Education Tech Research Dev (2009) 57:767–785
DOI 10.1007/s11423-009-9117-x

DEVELOPMENT ARTICLE

Re-examining cognition during student-centered, Web-based learning

Michael Hannafin · Kathleen Hannafin · Bruce Gabbitas

Published online: 27 March 2009

Abstract During student-centered learning, the individual assumes responsibility for determining learning goals, monitoring progress toward meeting goals, adjusting or adapting approaches as warranted, and determining when individual goals have been adequately addressed. This can be particularly challenging while learning from the World-Wide Web, where billions of resources address a variety of needs. The individual must identify which tools and resources are available and appropriate, how to assemble them, and how to manage and support their unique learning goals. We analyze the applicability of cognitive principles to learning from Web-based multimedia, review and critically analyze issues related to cognition and student-centered learning from Web-based multimedia, and describe implications for design research and practice.

Keywords Student-centered learning · Web-based learning · Cognitive complexity

This paper is based, in part, on a presentation made during the 2008 IADIS international conference on Cognition and Exploratory Learning in the Digital Age (CELDA), Freiburg, Germany and a paper published [Hannafin and Hannafin (2008). Cognition and student-centered, Web-based learning: Issues and implications for research and theory. In D. G. Kinshuk, J. M. Sampson, P. Spector, D. Isaías, & D. Ifenthaler (Eds.), *Proceedings of the IADIS international conference on cognition and exploratory learning in the digital age* (pp. 113–120). Freiburg, Germany: IADIS].

M. Hannafin (✉)
University of Georgia, 601 Aderhold Hall, Athens, GA 30602, USA
e-mail: Hannafin@uga.edu

K. Hannafin
University of Georgia, 614 Aderhold Hall, Athens, GA 30602, USA
e-mail: Khannafi@uga.edu

B. Gabbitas
University of Georgia, 609 Aderhold Hall, Athens, GA 30602, USA
e-mail: Gabbitas@uga.edu

The application of didactic methods when applied to direct teaching-learning of multimedia has been well-documented (see Dillon and Gabbard 1998). Much of this research has focused on the learning of externally defined knowledge and skills facilitated through cognitively-rooted, design principles. Indeed, many time-tested, research-based learning and cognition principles may be applicable across technologies. However, some research may prove of questionable applicability to student-centered, Web-based learning. In this paper, we examine the cognitive implications of student-centered learning in Web-based environments, compare the cognitive demands of student-centered and externally directed learning, and describe implications for research and practice.

Web-based learning, per se, is not inherently student-centered in nature. Rather, it may be externally-directed, student-directed, free-choice, or combinations of each (see Berge and Mrozowski 2001; Bernard et al. 2004). In directed online learning, for example, the boundaries are often specified explicitly by course designers, such as by identifying required resources, specifying learning and performance expectations, and assessing students over defined concepts and constructs (Sharma et al. 2007). Indeed, the student may seek resources beyond the boundaries established by the designer but the structures define and support the expected learning and performance (Hannafin and Hill 2007). Similarly, learning and performance needs may be highly specific in nature and require only specific answers rather than reasoning. In both instances, student effort is directed via external design structures.

In contrast, Hannafin et al. (1999) described student-centered learning where the locus of activity and control shifts to individual responsibility for establishing learning goals and/or determining learning means. Rather than posing direct questions that require correct or incorrect answers, for example, Blumenfeld et al. (1991) implemented "problem[s] that serves to organize and drive activities [that] result in a series of artifacts, or products [where] students can be responsible for the creation of both the question and the activities, as well as the nature of the artifacts" (p. 371). Linn et al. (2003) described a Web-based environment (WISE) that scaffolds middle schoolers' scientific inquiry by posing questions such as, "How far does light travel?" The student learns scientific concepts, but also the reasoning associated with *doing* science as they evolve and test working theories.

Thus, student-centered, cognitive demands shift from primarily selecting, processing, and encoding via directed activities to anticipating, seeking, and assessing the relevance of affordances based on individually evolving needs and goals (Kuiper et al. 2005). Often, this has proven both difficult and problematic. Students often failed to develop theories or explanations (de Jong and van Joolingen 1998), to reflect or enact metacognitive processes (Moos and Azevedo 2008b), and to develop coherent, evidence-based explanations (Nicaise and Crane 1999). Land (2000, pp. 75–76) concluded that without effective support,

> misperceptions, misinterpretations, or ineffective strategy use … can lead to significant misunderstandings that are difficult to detect or repair…metacognitive and prior knowledge are needed to ask good questions and to make sense.

The epistemological shifts associated with student-centered, Web-based learning raise important, but largely unanswered questions. Sweller et al. (1998), for example, detailed links between instruction strategies and cognitive architecture, and provided recommendations for managing cognitive demands. Mayer (2003) and Clark and Mayer (2003) subsequently detailed how time-tested principles of cognition and instruction should be applicable to multimedia and online learning.

According to Hill and Hannafin (2001), however, this may become substantially more complex in the digital era: "a digital resource's 'meaning' is influenced more by the diversity than the singularity of the perspectives taken" (p. 40). In effect, the potential for increased and largely unregulated resources alters the predictably of cognitive demands associated with resource access and use. Designers are unable to account for individual cognitive demands in advance since the context of learning is often spontaneous and the availability and use of resources evolving continuously. In addition, the evolved cognitive constructs and design principles have been based on directed-learning models where the learning requirements are determined by external agents, not individual students. In this paper, we briefly discuss several issues that have emerged through efforts to design and validate, and identify implications for research and theory related to student-centered, Web-based learning.

Cognitive demands of externally directed and student-centered learning

Table 1 contrasts the demands associated with externally directed and student-centered learning. The American Psychological Association published learner-centered psychological principles which delineated criteria for student-centered learning design and implementation (Alexander and Murphy 1998). Although much of the supporting research pre-dates the advent of the Web, the principles have informed the theory and design of student-centered, Web-based learning. Table 2 summarizes relationships between and among student-centered learning assumptions and design strategies. Since it is beyond the scope of this paper to address all relevant constructs, we focus briefly on constructs with particular relevance for student-centered learning: Prior knowledge, cognitive load, metacognition, beliefs and dispositions, and scaffolding.

Prior knowledge

Classically, cognitive psychologists characterized prior knowledge as networked schema which represents the organization of, and relationships among, each individual's existing knowledge and skill: The more extensive and connected, the richer the prior knowledge organization (schema), the more amenable to encoding new, related knowledge (see, for example, review by Sweller et al. 1998). Prior knowledge is often elicited by posing criterion-based questions (Pressley et al. 1992), eliciting peer questioning to identify gaps in understanding (Choi et al. 2005), and providing feedback (Smits et al. 2008) to retrieve and process prior knowledge in working memory and facilitate connections between existing and new knowledge. For example, Gagné et al.'s *Events of Instruction* (1988), aligned with information-processing theory, emphasizes recall of prerequisite knowledge and skill to stimulate internal cognitive events (the association of existing with new knowledge) for acquiring and retaining new knowledge.

