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Help Seeking and Help Design in Interactive Learning Environments

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Many interactive learning environments (ILEs) offer on-demand help, intended to positively influence learning. Recent studies report evidence that although effective help-seeking behavior in ILEs is related to better learning outcomes, learners are not using help facilities effectively. This selective review (a) examines theoretical perspectives on the role of on-demand help in ILEs, (b) reviews literature on the relations between help seeking and learning in ILEs, and (c) identifies reasons for the lack of effective help use. We review the effect of system-related factors, of student-related factors, and of interactions between these factors. The interaction between metacognitive skills and cognitive factors is important for appropriate help seeking, as are a potentially large space of system-related factors as well as interactions among learner- and system-related factors. We suggest directions for future research.

KEYWORDS: computer-based instruction, educational hypermedia, epistemological beliefs, help design, help seeking, help systems, intelligent tutoring systems, interactive learning environments, metacognition, on-line help, self-regulation.

With the rapid development of new technologies, interactive learning environments (ILEs) have become widespread and are beginning to have a profound influence on the daily practice of education (Dillon & Gabbard, 1998; Koedinger, Anderson, Hadley, & Mark, 1997). Different types of ILEs offer different types of support to learners. Almost without exception, ILEs provide on-demand help, ranging from context-specific hints (Anderson, Corbett, Koedinger, & Pelletier, 1995) to specially designed hyperlinked background material (Slotta & Linn, 2000), hyperlinked textbooks (Hofer, Niegemann, Eckert, & Rinn, 1996), and on-line glossaries (Aleven & Koedinger, 2000; Gräsel, Fischer, & Mandl, 2001;

Shute & Gluck, 1996). At first blush, these help facilities would seem to be important assets for learners who try to master a new set of skills or subject matter. The proficient use of help facilities would seem to be an important factor determining learning outcomes among individuals working with these environments. However, an increasing number of studies provide evidence that learners often do not use help functions very effectively or even ignore them totally (Aleven & Koedinger, 2000; du Boulay, Luckin, & del Soldato, 1999; Gräsel, et al, 2001; Hofer et. al., 1996; Renkl, 2002; Wood & Wood, 1999). Thus, there is a danger that ILEs will not live up to their potential unless we can find ways to help learners take better advantage of the help facilities offered by these systems. Further, considering that help seeking is an important metacognitive skill (Nelson-LeGall, 1981; Newman, 1994) that is likely to influence learning in a great many situations and domains, ILEs will be all the more valuable if we find ways of designing them so that they help students to become better help seekers (Aleven & Koedinger, 2001; Gräsel, et al., 2001).

In addition to having great practical impact, the topic of help seeking in ILEs is interesting from a theoretical point of view. Help seeking is a manifestation of self-regulated behavior. Many authors have taken the viewpoint that rather than being an activity signaling and promoting the dependence of the learner, help seeking is an important strategy and can be instrumental in the development of independent skill and ability (Ames, 1983; Nelson-LeGall, 1981; Newman, 1994). It is likely that learners' help-seeking behavior reflects their metacognitive and domain-specific skills and knowledge (Newman, 1994, 1998a; Puustinen, 1998; Wood & Wood, 1999). It can be assumed also that learners' help-seeking behavior reflects their attitudes about learning, their achievement goals (Arbreton, 1998; Newman, 1998a; Ryan & Pintrich, 1997), and their epistemological beliefs. However, not all ways of seeking help are (equally) conducive to learning. It is therefore important to study how the more productive and less productive forms of help seeking can be distinguished, what factors lead to productive help seeking, and how help seeking is related to the development of independent skill and ability. There is a significant body of literature that has looked at these questions from a variety of different angles. To a great extent, that literature has focused on help seeking in classrooms or other "regular" learning or social environments. Help seeking in ILEs has not received the same amount of attention, although recently interest in the topic has increased. As we argue further below, there is reason to be cautious in extrapolating results obtained in social contexts to ILEs. One of the main points of the current review is that help seeking in ILEs deserves to be its own field of study.

In this article, we look for reasons for ineffective help-seeking behavior from psychological perspectives. We do so by a selective analysis of the literature. We first present a number of theoretical perspectives on the role of help in ILEs that have been put forward by designers of ILEs. Then we review empirical evidence for the claim that help systems in ILEs often are not used appropriately, followed by evidence that on-demand help is helpful when used appropriately. Further, we look at empirical studies that have examined how various features of help content and the help system influence help seeking and learning. We do the same for a number of learner-related factors, such as prior knowledge, metacognitive skill, gender, and cognitive development. In a separate section, we discuss the effects

of achievement orientation, a factor that has not been studied much in the context of ILEs, and epistemological beliefs, a factor whose influence on help seeking has not received much attention at all, even outside of the context of ILEs. Finally, we formulate several conclusions and identify the most pressing open research questions.

In selecting literature for discussion, we have tried to be comprehensive with respect to empirical studies of help seeking and help design in ILEs, the main focus of the article. On the other hand, we have been selective with respect to literature that is mainly theoretical or focuses on help seeking outside of the context of ILEs. The inclusion criteria are briefly stated in the relevant sections.

