Bell, R. Stevens & T. Satwicz (eds.). *Keeping Learning Complex: The Proceedings of the Fifth International Conference of the Learning Sciences (ICLS)*, pp. 352–358. Mahwah, NJ: Erlbaum.

Puntambekar, S. & Stylianou, A. (2005). Designing navigation support in hypertext systems based on navigation patterns. *Instructional Science* 33 (5–6): 451–481 (this issue).

Salomon, G., Perkins, D.N. & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher* 20: 10–16.

Scardamalia, M. & Bereiter, C. (1985). Fostering the development of self-regulation in children's knowledge processing. In S.F. Chipman, J.W. Segal and R. Glaser, eds, *Thinking and Learning Skills: Research and Open Questions*, Vol. 5, pp. 563–577. Hillsdale, NJ: Erlbaum.

Schoenfeld, A.H. (1985). *Mathematical problem solving*. NY: Academic Press.

Schunk, D.H. (2001). Social cognitive theory and self-regulation. In B.J. Zimmerman and D.H. Schunk, eds, *Self-regulated Learning and Academic Achievement*, Mahwah, NJ: Lawrence Erlbaum Associates.

Shute, V.J. & Psotka, J. (1996). Intelligent tutoring systems: Past, present, and future. In D. Jonassen, eds, *Handbook of Research for Educational Communications and Technology*, Vol. 5, pp. 570–600. New York, NY: Macmillan.

Sleeman, D.H. & Brown, J.S. (1982). *Intelligent tutoring systems*. London: Academic Press.

Snow, R.E. (1989). Toward assessment of cognitive and conative structures in learning. *Educational Researcher* 18(9): 8–14.

Spiro, R.J., Feltovich, P.J., Jacobson, M.J. & Coulson, R.L. (1991). Cognitive flexibility constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational Technology* 31(5): 24–33.

Stone, C.A. (1998). The metaphor of scaffolding: Its utility for the field of learning disabilities. *The Journal of Learning Disabilities* 31: 344–364.

Vygotsky, L.S. (1978). *Mind and Society: The Development of Higher Mental Processes*. Cambridge, MA: Harvard University Press.

Whipp, J.L. & Chiarelli, S. (2005). Self-regulation in a Web-based course: A case study. *Educational Technology Research and Development* 52(4): 5–22.

Winne, P.H. (2001). Self-regulated learning viewed from models of information processing. In B. Zimmerman and D. Schunk, eds, *Self-regulated Learning and Academic Achievement: Theoretical Perspectives*, Vol. 5, pp. 153–189. Mahwah, NJ: Erlbaum.

Winne, P.H. & Hadwin, A.F. (1998). Studying as self-regulated learning. In D.J. Hacker, J. Dunlosky and A. Graesser, eds, *Metacognition in Educational Theory and Practice*, Vol. 5, pp. 277–304. Hillsdale, NJ: Erlbaum.

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

Zimmerman, B.J. & Kitsantas, A. (1999). Acquiring writing revision skill: Shifting from process to outcome self-regulatory goals. *Journal of Educational Psychology* 91: 1–10.

Zimmerman, B.J. & Schunk, D.H. (2001). *Self-regulated learning and academic achievement*. Mahwah, NJ: Lawrence Erlbaum Associates.