While there is broad agreement on the role and importance of prior knowledge to learning, disagreements exist regarding the locus, nature, and meaning of knowledge. Rather than assuming reality exists externally and meaning is transmitted to the learner (accretion, accumulation), constructivists assert that learners construct meaning uniquely based on personal interactions with society, individuals, and objects (Hannafin et al. 1997). Differences in underlying assumptions have compelling implications for designing grounded learning environments that are aligned with any epistemological perspective. Constructivist-inspired learning environments often provide resources for learners to manage their own learning through exploration, hypothesis formation, and student-relevant feedback (Hannafin et al. 1997).

Table 1 Contrasting cognitive demands of externally directed and student-centered perspectives on learning

Cognitive construct	Locus	Description	Supporting literature
Metacognition	Externally directed	Formal structures (learning sequences, mastery verification, etc.) provide specific pathways to minimize confusion and follow presumed ideal learning pathway	Well-structured problems require rules and pathways to specific solutions (Jonassen 1997; Shin et al. 2003) Linear designs facilitate factual recall (Eveland et al. 2004)
	Student-centered	Open or ill-structured environments require that learners determine goals and learning paths Learner analyzes and detects ongoing understanding while testing and evolving theories in action	Self-regulated learners perform better than those who are not (Young 1996) Self-regulated understanding improves in environment (Azevedo and Cromley 2004) Students focus on *how* to solve the problem more than the solution itself (Kauffman et al. 2008) Ill-structured problem solving requires effective monitoring and knowledge of cognition (Shin et al. 2003) Non-linear designs improve learners' detection of relationships and connections with new content. (Eveland et al. 2004)
Cognitive load	Externally directed	Learning and information flow is structured and metered per external criteria	Cognitive load anticipated through structured designs that manage working memory demands (Sweller et al. 1998) Extraneous messages interfere with the learner's ability to attend to and process information (Mayer et al. 2001) Presentation externally paced to manage demands on working memory (Mayer and Moreno 1998) Explicit guidance minimizes cognitive demands, thereby reducing cognitive load (Kalyuga 2007; Kirschner et al. 2006) Worked examples aid learning during problem solving (Sweller and Cooper 1985)
	Student-centered	Various resources available and learner sorts through to identify and choose most individually relevant Working memory taxed by new content and simultaneously managing relevance and progress toward goals Availability of relevant or requisite schemata influences cognitive demands	Discovery methods with minimal guidance increase cognitive load (Kirschner et al. 2006) Complex and authentic learning tasks have high interactivity, increasing cognitive load (van Merrienboer and Sweller 2005) Students test and refine theories-in-action through individual experimentation (Land and Hannafin 1996)

Table 1 continued

Cognitive construct	Locus	Description	Supporting literature
Prior knowledge	Externally directed	Learner directed to associate prerequisite knowledge with new information If deficient, learner reviews requisite prior knowledge through structured sequences Learners' misconceptions "corrected"	Learners connect prior with to-be-learned knowledge by answering externally supplied, criterion-based questions (Pressley et al. 1992)
	Student-centered	Prior knowledge informs individual questioning and decision-making Interactions and meaning based on prior knowledge and experiences Existing understanding key in establishing learners' expectations and individual knowledge construction	Discovery learning increases cognitive load for learners with limited prior knowledge (Tuovinen and Sweller 1999) Misconceptions aid in refining prior knowledge (Smith et al. 1993) Prior domain knowledge improves self-regulation and strategies in a hypermedia environment (Moos and Azevedo 2008b)
Beliefs and dispositions	Externally directed	Canonical understanding emphasized over individual beliefs Learner accommodates or assimilates beliefs consistent with lesson objectives Motivation emphasizes balancing perceived intrinsic value of to-be-learned content with extrinsic incentives to learn	Field dependent learners improve in structured environments (Graff 2006) Field-dependent learners most effective in a linear, hierarchical, or relational hypertext architecture (Graff 2003a)
	Student-centered	Existing beliefs both inform interpretations as meaning is constructed and are revised through the processes of construction Cognitive skills guide the learner in choosing how to learn from unstructured resources Motivational orientation influences the kind of goals learners choose	Field independent learners improve in ill-structured environments (Graff 2006) Beliefs about knowledge and learning influence web-based learning activities (Yang and Tsai 2008) Motivation influenced by the type of learning goals (mastery versus extrinsic); self-efficacy and task value beliefs influence self-regulation (Pintrich 1999)
Scaffolding	Externally directed	Guidance, help and instructions increase likelihood of learning externally defined objectives Guidance minimizes attention to or non-essential aspects of learning environment	Guidance during multimedia presentation enhances retention but not transfer (Jamet et al. 2008)
	Student-centered	Guidance supports efforts to pursue individual learning goals Support focuses on goal identification, pursuit, attainment and reasoning	Conceptual scaffolding promotes deeper understanding (Moos and Azevedo 2008a) Guides/helps and representations may aid those with less knowledge (Kalyuga 2007)

Table 1 continued

Cognitive construct	Locus	Description	Supporting literature
			Prior knowledge influences how learners make use of embedded scaffolds in a web-based learning environment (Ge et al. 2005) Adding visual cues improved retention but replacing with oral lowered retention and transfer (Tabbers et al. 2004)

Among student-centered theorists, prior knowledge and experience are perceived as uniquely shaping the individual's understanding between, as well as expectations among, existing and new knowledge (Land 2000). Understanding and meaning are not assumed to be uniform across, but rather unique to, individual learners. Differences in prior domain knowledge, for example, has been reported to influence the effectiveness of both self-regulation and strategy use during learning from hypermedia (Moos and Azevedo 2008b). Thus, initial understandings, including misconceptions, influence what and how the individual knows and understands as well as the perceived relevance of candidate activities and resources. Rather than imposing a canonical perspective to supplant initial conceptions, student-centered approaches guide the learners in challenging their initial assumptions as they test and refine initial conceptions (Smith et al. 1993).

Thus, prior knowledge and experience mediate the learner's ability to assume responsibility for their own learning—a central assumption of student-centered learning. They shape the formative, often naïve and incomplete theories-in-action learners employ as they attempt to interpret, make sense and understand (Land and Hannafin 1996). Prior knowledge also mediates how understandings are constructed initially and reconstructed subsequently (Schuh 2003). Relevant knowledge influences the individual's ability to assess and evaluate information and detect inconsistencies and contradictions between new and existing understanding (Land and Hannafin 2000), to perceive relevance about learning tasks (Kuiper et al. 2005), and to determine when learning goals have been achieved. In many instances, however, domain knowledge alone is not sufficient to facilitate student-centered, Web-based learning. Hill and Hannafin (1997) reported among adult learners, prior Web experience (system knowledge) proved more important than prior domain knowledge in seeking and identifying relevant resources.