Role of On-Demand Help in Interactive Learning Environments

Before looking at empirical studies of help seeking, we review the role of help systems in ILEs from a theoretical perspective. First, we clarify what we mean by "ILE" and by "help." Next, we review a model of the process of help seeking in social contexts (e.g., classrooms) that has been put forward by social psychologists. Guided by this model, we discuss how help seeking in ILEs may be different from help seeking in the settings in which it has been studied more extensively, such as classroom contexts. We compare and contrast four major theoretical frameworks and identify a number of theoretical concepts that appear useful but have not been addressed by these frameworks. Further, we describe ways in which the designers of different types of ILEs have thought about the role of help. Finally, we briefly consider research on teaching as it relates to help seeking in ILEs.

Overview and Definition of Terms

By *interactive learning environments* (ILEs), we mean computer-based instructional systems that offer a task environment and provide support to help novices learn skills or concepts involved in that task. This support may be in the form of hints and feedback, opportunities for reflection, or simply by making available a space of linked information (e.g., hypertext pages) that is likely to be relevant to the learner. ILEs are used in a broad spectrum of domains and for different learning tasks from vocabulary training to the acquisition of complex skills. Accordingly, we define learning loosely as cognitive activities in which the processing of new information results in the acquisition of new skills or knowledge. In the studies discussed in this review, the learning gains afforded by instructional treatments are typically measured by means of pretests and posttests that focus on domain-specific skills and knowledge. These tests usually include items similar to the ones that the learners encountered during their work with the ILE and may also contain transfer items aimed at measuring how well the learner is able to apply what was learned in a slightly unfamiliar context.

The current review concentrates on ILEs that are designed to support *individual* learning. We recognize that learning environments that offer opportunities for *collaborative* learning are widespread and important from a theoretical standpoint. However, it makes sense to consider the two types of ILEs separately when studying help seeking. In particular, help seeking in collaborative learning environments is likely to be influenced by social factors that are much less influential when learning activities are carried out individually.

In general, different ILEs offer many different types of support to learners; however, almost without exception, they offer on-demand help. By *on-demand help* we mean information actively solicited by the learner and provided by the system, for the purpose of helping learners learn better with the ILE. Thus, we focus on help functions designed to support learning, not task performance per se. As discussed later in this review, help aimed at supporting task performance does not always lead to better learning, and vice versa. Some of the most prominent types of ILEs are described next.

Intelligent tutoring systems (ITSs) provide individualized instruction, typically assistance in the context of learning by doing (Corbett, Koedinger, & Anderson, 1997; Shute & Psotka, 1996; Wenger, 1987). ITSs rely on techniques from artificial intelligence and cognitive science to model student knowledge and pedagogical knowledge. Using their models, they follow learners in their individual approach through a problem, providing context-sensitive hints and feedback not just on learners' final solutions but on their intermediate steps as well.

Computer-assisted instruction (CAI) systems also provide support for learners as they work through problems on the computer (Eberts, 1997; Gibbons & Fairweather, 1998; Larkin & Chabay, 1992). However, they provide mostly feedback on answers, often in the form of explanations of why the answer is the way it is and why wrong answers are wrong. CAI systems work by prestoring sets of answers (right or wrong) and the associated feedback messages, with little or no attempt to individualize feedback for particular students.

Educational hypermedia systems provide a cross-linked information space (typically, Web-based) that learners can explore in order to gather information about a topic or to accomplish a given task such as writing an essay (Dillon & Gabbard, 1998; Quentin-Baxter, 2000). *Adaptive* hypermedia dynamically adapt the presentation of the information space to the characteristics of the individual learner, by filtering and ordering links as they are displayed on the page and also by tailoring the content of the documents in the information space (Brusilovsky, 2001; De Bra, Brusilovsky, & Houben, 1999).

Project or problem-oriented learning environments are often inspired by situated learning approaches and use technology to create authentic contexts in classrooms (Cognition and Technology Group at Vanderbilt, 1997; Jacobson & Archodidou, 2000; Slotta & Linn, 2000). Such authentic problems are often highly complex from the learners' perspective and are designed to stimulate learners to seek, actively and systematically, knowledge that could help in finding a solution to the problem. The role of help functions in such a system is to provide systematic background information together with hints about how this knowledge can be applied to the problem at hand.

The different types of ILEs vary greatly in the amount and content of help that they provide, as well as the proportion of system-initiated and learner-initiated help. Further, they differ greatly in the extent to which the help they provide is "context sensitive," meaning that it is adapted to the task at hand, the state of problem solving, or the characteristics of the learner. Often, these differences reflect the underlying pedagogical approach of the systems and the learning goals they are designed to support. As a rough generalization, ITSs and CAI systems tend to provide context-sensitive hints in order to help students learn a complex cognitive skill "by doing." On the other hand, the help functions of educational

hypermedia systems or problem-oriented learning environments tend to provide rich and systematic background knowledge in order to help learners acquire a better conceptual understanding of a domain, often in the context of a realistic problem scenario.

A Model of the Help-Seeking Process

Before looking at theoretical frameworks of help in ILEs, we review a model of the process of help seeking in social contexts, such as classrooms. This model was put forward by researchers focusing on help seeking outside the context of ILEs, well before most of the studies on help seeking in ILEs were published. In our literature search, we have not found a general model for help seeking in ILEs, although Aleven and Koedinger (2001) sketch a model that is specific to one particular ILE (the Geometry Cognitive Tutor).

The model we discuss provides a Vygotskian framework to understand help seeking (e.g., Nelson-LeGall, 1981; Newman, 1994; Puustinen, 1998). It is essentially a task analysis of the help-seeking process, and it comprises the following steps:

1. Become aware of need for help.
2. Decide to seek help.
3. Identify potential helper(s).
4. Use strategies to elicit help.
5. Evaluate help-seeking episode.

This model was originally presented by Nelson-LeGall (1981) and later elaborated by Newman (1994; see also Ryan, Pintrich, & Midgley, 2001). In this model, a learner first must become aware that the task is difficult or that she or he is stuck and in need of help, which may not be straightforward. The ability to assess task difficulty, monitor task progress, and evaluate one's own comprehension and knowledge are major metacognitive functions (Nelson LeGall, 1981; Newman, 1998a). In the next step, learners must consider all available information and decide whether to seek help. Puustinen (1998) assumed that efficient self-regulated learners first question themselves, seeking the right answer or solution to the task at hand before deciding to ask for help. This stage is a critical junction in the help-seeking process (Ryan & Pintrich, 1998). Many of the learner-related factors discussed in this overview have an effect on this decision. For example, learners may not ask for help out of fear that they will receive less credit for a successful outcome (Nelson-LeGall, 1981) or that the teacher or their peers will view them as incompetent (Nelson-LeGall, 1981; Ryan et al., 2001).

Once the decision has been made to ask for help, a suitable helper must be found. In classroom contexts, the teacher or a peer might serve this role. The criteria for selecting the helper appear to differ with the age of the learner and may include the perceived competence of the helper and his or her expected sensitivity to the needs of the learner (Nelson-LeGall, 1981). In the next step, the request for help must be expressed in a suitable way. This step is influenced by students' knowledge and skills of discourse (Newman, 1998a); the request must match the task demands. When students have received help, they must decide to what degree the help is useful and addresses their difficulties. If it does not help them, they must request further help, or they may even need to identify a new helper. In this last

step, the learners must integrate the new information with their existing knowledge and evaluate the quality of the help they received.

Although Nelson-LeGall's (1981) model addresses help seeking in social contexts, the same steps seem to apply to help seeking in ILEs. However, each step may take on a somewhat different character when we consider help seeking in ILEs:

1. *Become aware of need for help.* By giving feedback, the ILE may lessen the need for accurate self-monitoring.
2. *Decide to seek help.* Certain obstacles to deciding to use help may not come into play in the context of help seeking with an ILE, for example, fear of not getting credit for task completion or fear of being seen as incompetent. Other factors may come into play. For example, some ILEs levy a certain cost for using help, such as estimates of skill mastery decreasing, which may deter learners from using the ILE's help functions unnecessarily but may at times have the unintended consequence of deterring potentially productive help use as well.
3. *Identify potential helper(s).* In ILEs, students may have more choices of helpers than in a social context. Even when help functions are built into the ILE, the learners may still have the choice of asking the teacher for help, consulting fellow students, looking things up in the textbook, or using the built-in help functions. In addition, the ILE may have more than one kind of help, for example, a glossary and a hint system.
4. *Use strategies to elicit help.* Typically, when using an ILE the learner has less latitude and flexibility in expressing a help request than in other settings. Further, there tends to be less interaction between the helper and the learner. Using an ILE, the learner can sometimes frame a query in natural language, but the system is not as well equipped as many human helpers to handle a range of help requests. Further, in help systems that do not provide context-sensitive information (i.e., information that is tailored to the task at hand), the learner may have considerably more work to do in order to find relevant information and judge its applicability to the problem at hand. On the other hand, the help content that ILEs offer, especially when it is context sensitive, may be of higher quality than that offered by peer helpers, for example, who sometimes do little more than type in the correct answer without further explanation.
5. *Evaluate help-seeking episode.* The potential of ILEs to provide timely feedback on learners' problem-solving activities, one of the most useful features of ILEs, may reduce students' motivation to reflect on or evaluate their own help-seeking behavior. The feedback offered by the ILE may make it readily clear to learners whether they can proceed with the task at hand after a help episode. To the degree that many ILEs put more emphasis on this kind of immediate feedback as compared to other kinds of help providers, they might contribute to a tendency of the learner to process the help episode rather superficially.

Given these differences, it should not automatically be assumed that empirical findings on help seeking in social or classroom contexts carry over to help seeking in ILEs. Help seeking in ILEs is an interesting field of study in its own right that, in our opinion, deserves more attention than it has received so far.

Given the many obstacles that face a learner who must rely on on-demand help, described in the previous section, why do ILEs provide on-demand help at all? Would learners not be better off if help provision was largely or completely under system control? Several developers of ILEs have presented theories or principles that address the role of help in ILEs in the context of a system's larger set of functions designed to support learners. We review a number of important approaches, essentially in chronological order. We do not claim to be exhaustive. We have selected frameworks that in our opinion are well developed and insightful, are linked to important lines of research, and that as a group cover a variety of viewpoints. While there are no deliberate omissions, it seems likely that one might find additional commentary in the literature on the role of help seeking in ILEs.