Cognitive load

In recent issues of *Educational Technology Research & Development* (van Merrienboer and Ayers 2005) and *Educational Psychologist* (Paas et al. 2003), researchers and theorists examined the interplay among the content and attributes of instruction and associated intrinsic, extraneous, and germane cognitive load. Explicit guidance is believed to minimize cognitive load demands (Kirschner et al. 2006). Researchers have attempted to reduce or eliminate extraneous load by amplifying those aspects considered central (germane) to defined goals (Mayer et al. 2001), providing explicit guidance (van Merrienboer and Sweller 2005) and controlling the pace of instruction and demands on working memory (Mayer and Moreno 1998). Worked examples have been reported to reduce cognitive load by providing

Table 2 Assumptions and design strategies associated with student-centered learning

Student-centered learning assumption(s)	Cognitive construct	Research on design strategies
Individuals assume greater responsibility for their learning	Metacognition Comprehension monitoring Orientation-disorientation Self-regulation Self-assessment Detection and repair	Cues, in the form of meta-navigation checks, help students consider their goals and evaluate their navigation decisions (Puntambekar and Stylianou 2005) Navigation site maps help to overcome disorientation, while supporting learning goals (Shapiro 2005) Self-regulation training optimizes learning in hypermedia (Azevedo & Cromley 2004)
Understanding supported when cognitive processes are augmented by technology	Cognitive load Cognitive capacity Working memory Intrinsic load Extraneous load Germane load	Notations and labels help novices to make connections and recognize relationships (Shapiro 2008) Introduce and learn tools prior to rather than concurrent with new learning (Clarke et al. 2005)
Understanding most relevant when rooted in personal experience; understanding evolves continuously; learning best when varied/multiple representations are supported; knowledge personally constructed via interpretation and negotiation	Prior knowledge Schema theory Domain knowledge, skill and expertise System knowledge, skill and expertise Personal experience "Errors" during learning Familiarity	Varying structures accomodate differences in learner aptitude (Shin et al. 1994) Additional control to individuals with greater prior knowldge but additional support and guidance to those with less (Shapiro 2008) Peer interaction and questioning identifies gaps in understanding to modify understanding (Choi et al. 2005) Feedback (global versus elaborate) adjusted based on the extensiveness of prior knowledge (Smits et al. 2008)
Understanding requires time; direct instruction alone does support varied learning requirements	Beliefs and dispositions Cognitive style Learning style Motivation Perceived self efficacy Perceived demand characteristics	Hypermedia/website structure matched to a learner's cognitive style (Graff 2006) Anonymously provided online feedback increases self-efficacy (Wang and Wu 2008) Technologies adapt to differences in aptitude (e.g. Lajoie 2003; Shute and Towle 2003)

Table 2 continued

Student-centered learning assumption(s)	Cognitive construct	Research on design strategies
Learning environments support underlying cognitive processes, not solely products of understanding; learners make, or can be guided to make, effective choices	Scaffolding Procedural Metacognitive Conceptual Strategic	Scaffolds tailored and dynamically presented to accommodate specific kinds of learning, tools available, and individual learner needs (Azevedo and Hadwin 2005) Conceptual scaffolds help the learner to identify and use information relevant to the learning context (Brush and Saye 2001) Metacognitive prompts embedded throughout web-based environment scaffold self-regulation and self-monitoring (Kauffman et al. 2008) Peer interaction and question prompts help the learner to represent and generate solutions to ill-structured problems (Chen and Bradshaw 2007; Ge and Land 2004) Coach/tutor diagnose and adapt scaffolding dynamically during learning (Azevedo et al. 2004) Embedded prompts mapped to differences in individual prior knowledge, experience and perceptions (Ge et al. 2005) Cognitive processes modeled during web-based learning environment through the use of videos, artifacts, and think-aloud protocols (Dickey 2008)

Note: The assumptions are organized to illustrate their applicability to selected cognitive constructs; in practice, the assumptions and constructs are interdependent concrete models during problem solving (Sweller and Cooper 1985). To mitigate extraneous cognitive load during learning, some authorities advocate that tools be introduced and learned prior to rather than concurrent with new learning (Clarke et al. 2005).

Student-centered learning researchers emphasize the individual's capacity to identify relevant resources and mediate cognitive load. Land and Hannafin (1996) described a method for formalizing, defining and refining working theories (theories in action), where students engaged in complex learning environments, engaged both task-relevant and non-relevant resources as they individually selected and discarded candidate resources as their working theories evolve. Recently, researchers have described self-checking procedures designed to guide learners in goal-setting and Web navigation. Cues, meta-navigation checks during which students were promoted to reassess and evaluate progress, helped students to reconsider their goals, evaluate navigation decisions, and alter subsequent goals and decisions (Puntambekar and Stylianou 2005). Azevedo and Cromley (2004) trained students in self-regulated learning to facilitate learning in a hypermedia learning environment. Collectively research suggests that domain-independent guidance and advance training to refine self-regulation skills may prove beneficial, and in some cases, necessary for learners to engage student-centered environments effectively.

Metacognition

Flavell (1979) conceptualized metacognition as the active, ongoing monitoring of one's cognitive processes. In addition, since designers' expectations and requirements influence the extent to which to-be-learned knowledge (and to-be-solved problems) are structured, direct instruction proponents emphasized formal structures and prescribed pathways, such as providing explicit sequences (Dillon and Gabbard 1998) and assessing en-route learning (Hannafin and Rieber 1989) to verify student understanding. Student-centered learning advocates, in contrast, emphasized learning in less-structured or ill-structured environments where students regulate their individual learning (Young 1996).

Few researchers have documented significant improvements across learning types via either directed or student-centered metacognitive support. Researchers who have contrasted the effects of externally- and student-directed Web-based learning designs on student performance have suggested that varied learning requirements require different types of metacognitive support. Eveland et al. (2004) examined the influence of Website organization on three adult learning outcomes, and concluded that while linear design and support improved factual recall, non-linear designs and supports increased the density or connectedness of student knowledge. In effect, one type of learning (factual) was facilitated at the expense of the other (individual associations). Similarly, Shin et al. (2003) posed open-ended organizing questions to assess students' solving of well- and ill-structured problems in an open-ended, multimedia learning environment and concluded that solving each type of problem required different skills. Whereas domain knowledge and justification skills were significant predictors for solving well-structured problems, ill-structured problem-solving

> requires that students possess not only the necessary knowledge but also regulation of cognition, including modifications of plans, reevaluation of goals, and monitoring of one's own cognitive efforts. If the problem is not structurally complicated enough, the students may not use their regulation of cognitive skills even though they possess them. (p. 23).