Help from the perspective of cognitive skill acquisition. Anderson (1993) discusses the use of help in Cognitive Tutors, a particular type of intelligent tutoring systems, from the perspective of skill acquisition. Under his ACT-R (Atomic Components of Thought–Rational) theory of cognition and learning, a complex skill can be decomposed into smaller units called production rules. These production rules are learned from examples and applied later by analogy. Finally, they become automated through practice.

Cognitive Tutors use a production rule model of the skill targeted in the instruction to guide students as they work through problems. Several such tutors have been built, of which the Algebra Cognitive Tutor is the most successful. A number of evaluation studies have shown that the curriculum of which this tutor is an integrated part leads to better learning than typical classroom instruction, measured both by standardized test and tests focused on the use of representations and problem solving (Koedinger, Anderson, Hadley, & Mark, 1997). The Algebra Cognitive Tutor is currently in use in 1,200 schools nationwide.

According to Anderson, the help in such tutors should be instrumental in turning a problem for which the student has insufficient knowledge into an example from which the student can learn a new production rule by analogy. In order to use a problem in this way, the student must come to the correct solution and must understand why it is correct, preferably by constructing an explanation with guidance (but no more than necessary) from the system's help messages (Anderson, 1993, p. 241). Typically, Cognitive Tutors offer multiple levels of help messages. The first message typically states the problem-solving goal to which a rule contributes. Later levels typically draw attention to important features of the problem-solving context, and the final message (often referred to as the "bottom-out hint") specifies the action to be taken. Although Cognitive Tutors frequently provide error feedback messages, most of the help is given on demand only. The learner controls the level of help.

Providing multiple levels of help and putting help under student control may well be an imperfect solution, but nonetheless it has a number of advantages (Anderson, 1993). When a student makes an error, it is difficult for the system to distinguish among errors caused by slips, missing knowledge, or misconceptions, each of which would require different help or perhaps even no help at all. By putting help under student control, the system gives the student an opportunity to

fix slips or superficial misunderstandings without having to process elaborate explanations presented by the system. Giving students control over the level of help may also have the advantage that students produce their own explanations of correct responses, which is likely to improve retention (Anderson, 1999, chap. 6). On the downside, there is nothing to prevent students from trying to guess the answer when they should be using help or to use help in ways that are not conducive to learning, as discussed further below.

Help from a tutoring perspective. Wood and Wood's (1999) theory of contingent tutoring is based on empirical investigations of human tutors as they help learners perform a task they are unable to perform independently. The principle is that the help given by the tutor must be contingent upon the learner's needs. When the learner is in trouble (i.e., cannot complete a problem-solving step independently), the tutor provides help. If the help is not effective, the tutor gives progressively more detailed and more explicit help until the learner is able to complete the step. If the help does not have the desired effect, the tutor demonstrates the step. On the other hand, when the learner is successful, the tutor reduces the level of help. In this way, both the learner and the tutor contribute to creating an interaction that is contingent upon the learner's needs.

In implementing a computer tutor that is capable of participating in such contingent interactions, one faces the difficulty that computer tutors have far less information about the learner's likely state of mind than human tutors, who can much more easily pick up on many verbal and nonverbal cues. It is therefore difficult for a computer tutor to judge when the learner is in trouble and would benefit from help. Providing help on demand only reduces the chance that the help provided is unnecessary or inappropriate. However, on-demand help does place demands on the learner. A particular disadvantage is that less able students are most likely to be disadvantaged (see Wood & Wood, 1999). Wood and Wood developed a number of ILEs in order to investigate how students' help-seeking behavior with an ILE contributes to the contingent provision of help by the tutor and how it influences learning (Wood, 2001). Their studies are discussed further below.

Wood and Wood note that the recommendations for help systems based on their theory of tutoring are quite consistent with those developed by Anderson (1993) based on a theory of learning (Wood, 2001; Wood & Wood, 1999), and they call for further integration of the two theories. Both also note similar limitations of on-demand help. One subtle difference is that in contingent tutors, the tutor decides about the level of help, whereas in Cognitive Tutors, the learner makes this decision. It is unknown at present how this influences the effectiveness of help seeking in both types of systems.

A Vygotskian perspective on help. Luckin and du Boulay (1999) proposed a Vygotskian view of help and help seeking in ILEs. From their perspective, Vygotsky's zone of proximal development (ZPD) is an essential ingredient of any instructional situation. The ZPD covers those activities that are beyond the learner's independent capability but are within what she or he can do with assistance. Co-constructing the ZPD and targeting it requires a more able learning partner who provides appropriately challenging activities in combination with assistance. While Luckin and du Boulay (1999) do not discuss the role of proactive

help seeking on the part of the learner, it might be interpreted as one of the ways in which the learner can help the more able learning partner in co-constructing the ZPD and providing appropriate assistance.