Beliefs and dispositions

Researchers and theorists conceptualize and operationalize beliefs and dispositions quite differently. Externally directed approaches tend to provide activities that stimulate processing consistent with to-be-learned canonical beliefs. Predictably, field-dependent learners—those who tend to rely on external agents for guidance—performed most effectively in structured, linear, hierarchical, or relational hypertext architecture (Graff 2003a, b). Student-centered learning advocates typically emphasize the mediating aspects of the individual's perceptions and beliefs on both dispositions to learn and the state of understanding (Blumenfeld et al. 1991; Kauffman 2004). Typically, they identify how to-be-learned concepts are initially understood by individuals in order to build from, rather than directly correcting, existing beliefs and dispositions. Not surprisingly, field-independent learners—who tend to self-organize and work independently—performed best in a less-structured learning environment (Graff 2006).

Context has demonstrated important influence on the meaningfulness of students' learning. Context, is inextricably tied to knowledge and influences understanding and meaning; knowledge and understanding vary according to the contexts in which learning occurs. According to Mayer (1989), learning becomes increasingly meaningful when appropriately selected, organized, and integrated within existing cognitive structures. Mayer (2001, 2005) subsequently extended and adapted classical instructional design principles to multimedia learning environment design.

Nearly a century ago, Whitehead (1929) criticized classical British schooling for engendering inert knowledge that has little or no utility and advocated a change in both the goals as well as the methods of education to emphasize knowledge as a tool for reasoning and solving problems. These perspectives were subsequently advanced through the work of Dewey (1998) and subsequently constructivist designers who emphasized the importance of authentic experience and participation.

Accordingly, student-centered learning environments often provide authentic experiences or realistic vignettes to facilitate interaction and learning. In the Jasper Woodbury Series (CTGV 1992), students watch a short video to provide context and orient learning before solving mathematics problems situated in realistic settings (e.g., determining how much gas is needed and what route to take to navigate a boat to desired locations). Thus, contexts may help students to identify learning goals, form and test hypotheses, and situate learning in authentic experiences. Knowledge is constructed while individuals engage activities, receive and provide feedback, and interact within the learning environment. When authentic, active engagement enables learners to gain access (i.e., enculturation or identify formation) to the ordinary practices of a culture from a real-world perspective.

Scaffolding

Scaffolding often assumes the form of explicit directions, explicit guidance, and activities designed to increase the probability of learning defined concepts, constructs, and procedures (Azevedo and Hadwin 2005). In effect, scaffolding guides by simultaneously amplifying lesson aspects considered most central to the defined outcomes while minimizing attention to those aspects considered less essential or extraneous.

During student-centered learning, scaffolding is designed to support the individual's efforts to identify relevant goals, pursue and monitor efforts toward those goals, and reconcile differences between existing understanding and to-be-learned concepts and constructs. Kauffman et al. (2008) examined the effects of scaffolding in the form of problem-solving and self-reflection prompts on students' complex problem solving in a Web-based learning environment. They reported that reflection prompts positively influenced problem solving and writing, but only when students also received the problem solving prompts, suggesting that reflection alone influences problem solving when students understand what they reflect on. Similarly, navigation site maps helped students to overcome enroute disorientation due to cognitive overload and facilitate decision-making, while supporting learning goals (Shapiro 2005).

Issues and implications

Role of system versus domain knowledge: how to learn versus what to learn?

Research suggests that familiarity with Web-based tools may play a significant role in individual success or failure. Several authors have advocated affording greater decision-making control to individuals with greater prior knowledge but providing additional support and guidance to those with less (Shapiro 2008). Thus, the presence (or lack of) relevant prior knowledge and skill poses significant hurdles for designers of student-centered learning environments. Song et al. (2004) found that college students who reported greater prior knowledge of online tools managed their time more efficiently than students preferring traditional instruction. Hill and Hannafin (1997) asked teachers to locate Internet content and grade-appropriate materials on a subject of their choosing, and reported that those with previous experience with the Internet were more successful and reported greater confidence in the task—regardless of prior teaching experiences. In both studies, prior tool expertise facilitated learning more than prior domain knowledge or experience. In some student-centered learning contexts, familiarity with available Web-based tools may better predict success than prior domain knowledge and experience.

Although student-centered learning environments purportedly foster exploration and hypothesis formation, validation has proven problematic. McCombs and Whisler (1997) described learner-centered environments where learners engage in complex and relevant activities, collaborate with peers, and employ resources to collect, analyze, and represent information. However, Remillard's (2005) synthesis indicated that teachers' content knowledge, pedagogical content knowledge, beliefs, and their interpretation of the curriculum influenced and often dominated how presumed learner-centered activities were actually enacted in classroom settings. Researchers have also documented instances where teachers supplied rote algorithms for students to follow and did not guide students to seek and pursue unique solutions (Doyle 1988).

Likewise, although the Web affords a range of affordances in support of student-centered learning, it has proven difficult to establish conclusive relationships between technology and student learning (e.g., Roschelle et al. 2001). Some researchers have documented positive effects using technology to facilitate problem solving, conceptual development and critical thinking (Ringstaff and Kelley 2002; Sandholtz et al. 1997). Wenglinsky (1998) reported that where teachers used technology in conjunction with learner-centered pedagogies, students scored significantly higher on the mathematics portion of assessments of educational progress than students that did not: 8th graders who used technology for mathematics drill and practice scored significantly lower than peers who used no technology.

Information overload and disorientation: lost in hyperspace?

Disorientation in hyperspace—initially described for hypertext navigation (e.g., Edwards and Hardman 1999)—has become increasingly problematic in student-centered, Web-based environments where learners need to identify, select, and evaluate available resources based on their unique tasks and goals. Web resources are largely unregulated, with quality varying widely in terms of accuracy, authority, and completeness and have been criticized for containing naïve and ill-informed information and propagating misinformation, disinformation, and propaganda (Jowett and O'Donnell 2006). Since students must assess veracity and relevance while attempting to address their individual learning needs and monitoring their understanding, research is needed to examine how students' evaluate and adapt based on perceptions of a resource's integrity. Web resource creators can append metadata to simplify their identification and physical locations and narrative descriptors to convey their contents, cataloguing systems typically rely on content creators to generate metadata tags for online materials and cannot be aware of the myriad ways they might ultimately be accessed and interpreted (Maule 2001).

Canonical versus individual meaning: situated learning paradox?

Constructivist learning environments emphasize personal investigation, hypothesis formation and testing. Without adequate background knowledge and support, learners may fail to detect inaccurate information or reject erroneous hypotheses in the face of contradictory evidence. In Land and Zembal-Saul's (2003) inquiries into the nature of light, participants obtained evidence during experiments, stored it in portfolios with their findings, and generated hypotheses to orient future inquiries. While some groups benefited from computer-assisted inquiry, others relied on faulty results from prior experiments and subsequently misdirected future inquiries and retained erroneous results even when later studies contradicted them. The authors suggested that student-centered inquiry functioned as anticipated only when students had sufficient background knowledge, self-evaluated their knowledge limitations, engaged in critical questioning and clarification, and feedback to challenge faulty explanations. The *situated learning paradox* suggests that prior knowledge, important for orienting and helping learners to make sense of phenomena, is often based on incomplete and inaccurate conceptions (Land and Hannafin 2000). Without support, misinformation and disinformation may go undetected; fundamental misunderstandings may become reified rather than reconciled.

The shifting nature of knowledge: accretion versus tool?

Whitehead (1929) advocated an emphasis on promoting knowledge as a tool. Tool-based knowledge, valued in student-centered learning, is presumed to facilitate goal acquisition and transfer: When students grasp the underlying reasoning behind the algorithms and their application to authentic problems, knowledge becomes a tool to facilitate problem solving in related contexts. Yet, researchers suggest that tools touted to support student-centered learning are often used inappropriately and ineffectively and engender dependence, rather than independence, especially among young learners. Oliver and Hannafin (2001) examined middle-school students' use of Web-based *Knowledge Integration Environment* prompts designed to scaffold teacher support and student thinking and reasoning. Although guidance was intended to become internalized and faded through sustained use, students continued to rely on them. In effect, conceptual and metacognitive scaffolds served as procedural job-aids.

Scaffolding variable knowledge and skills: to guide or to tell?

Saye and Brush (2007) distinguished between hard and soft scaffolds: Hard scaffolds are fixed in nature and designed to support common learning needs across students, freeing the instructor to provide adaptable, on-demand, contextually sensitive soft scaffolding support based on emergent, individual needs. Kim et al. (2007) proposed a scaffolding framework to optimize the interplay between and among technology, teachers and students in everyday student-centered, Web-based learning contexts. Azevedo and Hadwin (2005) implemented scaffolds tailored and presented dynamically to accommodate specific types of learning, tools available, and individual learner needs. Conceptual scaffolds helped learners to identify and use information relevant to the learning context (Brush and Saye 2000, 2001). Embedded metacognitive prompts have been applied in Web-based environments to scaffold self-regulation and self-monitoring and adapted to accommodate differences in individual priori knowledge, experience and perceptions (Kauffman et al. 2008). Peer interaction and question prompts helped learners to represent and generate solutions to ill-structured problems (Chen and Bradshaw 2007; Ge and Land 2004), and coach/tutors deployed to diagnose needs and adapt scaffolding dynamically during learning (Azevedo et al. 2004). Finally, cognitive processes have been effectively modeled during Web-based learning through the use of videos, artifacts, and think-aloud protocols (Dickey 2008).

Research also indicates that soft scaffolding technologies have the potential to address the varied needs of individual student-centered learners (Saye and Brush 2007). Unlike domain supports, soft scaffolding provided by teachers, peers and other human resources is thought to accommodate real-time, dynamic changes in learner needs and cognitive demands. Again, however, these effects have often proven equivocal. Technology-enhanced support during multimedia presentation improved the learning of basic information, but not the transfer ascribed to student-centered learning (Jamet et al. 2008).

Reconciling epistemological differences: the influence of attitudes, beliefs and practices

Song et al. (2007) reported conflicts when learners engage resources that are inconsistent or incompatible with individual goals and beliefs—especially when students are unable to identify and reconcile the differences. Thus, while designers and instructors of Web-based multimedia may assume that extending the array of resources will enhance learning, the individual's familiarity, beliefs, motivations, and practices may influence the extent to which available resources complement or confound student-centered learning.

Some researchers suggest that while Web-based approaches have the potential to promote deeper learning when strategies are followed, many strategies are unutilized or underutilized. In an effort to deepen understanding of mathematics through investigation, Orrill (2006) created an extensive Website including open-ended investigations, a mathematics dictionary, discussion board, and electronic portfolios. Teachers explored available resources, selected problems, and identified their own instructional paths (combined with attendance in face-to-face workshops). Improvements in mathematics skills and depth of knowledge were expected, but teachers typically focused on technology skills and did not refine their understanding or skills. Research is needed to examine how affordances are utilized and negotiated individually, meaning is assembled differentially based on unique needs and goals, and the extent to which individual needs are addressed.

Addressing limited cognitive resources: the cognitive load conundrum

Eveland et al. (2004) reported that students learned factual content best from linear Websites, but understood relationships better from nonlinear Websites. Eveland and Dunwoody (2001) compared the performance of students assigned to browse a Website with different hyperlinking and navigation structures with a paper-only format. The paper-based control group outperformed two of the online groups, indicating that hyperlinking may increase extraneous cognitive load. Thus, nonlinear Websites may increase germane load for some types of learning but increase extraneous load for others (Eveland et al. 2004). Given the demands associated with student-centered, Web-based learning, the ability to meter or manage cognitive load will prove essential for effective online students (Hill et al. 2005).

Monitoring student-centered learning: prerequisite versus emergent

Students who have, or develop, metacognitive strategies tend to perform more successfully than those who do not. Smidt and Hegelheimer (2004) interviewed high, middle, or low-performing adult learners regarding their Web learning strategies; only advanced learners used strategies (as well as cognitive ones). Intermediate and lower-level students relied on cognitive strategies only, suggesting that advanced metacognitive abilities may be either associated with or requisite to effective online learning. Thus, we need to clarify the extent to which learners must possess metacognitive strategies, require advance training, or can develop the requisite skills needed to monitor their progress.

Closing comments

The purpose of this paper was neither to advocate for, nor refute or minimize the value of, either student-centered or direct-instruction approaches. Rather, we clarified where differences are alleged to exist, and described how researchers have studied cognition during directed and student-centered, Web-based learning. Many cognitive constructs are relevant to student-centered and externally directed learning, but the manner in which they are manifest and studied may vary significantly. While Web-based and student-centered learning have gained considerable momentum recently, it is important to distinguish between the promise (and perhaps potential) and the evidence supporting these approaches. Clearly, many issues remain unaddressed, and those issues will not be readily resolved.

Much of the published literature has emphasized research on design, where specific strategies are examined for differential impact on learning. Indeed, while cognition and instruction design practices have been proposed (Clark and Feldon 2005; Clark and Mayer 2003; Jacobson 2008; Mayer 2005; Moreno and Mayer 1999, 2000), their application in student-centered, Web-based, multimedia, and online learning environments has been questioned (DeSchryver and Spiro 2009; Hannafin et al. 2007, 2009; Knowlton 2000). Comparatively little design-based research has documented the theory and practice related to optimizing student-centered learning. Both methods provide potentially important findings, but they do not provide identical information, pose or address the same questions, or generate equivalent evidence. The design issues raised in this paper require not simply to reexamine our assumptions underlying student-versus-externally centered approaches, but to also reconceptualize how we frame research questions, the discipline employed to address the questions, and our goals for the inquiry. As interest in optimizing the impact of student-centered, Web-based learning environments continues to emerge, it becomes critical that we address design and performance questions using methods that extend and refine research, theory, and practice.