The role of the more able learning partner can be played by a teacher or peer, but also by a computer tutor. In developing systems that can play this role, the system developer faces questions such as: How can the ZPD of a given student at a given point in time be assessed? Along which dimensions should the system be able to vary the degree of challenge within an activity, and how can it select appropriately challenging activities for a given student, at a given point in time? Along which dimensions should the system be able to vary the level of assistance, and how can it provide the right level of assistance in a given instructional situation? At this point in time, one can only explore answers to such questions by means of experimentation. Luckin and du Boulay (1999) therefore developed three versions of the Ecolab system, an ITS for teaching food web ecology, each with slightly different ways of addressing questions such as those just offered. The results are discussed further below. Eventually, this kind of experimentation will lead to a set of design principles for developing tutors within the Vygotskian framework.

The goals of creating contingent interactions and of providing assistance within the ZPD appear rather similar. The framework presented by Luckin and du Boulay (1999) can be seen as broadening the contingent tutoring framework of Wood and Wood (1999), as it is applied to a new and more extensive subject matter. Luckin and du Boulay consider a broader range of task selection strategies, a broader range of strategies for dividing the responsibility for controlling the level of hints, and concomitant issues of student modeling.

Help to complement self-explanations. (2002) formulated a set of principles to guide the design of ILEs whose goal is to leverage the complementary strengths of self-explanations and instructional explanations provided by the system. On the one hand, when learning from worked-out examples, one of the most effective learning strategies is to explain the rationale of the solution steps to oneself. However, it is difficult for learners to produce self-explanations of high quality. Instructional explanations, on the other hand, lead to lower learning gains than self-explanations (e.g., Brown & Kane, 1988; Chi, 1996; Stark, in press). They cannot be adapted to the learners' prior knowledge, and it is difficult to provide them at the right time, just when they are needed. However, instructional explanations are usually correct, in contrast to self-explanations. Instructional explanations can help to solve comprehension problems and reduce illusions of understanding. Renkl (2002) developed the SEASITE principles (*S*elf-*E*xplanation *A*ctivity *S*upplemented by *I*ns*T*ructional *E*xplanations), aimed at optimizing learning from instructional explanations and self-explanations.

1. *As much self-explanation as possible, as much instructional explanation as necessary.* Ideally, learners use instructional explanations only when they are not able to elaborate the examples by themselves or when they are not sure that their self-explanations are correct.
2. *Provision of feedback.* The ILE should provide feedback in order to reduce learners' illusion of understanding, for example, after asking learners to complete one or more steps in any given example.

3. *Provision on learner demand.* The instructional explanations should be given at the learner's request. This should ensure that the explanations are appropriately timed so as to be useful in the process of constructing new knowledge.
4. *Minimalism.* The instructional explanations should be as brief as possible.
5. *Progressive help.* More extensive explanations should be provided only when minimalist explanations are insufficient (i.e., the help should adapt to the learner's prior knowledge).
6. *Focus on principles.* The explanations should state the domain principles.

Discussion of Theoretical Perspectives

Thinking about how learners' interactions with ILEs relate to theories of learning or tutoring, a number of researchers have come to the conclusion that on-demand help is an important feature of ILEs, in addition to system-initiated feedback. There seems to be an expectation among these researchers that on-demand help is quite essential to ensuring that learners have smooth interactions with these systems and perhaps also that learners will obtain better results when they use the help facilities appropriately. The help given by the ILE should focus on communicating the principles of the domain (Renkl, 2002) or, in the context of ILEs that support the learning of a cognitive skill, on how the principles can be applied to solve problems (Anderson, 1993). While all frameworks focus on multilevel (or progressive) help, they differ on whether the learner or the system should control the level of the help given. Given that the theoretical recommendations with respect to this issue diverge, there seem to be interesting opportunities for empirical work.

The proponents of all four theoretical frameworks seem to have considered designing systems so that they volunteer a considerable amount of help, as an alternative to (or in addition to) providing help at the student's request. However, none of them recommend this option. The common thread in the motivations offered for providing help mainly at the learner's request is that ILEs tend not to have enough information about the learner to make good judgments about when to volunteer help. ILEs do not have access to the verbal and nonverbal cues that skilled human tutors use to interpret whether a learner needs help (Wood & Wood, 1999). When a learner makes an error, the system does not know the exact nature of the error or how best to remedy it (Anderson, 1993). Further, placing help under the control of the learner is likely to improve the *timing* of the explanations so that they are received at a moment when they are most useful for constructing new knowledge (Renkl, 2002).

Importantly, both Anderson (1993) and Wood and Wood (1999) emphasize that providing help on demand may be an imperfect solution. Anderson argues that a system could provide more helpful feedback after the student makes an error if it had more information about the nature of the student's difficulties. Wood and Wood point out that placing control over help in the students' hands puts demands on their ability to use help in an appropriate manner. Given what is known about help seeking in contexts other than ILEs, this requirement may be a significant obstacle to the effectiveness of learning with ILEs, especially (unfortunately) for less able students. It is important to note further that none of the theoretical frameworks address the question of how an ILE might help students become better help seekers. This topic was not taken up systematically by researchers involved in the development of ILEs until very recently, as discussed later in this article.

The theoretical perspectives on help seeking discussed in the literature do not involve certain psychological concepts that are likely to be useful for explaining or improving help-related activities. For example, help-seeking activities require additional cognitive effort by the learner. Such effort may increase cognitive load and consequently may sometimes reduce learning outcomes (Sweller, 1988, 1999). Applied to help seeking, the concept of cognitive load implies that even if the help might be useful, learning outcomes may be reduced because dealing with the task and simultaneously with help imposes too much cognitive load on learners. In addition, learners may sometimes refrain from seeking help in order to avoid cognitive overload.

There are multiple lines of conceptual and empirical research that might guide help design from a cognitive processing perspective. There are, for example, elaborated models for the design of text based on research on *text comprehension* (e.g., Kintsch, 1998). These models may show ways to write help texts that are comprehensible in the context of the actual learning task performed in the ILE. Another line of cognition research with many implications for help design is that involving theories of multimedia learning (e.g., Mayer, 2001). These theories explicate assumptions on how multiple codes (text, picture, and sound) are processed in different cognitive modes (visual, verbal). From these assumptions, specific bottlenecks of the cognitive system can be identified and design rules for multimedia products can be formulated and tested with regard to their effects on knowledge acquisition. Mayer reported a series of design rules based on extensive experimental research. One of these rules suggests, for example, that explanations accompanying dynamic animations or simulations should be spoken rather than written because of possible overload of parts of the cognitive information-processing system in the latter case. More empirical work is needed, informed by these concepts from psychology that have so far been neglected in the design of help systems.

Help Seeking and Teaching

Given that the literature on teaching is vast and given that ILEs (within the limited domains in which they are used) take on some of the functions of a teacher's assistant, it may be surprising that none of the theoretical frameworks we have come across consider how studies of (human) teachers might inform the design of help functions of ILEs. One might expect that the literature on teaching contains much useful information in this regard. The reality, however, is that there is scant evidence in research on teaching that addresses the details of responding to individual student requests for help. In part, this absence of a solid knowledge base reflects the nature of classroom teaching, where teachers must attend to the class as a whole even while interacting with individual students. The complexities of teaching rarely allow for real-time, detailed, individual analysis of student cognition in the ways that might be designed into ILEs.

One body of research that has implications for help seeking is process/product research, which was carried out in the 1970s and 1980s. In this work, researchers investigated correlations between teacher behaviors and student achievement in an effort to understand the components of effective teaching. In a review of that research, Brophy and Good (1986) summarize the findings of dozens of studies about behaviors such as allowing wait time, asking questions of varying difficulty and complexity, selecting respondents, and reacting to correct and incorrect responses.

Although none of the reviewed studies specifically addressed teacher responses to student requests for help, of interest here are the results on teacher responses to incorrect answers. Studies found positive correlations with student achievement when teachers gave negative feedback, indicating that the response was incorrect, followed by questions or clues to elicit a correct response. Brophy and Good continue:

> Sometimes the feedback following an incorrect answer should include not only the correct answer but a more extended explanation of why the answer is correct or how it can be determined from the information given. Such extended explanation should be included in the feedback whenever the respondent (or others in the class) might not "get the point" from hearing the answer alone, as well as at times when a review or summary of part of the lesson is needed. (1986, p. 364)

Keeping in mind that this research addresses responding to the student within a whole class setting, several points are worth noting. First, the studies on which these results are based are highly contextualized. Achievement level, subject matter, and grade level are some of the significant factors in these studies. Second, the prescriptions derived from process/product research leave much to the discretion of the teacher. The results do not detail the exact conditions under which the teacher should give extensive feedback, for example, but rather point to a correlation of that occasional behavior with positive student achievement. Although these results might provide general principles for the design of ILEs, they leave open the detailed questions addressed in the literature reviewed here. Finally, the program of process/product research had largely been abandoned by the 1990s: Causal connections were difficult to verify, and a new interest in a holistic approach to research on teaching spurred new programs of research (Shulman, 1986a). Changing conceptions of teaching and learning moved the research focus to inquiry or problem-based learning in which the complexities of teacher and student behaviors are less amenable to the techniques of the process/product era (for a current review of the state of research on effects of teaching, see Floden, 2001). In short, although the parallel between teachers and ILEs exists, literature on teaching has typically not addressed behavior at a level that is useful for the design and implementation of ILEs.

To summarize, a number of important differences exist between help seeking in social contexts such as classrooms and help seeking with ILEs. These differences imply that help seeking with ILEs deserves to be its own field of study. A number of theoretical frameworks relate the design of ILEs and their help functions to theories of learning, development, or tutoring. The consensus among the proponents of these frameworks is that on-demand help is a useful feature, in addition to other forms of support that ILEs might provide learners, even if it is not ideal from a theoretical point of view. Some psychological concepts seem to have much to offer to improve existing help systems, such as research on cognitive load, reading comprehension, and multimedia design, yet they will not help overcome the limitations noted by Anderson and by Wood and Wood.

Help Use and Its Effect on Learning

Having discussed help from a theoretical perspective, let us now turn to empirical studies of help seeking and learning with ILEs. Surprisingly little empirical research exists on this topic. The studies that have been done show that help use is

often far from ideal but also provide evidence of the potential effectiveness of on-demand help. We first discuss a number of studies that have documented ineffective help use. Then we turn to studies that document positive connections between help seeking and learning. The review in this section and the next is meant to be comprehensive. We discuss all empirical studies of help use and help design in ILEs that we have come across in our literature searches.