References

Alexander, P. A., & Murphy, P. K. (1998). The research base for APA's learner-centered psychological principles. In N. M. Lambert & B. L. McCombs (Eds.), *Issues in school reform: A sampler of psychological perspectives on learner-centered schools* (pp. 33–60). Washington, DC: American Psychological Association.

Azevedo, R., & Cromley, J. G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of Educational Psychology, 96*(3), 523–535. doi:10.1037/0022-0663.96.3.523.

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*, 344–370. doi:10.1016/j.cedpsych.2003.09.002.

Azevedo, R., & Hadwin, A. (2005). Scaffolding self-regulated learning and metacognition: Implications for the design of computer-based scaffolds. *Instructional Science, 33*, 367–379. doi:10.1007/s11251-005-1272-9.

Berge, Z., & Mrozowski, S. (2001). Review of research in distance education, 1990–1999. *American Journal of Distance Education, 15*(3), 5–19.

Bernard, R., Abrami, P., Lou, Y., Borokhovski, E., Wade, A., Wozney, L., et al. (2004). How does distance education compare with classroom instruction? A meta-analysis of the empirical literature. *Review of Educational Research, 74*(3), 379–439. doi:10.3102/00346543074003379.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3–4), 369–398. doi:10.1207/s15326985ep2603&4_8.

Brush, T., & Saye, J. (2000). Implementation and evaluation of a student-centered learning unit: A case study. *Educational Technology Research and Development, 48*(3), 79–100. doi:10.1007/BF02319859.

Brush, T., & Saye, J. (2001). The use of embedded scaffolds with hypermedia-supported student-centered learning. *Journal of Educational Multimedia and Hypermedia, 10*(4), 333–356.

Chen, C.-H., & Bradshaw, A. (2007). The effect of Web-based question prompts on scaffolding knowledge integration and ill-structured problem solving. *Journal of Research on Technology in Education, 39*(4), 359–375.

Choi, I., Land, S., & Turgeon, A. (2005). Scaffolding peer-questioning strategies to facilitate metacognition during online small group discussion. *Instructional Science, 33*(5–6), 483–511. doi:10.1007/s11251-005-1277-4.

Clark, R., & Feldon, D. (2005). Five common but questionable principles of multimedia learning. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 97–115). New York: Cambridge University Press.

Clark, R. C., & Mayer, R. (2003). *E-learning and the science of instruction*. San Francisco, CA: Wiley.

Clarke, T., Ayres, P., & Sweller, J. (2005). The impact of sequencing and prior knowledge on learning mathematics through spreadsheet applications. *Educational Technology Research and Development, 53*(3), 15–24. doi:10.1007/BF02504794.

Cognition and Technology Group at Vanderbilt. (1992). The Jasper experiment: An exploration of issues in learning and instructional design. *Educational Technology Research and Development, 40*(1), 65–80. doi:10.1007/BF02296707.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*, 179–202.

DeSchryver, M., & Spiro, R. (2009). New forms of deep learning on the Web: Meeting the challenge of cognitive load in conditions of unfettered exploration in online multimedia environments. In R. Zheng (Ed.), *Cognitive effects of multimedia learning* (pp. 134–152). New York: Information Science Reference.

Dewey, J. (1998). *Experience and education: The 60th anniversary edition*. Indianapolis, IN: Kappa Delta Pi.
Dickey, M. (2008). Integrating cognitive apprenticeship methods in a Web-based educational technology course for P-12 teacher education. *Computers & Education, 51*(2), 506–518. doi:10.1016/j.compedu.2007.05.017.
Dillon, A., & Gabbard, R. (1998). Hypermedia as an educational technology: A review of the quantitative research literature on learner comprehension, control, and style. *Review of Educational Research, 68*(3), 322–349.
Doyle, W. (1988). Work in mathematics classes: The context of students' thinking during instruction. *Educational Psychologist, 23*(2), 167–180.
Edwards, D. M., & Hardman, L. (1999). 'Lost in hyperspace': Cognitive mapping and navigation in a hypertext environment. In R. McAleese (Ed.), *Hypertext: Theory into practice* (2nd ed., pp. 90–105). Oxford: Intellect Books.
Eveland, W. P., Cortese, J., Park, H., & Dunwoody, S. (2004). How Website organization influences free recall, factual knowledge, and knowledge structure density. *Human Communication Research, 30*(2), 208–233. doi:10.1111/j.1468-2958.2004.tb00731.x.
Eveland, W. P., & Dunwoody, S. (2001). User control and structural isomorphism or disorientation and cognitive load? *Communication Research, 28*(1), 48–78.
Flavell, J. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *The American Psychologist, 34*(10), 906–911. doi:10.1037/0003-066X.34.10.906.
Gagné, R., Briggs, L., & Wager, W. (1988). *Principles of instructional design* (3rd ed.). New York: Holt, Rinehart and Winston.
Ge, X., Chen, C.-H., & Davis, K. (2005). Scaffolding novice instructional designers' problem-solving processes using question prompts in a Web-based learning environment. *Journal of Educational Computing Research, 33*(2), 219–248. doi:10.2190/5F6J-HHVF-2U2B-8T3G.
Ge, X., & Land, S. (2004). A conceptual framework for scaffolding ill-structured problem-solving processes using question prompts and peer interactions. *Educational Technology Research and Development, 52*(2), 5–22. doi:10.1007/BF02504836.
Graff, M. (2003a). Assessing learning from hypertext: an individual differences perspective. *Journal of Interactive Learning Research, 14*(4), 425–438.
Graff, M. (2003b). Learning from Web-based instructional systems and cognitive style. *British Journal of Educational Technology, 34*(4), 407–418. doi:10.1111/1467-8535.00338.
Graff, M. (2006). Constructing and maintaining an effective hypertext-based learning environment: Web-based learning and cognitive style. *Education & Training, 48*(2–3), 143–155. doi:10.1108/00400910610651773.
Hannafin, M., & Hannafin, K. (2008). Cognition and student-centered, Web-based learning: Issues and implications for research and theory. In D. G. Kinshuk, J. M. Sampson, P. Spector, D. Isaías, & D. Ifenthaler (Eds.), *Proceedings of the IADIS international conference on cognition and exploratory learning in the digital age* (pp. 113–120). Freiburg, Germany: IADIS.
Hannafin, M. J., Hannafin, K. M., Land, S., & Oliver, K. (1997a). Grounded practice and the design of constructivist learning environments. *Educational Technology Research and Development, 45*(3), 101–117. doi:10.1007/BF02299733.
Hannafin, M. J., & Hill, J. (2007). Resource-based learning. In M. Spector, M. D. Merrill, J. van Merrienboer, & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 525–536). Mahwah, NJ: Erlbaum.
Hannafin, M. J., Hill, J., & Land, S. (1997b). Student-centered learning and interactive multimedia: Status, issues, and implications. *Contemporary Education, 68*(2), 94–99.
Hannafin, M. J., Hill, J., Song, L., & West, R. (2007). Cognitive perspectives on technology-enhanced distance learning environments. In M. Moore (Ed.), *Handbook of distance education* (2nd ed., pp. 123–136). Mahwah, NJ: Erlbaum.
Hannafin, M. J., Land, S., & Oliver, K. (1999). Open learning environments: Foundations and models. In C. Reigeluth (Ed.), *Instructional design theories and models: A new paradigm of instructional theory* (pp. 115–140). Mahwah, NJ: Erlbaum.
Hannafin, M. J., & Rieber, L. P. (1989). Psychological foundations of instructional design for emerging computer-based instructional technologies: Part I. *Educational Technology Research and Development, 37*, 91–101. doi:10.1007/BF02298293.
Hannafin, M., West, R., & Shepherd, C. (2009). The cognitive demands of student-centered, Web-based learning: Current and emerging perspectives. In R. Zheng (Ed.), *Cognitive effects of multimedia learning* (pp. 194–216). New York: Information Science Reference.