A series of studies on problem-oriented learning in the medical domain produced strong indications of inadequate use of help facilities by advanced medical students (Mandl, Gräsel, & Fischer, 2000). This research involved a case-based ILE on anemia and related diseases with different kinds of help facilities, including a glossary with in-depth information on important medical concepts, a link to specific lectures with the necessary background knowledge, and advice generated by an automated expert diagnostician. Learners using this environment seemingly tried to solve diagnosis problems on their own. Analyses of think-aloud protocols revealed that students tended to ignore many of the failures and gaps they had clearly identified before. In addition, following the identification of failures and gaps, students gave justifications for their own strategy or solution far more often than they engaged in help-seeking activities (e.g., using the help system and the glossary offered by the system) to enhance their knowledge (Gräsel, Fischer, & Mandl, 2001). Single case studies, however, indicated that some of the learners made frequent and seemingly appropriate use of the help facilities. As the studies did not focus on individual differences, the authors could not provide data to clarify the heterogeneous use of the help facilities documented in the case studies.

Even when students report that they find the help facilities offered by an ILE useful, they may still not use them very frequently. In a quasi-experimental study dealing with a learning environment for vocational primary education, Hofer et al. (1996) found that students tended to think more positively of the help offered by the system if it was related to the task to be performed. But even though the help was judged as useful, it was seldom used. In a second study, Hofer et al. investigated to what degree the help volunteered by the system was used. The system offered two types of help. In certain parts of the learning environment, hints were presented that enabled the learner to look at a specific part of a hyperlinked textbook. In other parts of the environment, the system provided feedback showing the student where a mistake occurred. The feedback was judged to be far more useful than the hyperlinks to the textbook. The hyperlinks were perceived to be quite informative but were rarely used. The authors did not elaborate on possible causes for their infrequent use.

Aleven and Koedinger (2000) found clear evidence of ineffective help-seeking behavior with the Geometry Cognitive Tutor. As described above, this tutor provides context-sensitive hints on demand, which are specific to the problem and to the particular solution approach that the student has taken so far. For each step, up to eight levels of hints are available with increasingly specific advice. The next level is presented when the student repeats the request for a hint. In addition to on-demand hints, the system provides decontextualized help in the form of an on-line glossary that lists the relevant problem-solving principles (i.e., geometry theorems and definitions) and illustrates each with a short example. An analysis of students' help-seeking strategies revealed that students focused largely on the tutor's bottom-out hints (the last hint level), which come very close to giving away the right answer to

the given step. They tended to spend little time with hints explaining why the answer is the way it is. Further, the students largely ignored the glossary when trying to find numerical answers to geometry problems. These help-seeking behaviors are not likely to be conducive to learning. In a different unit of the Geometry Cognitive Tutor, however, students did spend more time with the earlier hint levels (Aleven, 2001). Also, in the Lisp Cognitive Tutor, students used on average 1.5 out of 3 hint levels (Anderson, personal communication), suggesting that subtle differences in the hint sequences or other aspects of the domain or tutor may have been responsible. It is possible also that the age or related characteristics of the students made a difference. The study with the Geometry Cognitive Tutor involved high school students, whereas the Lisp Tutor was used primarily by college students.

The three studies discussed so far clearly document that learners tend not to make effective use of the help facilities offered by ILEs, but these studies offer no data on the possible effect on learning of ineffective help use. A few studies have addressed this question. We know of only two (related) studies that established a causal connection between the availability of help facilities in an ILE and better learning results. Both studies involved an ILE that supports self-explanation of examples. The goal of the first study, conducted by Renkl (2002), was to test the SEASITE principles described earlier, which focus on leveraging the complementary strengths of self-explanations and instructional explanations provided by the system. Renkl compared learning results obtained with two versions of an ILE for the domain of probability calculations, one in which the system provided explanations at the student's request (instructional explanations) and another in which no such on-demand help was available. Learners in the experimental condition could request either a minimalistic explanation or an extensive explanation. The minimalistic explanations stated the domain principle involved in the given step, and the extensive explanations showed how the principle could be applied. The posttest contained items dealing with probability calculations that had structures similar to those encountered during training, as well as far transfer items that had different structures but involved the same probability principles. The learners in the experimental condition were significantly more successful on the posttest, especially on the far transfer problems. Thus, the study shows that providing on-demand help can lead to better learning in the context of example studying, in particular, help focused on the domain-specific principles underlying the examples.

A related study by Schworm and Renkl (2002a, 2002b) provided further evidence for the effectiveness of on-demand help but showed also that the availability of such help sometimes interferes with productive learning processes. The experiment involved a similar computer-based learning environment, this time designed to help student teachers learn how to design and combine examples when preparing a mathematical lesson. The learning environment presented solved example problems that contained final solutions to problems but did *not* contain distinct solution steps, in contrast to the worked-out examples used in the study described above. The study examined the impact of prompts for self-explanations and the provision of instructional explanations in a 2×2 factorial design. The prompts asked learners to enter (via the keyboard) their thoughts about the learning topic. The learners were not able to continue with the program without providing some amount of elaboration. The instructional explanations were presented at the student's request, in audio format. After the audio presentation, the learner

could request a written presentation as well. There was only one level of explanation, offering help to quite an elaborated extent.