Hill, J., & Hannafin, M. J. (1997). Cognitive strategies and learning from the World-Wide Web. *Educational Technology Research and Development, 45*(4), 37–64. doi:10.1007/BF02299682.

Hill, J., & Hannafin, M. J. (2001). Teaching and learning in digital environments: The resurgence of resource-based learning. *Educational Technology Research and Development, 49*(3), 37–52. doi:10.1007/BF02504914.

Hill, J., Hannafin, M. J., & Domizi, D. (2005). Resource-based learning and informal learning environments: Prospects and challenges. In R. Subramaniam (Ed.), *E-learning and virtual science centers* (pp. 110–125). Hershey, PA: Idea Group, Inc.

Jacobson, M. (2008). A design framework for educational hypermedia systems: Theory, research and learning emerging scientific conceptual perspectives. *Educational Technology Research and Development, 56*(1), 5–28. doi:10.1007/s11423-007-9065-2.

Jamet, E., Gavota, M., & Quaireau, C. (2008). Attention guiding in multimedia learning. *Learning and Instruction, 18*(2), 135–145. doi:10.1016/j.learninstruc.2007.01.011.

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving and learning outcomes. *Educational Technology Research and Development, 45*(1), 65–94. doi:10.1007/BF02299613.

Jowett, G., & O'Donnell, V. (2006). *Propaganda and persuasion*. Thousand Oaks, CA: Sage.

Kalyuga, S. (2007). Enhancing instructional efficiency of interactive e-learning environments: A cognitive load perspective. *Educational Psychology Review, 19*(3), 387–399. doi:10.1007/s10648-007-9051-6.

Kauffman, D. (2004). Self-regulated learning in Web-based environments: Instructional tools designed to facilitate cognitive strategy use, metacognitive processing, and motivational beliefs. *Journal of Educational Computing Research, 30*(1/2), 139–161. doi:10.2190/AX2D-Y9VM-V7PX-0TAD.

Kauffman, D., Ge, X., & Xie, K. (2008). Prompting in Web-based environments: Supporting self-monitoring and problem solving skills in college students. *Journal of Educational Computing Research, 38*(2), 115–137. doi:10.2190/EC.38.2.a.

Kim, M., Hannafin, M. J., & Bryan, L. (2007). Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science Education, 96*(6), 1010–1030. doi:10.1002/sce.20219.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86. doi:10.1207/s15326985ep4102_1.

Knowlton, D. (2000). A theoretical framework for the online classroom: A defense and delineation of a student-centered pedagogy. *New Directions for Teaching and Learning, 84*, 5–14. doi:10.1002/tl.841.

Kuiper, E., Volman, M., & Terwel, J. (2005). The Web as an information resource in K-12 education: Strategies for supporting students in searching and processing information. *Review of Educational Research, 75*(3), 285–328. doi:10.3102/00346543075003285.

Lajoie, S. P. (2003). Individual differences in spatial ability: Developing technologies to increase strategy awareness and skills. *Educational Psychologist, 38*(2), 115–125. doi:10.1207/S15326985EP3802_6.

Land, S. (2000). Cognitive requirements for learning with open-ended learning environments. *Educational Technology Research and Development, 48*(3), 61–78. doi:10.1007/BF02319858.

Land, S., & Hannafin, M. J. (1996). A conceptual framework for the development of theories-in-action with open learning environments. *Educational Technology Research and Development, 44*(3), 37–53. doi:10.1007/BF02300424.

Land, S., & Hannafin, M. J. (2000). Student-centered learning environments. In D. H. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 1–23). Mahwah, NJ: Erlbaum.

Land, S., & Zembal-Saul, C. (2003). Scaffolding reflection and articulation of scientific explanations in a data-rich, project-based learning environment: An investigation of progress portfolio. *Educational Technology Research and Development, 51*(4), 65–84. doi:10.1007/BF02504544.

Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE design for knowledge integration. *Science Education, 87*(4), 517–538. doi:10.1002/sce.10086.

Maule, R. W. (2001). Framework for metacognitive mapping to design metadata for intelligent hypermedia presentations. *Journal of Educational Multimedia and Hypermedia, 10*, 27–45.

Mayer, R. (1989). Models for understanding. *Review of Educational Research, 59*(1), 43–64.

Mayer, R. (2001). *Multimedia learning*. Cambridge, UK: Cambridge University Press.

Mayer, R. (2003). The promise of multimedia learning: Using the same instructional design methods across different media. *Learning and Instruction, 13*(2), 125–139. doi:10.1016/S0959-4752(02)00016-6.

Mayer, R. (2005). Cognitive theory of multimedia learning. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31–46). New York: Cambridge University Press.

Mayer, R., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187–198. doi: 10.1037/0022-0663.93.1.187.

Mayer, R., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*(2), 312–320. doi:10.1037/0022-0663.90.2.312.

McCombs, B. L., & Whisler, J. S. (1997). *The learner-centered classroom and school: Strategies for increasing student motivation and achievement*. San Francisco: Jossey-Bass.

Moos, D. C., & Azevedo, R. (2008a). Exploring the fluctuation of motivation and use of self-regulatory processes during learning with hypermedia. *Instructional Science, 36*(3), 203–231. doi:10.1007/s11251-007-9028-3.

Moos, D. C., & Azevedo, R. (2008b). Self-regulated learning with hypermedia: The role of prior domain knowledge. *Contemporary Educational Psychology, 33*, 70–298. doi:10.1016/j.cedpsych.2007.03.001.

Moreno, R., & Mayer, R. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*, 358–368. doi:10.1037/0022-0663.91.2.358.

Moreno, R., & Mayer, R. (2000). Learner-centered approach to multimedia explanations: Deriving instructional design principles from cognitive theory. *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning*. Retrieved November 25, 2008, from http://imej.wfu.edu/articles/2000/2/05/index.asp.

Nicaise, M., & Crane, M. (1999). Knowledge constructing through hypermedia authoring. *Educational Technology Research and Development, 47*(1), 29–50. doi:10.1007/BF02299475.

Oliver, K., & Hannafin, M. J. (2001). Developing and refining mental models in open-ended learning environments: A case study. *Educational Technology Research and Development, 49*(4), 5–33. doi: 10.1007/BF02504945.

Orrill, C. H. (2006). What learner-centered professional development looks like: The pilot studies of the InterMath professional development project. *The Mathematics Educator, 16*(1), 4–13.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments [Special Issue]. *Educational Psychologist, 38*(1), 1–4.

Pintrich, P. R. (1999). The role of motivation in promoting and sustaining self-regulated learning. *International Journal of Educational Research, 31*(6), 459–470. doi:10.1016/S0883-0355(99)00015-4.

Pressley, M., Wood, E., Woloshyn, V. E., Martin, V., King, A., & Menke, D. (1992). Encouraging mindful use of prior knowledge: Attempting to construct explanatory answers facilitates learning. *Educational Psychologist, 27*(1), 91–109. doi:10.1207/s15326985ep2701_7.

Puntambekar, S., & Stylianou, A. (2005). Designing navigation support in hypertext systems based on navigation patterns. *Instructional Science, 33*, 451–481. doi:10.1007/s11251-005-1276-5.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*, 211–246. doi:10.3102/00346543075002211.

Ringstaff, C., & Kelley, L. (2002). *The learning return on our educational technology investment*. San Francisco: WestEd.

Roschelle, J., Pea, R., Hoadley, C., Gordin, D., & Means, B. (2001). Changing how and what children learn in schools with computer-based technologies. *The Future of Children, 10*(2), 76–101. doi:10.2307/1602690.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating student-centered classrooms*. New York: Teachers College Press.

Saye, J., & Brush, T. (2007). Using technology-enhanced learning environments to support problem-based historical inquiry in secondary school classrooms. *Theory and Research in Social Education, 35*, 196–230.

Schuh, K. L. (2003). Knowledge construction in the learner-centered classroom. *Journal of Educational Psychology, 95*, 426–442. doi:10.1037/0022-0663.95.2.426.

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

Shapiro, A. (2008). Hypermedia design as learner scaffolding. *Educational Technology Research and Development, 56*, 29–44. doi:10.1007/s11423-007-9063-4.

Sharma, P., Oliver, K., & Hannafin, M. J. (2007). Teaching and learning in directed environments. In M. Moore (Ed.), *Handbook of distance education* (2nd ed., pp. 259–270). Mahwah, NJ: Erlbaum.

Shin, N., Jonassen, D., & McGee, S. (2003). Predictors of well-structured and ill-structured problem solving in an astronomy simulation. *Journal of Research in Science Teaching, 40*(1), 6–33. doi:10.1002/tea.10058.

Shin, E. C., Schallert, D. L., & Savenye, W. C. (1994). Effects of learner control, advisement, and prior knowledge on young students' learning in a hypertext environment. *Educational Technology Research and Development, 42*, 33–46. doi:10.1007/BF02298169.

Shute, V., & Towle, B. (2003). Adaptive e-learning. *Education Psychologist, 38*(2), 105–114. doi:10.1207/S15326985EP3802_5.
Smidt, E., & Hegelheimer, V. (2004). Effects of online academic lectures on ESL listening comprehension, incidental vocabulary acquisition, and strategy use. *Computer Assisted Language Learning, 17*(5), 517–556. doi:10.1080/0958822042000319692.
Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the Learning Sciences, 2*(3), 115–163.
Smits, M., Boon, J., Sluijsmans, D., & van Gog, T. (2008). Content and timing of feedback in a Web-based learning environment: Effects on learning as a function of prior knowledge. *Interactive Learning Environments, 16*(2), 183–193. doi:10.1080/10494820701365952.
Song, L., Hannafin, M. J., & Hill, J. (2007). Reconciling beliefs and practices in teaching and learning. *Educational Technology Research and Development, 55*(1), 27–50. doi:10.1007/s11423-006-9013-6.
Song, L., Singleton, E. S., Hill, J. R., & Koh, M. H. (2004). Improving online learning: Student perceptions of useful and challenging characteristics. *The Internet and Higher Education, 7*(1), 59–70. doi:10.1016/j.iheduc.2003.11.003.
Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction, 2*, 59–89. doi:10.1207/s1532690xci0201_3.
Sweller, J., van Merreinboer, J., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251–296. doi:10.1023/A:1022193728205.
Tabbers, H., Martens, R., & van Merrienboer, J. (2004). Multimedia instructions and cognitive load theory: Effects of modality and cueing. *The British Journal of Educational Psychology, 74*, 71–81. doi:10.1348/000709904322848824.
Tuovinen, J. E., & Sweller, J. (1999). A comparison of cognitive load associated with discovery learning and worked examples. *Journal of Educational Psychology, 91*, 334–341. doi:10.1037/0022-0663.91.2.334.
van Merrienboer, J. J. G., & Ayers, P. (Eds.). (2005). Research on cognitive load theory and its design implications for e-learning [Special Issue]. *Educational Technology Research and Development, 53*(3), 5–13.
van Merrienboer, J. J. G., & Sweller, J. (2005). Cognitive load and complex learning: Recent developments and future directions. *Educational Psychology Review, 17*(2), 147–177. doi:10.1007/s10648-005-3951-0.
Wang, S.-L., & Wu, P.-Y. (2008). The role of feedback and self-efficacy on Web-based learning: The social cognitive perspective. *Computers & Education, 51*(4), 1589–1598. doi:10.1016/j.compedu.2008.03.004.
Wenglinsky, H. (1998). Does it compute? The relationship between educational technology and student achievement in mathematics. Retrieved November 26, 2008, from http://searcheric.org/ericdc/ED425191.htm.
Whitehead, A. (1929). *The aims of education*. New York: MacMillan.
Yang, F.-Y., & Tsai, C.-C. (2008). Investigating university student preferences and beliefs about learning in the Web-based context. *Computers & Education, 50*(4), 1284–1303. doi:10.1016/j.compedu.2006.12.009.
Young, J. D. (1996). The effect of self-regulated learning strategies on performance in learner controlled computer-based instruction. *Educational Technology Research and Development, 44*(2), 17–27. doi:10.1007/BF02300538.

Michael Hannafin is Professor in the Department of Educational Psychology and Instructional Technology at the University of Georgia, where he also directs the Learning and Performance Support Laboratory. His research is at the intersection of psychology, technology and education, where he develops and validates frameworks for the design of technology-enhanced student-centered teaching and learning.

Kathleen Hannafin is Research Scientist in the Learning and Performance Support Laboratory at the University of Georgia. Her educational preparation is in psychology and education. Her research focuses on the design and validation of technology-mediated systems to support teaching, learning and performance.

Bruce Gabbitas is a doctoral student in the Learning, Design and Technology program at the University of Georgia. His doctoral research focuses on student-centered teacher professional development and classroom teaching-learning practices.