After they had finished their work with the program, the students completed a posttest that contained several tasks related to the use of examples in a lesson plan. Of the four conditions, the self-explanation-only group (whose members were prompted to self-explain but could not request instructional explanations from the system) did best with respect to both the amount of elaboration activity during their work with the ILE and their learning outcomes. When prompts for self-explanations were combined with instructional explanations provided by the system, learners reduced their self-explanation activity (i.e., the amount of written elaboration), and their learning outcomes diminished. Evidently, having a correct explanation at hand reduced the students' efforts to provide explanations themselves, in response to the system's prompts. When there were no prompts for self-explanations, providing instructional explanations led to better learning outcomes. Thus, instructional explanations positively influence learning when students are *not* forced to split their attention between understanding an instructional explanation and trying to provide one for themselves. The study also found that *prompting* for self-explanations fosters learning to a greater extent than provision of instructional explanations.

These results are consistent with the findings of Renkl (2002), discussed on p. 290. Both studies found that adding instructional explanations to a system that supports self-explanation helps learning. However, the second study refines the results of the first by showing that adding instructional explanations to a system that already *prompts* students to provide self-explanations is detrimental to learning, as it may reduce the amount of self-explanation. Both studies establish a causal connection between the provision of on-demand help and learning. In both studies, the availability of help was a factor in the experimental design, and learning outcomes were compared with and without the presence of this factor while keeping other factors of the learning environment constant. The study by Schworm and Renkl (2002a, 2002b) showed further that providing on-demand help is not always effective: Adding on-demand help to a system that prompts students to self-explain examples leads to reduced self-explanation activity and reduced learning outcomes. This result underscores the need for empirical research on help seeking in ILEs.

A number of studies (including Renkl's) have probed how help seeking might mediate learning outcomes. These studies have tried to paint a more detailed picture of whether and how different patterns of help use are associated with different learning results. They provide evidence of correlations between help-seeking activity and learning outcomes.

In order to study the relationships among the students' prior knowledge, their use of the ILE, and their learning results, Renkl (2002) analyzed the data from the study mentioned above using a cluster analysis. This analysis yielded four clusters, which Renkl labeled successful rare users (i.e., users of instructional explanations provided on demand), unsuccessful rare users, successful users, and mediocre users. Successful rare users included learners who could rely on above-average prior knowledge. They rarely used instructional explanations, as they did not need them. Unsuccessful rare users showed slightly above-average prior knowledge but only under-average performance on the transfer items included in the posttest. Their infrequent use of instructional explanations seemed to be dysfunctional. Successful

users had low prior knowledge, but their performance on transfer problems was almost average, and they had above-average learning gains. This group used a balance of minimalist and extended explanations. The mediocre users had average pretest and far transfer posttest scores. Although they used explanations at about the same rate as the successful users, they relied primarily on minimalistic explanations and requested extensive explanations infrequently. This analysis suggests that learners who do not have high prior knowledge have greater learning gains when they seek help more often, as evidenced by the contrast between the successful users, on the one hand, and the unsuccessful rare users and the mediocre users, on the other. Renkl's analysis also shows that students who make balanced use of different types of explanations (i.e., request further detail as needed) tend to learn more than those who have a tendency to focus only on less detailed explanations.

Like Renkl, Wood and Wood (1999) found that students with lower prior knowledge learn more when they seek help more often. They studied relations among prior knowledge, help seeking, and learning using a computer-based learning environment for algebra called QUADRATIC. This ILE is based on the theory of contingent tutoring (see above), which adjusts the specificity of on-demand help according to the learner's performance. The study involved 42 learners 14 and 15 years of age, each of whom had two 30–50-minute sessions with QUADRATIC. The students' prior knowledge of algebra was measured using a variant of a standardized test. Their learning results were measured as the average score on a series of five repeated "probe tests" in which they were asked to expand the quadratic function $(x + n)^2$. Wood and Wood found a positive partial correlation between the tendency to seek help and learning, after the effects of prior knowledge had been partialled out. The tendency to seek help was measured by the following ratio: number of help requests/(number of errors + number of help requests). This partial correlation was found only for students with low prior knowledge. The study by Wood and Wood is discussed in more detail in the section on prior knowledge below.

Aleven and Koedinger (2001) tried to reproduce Wood and Wood's results using data obtained with the Geometry Cognitive Tutor. They found a trend in the same direction, but it was not significant. There were, however, a number of differences between the studies. In the study of Aleven and Koedinger, students worked with the ILE about six times as long as the subjects in the Wood and Wood study. Further, a number of differences existed between the help mechanisms used by the two systems, with respect to number of help levels, whether the student or the system controls the level of the help presented, and whether there is a cost to using help. Finally, the Geometry Cognitive Tutor selects problems on an individual basis, according to its assessment of the student's skill mastery. In QUADRATIC, the sequence of problems was fixed. More research is needed to verify how the details of help systems and task selection influence help seeking.

Shute and Gluck (1996) studied relations between learners' use of optional tools in an ILE and (among others) learning outcome and efficiency. The learners worked with the Ohm tutor, which was designed to help them learn principles of electricity by solving problems involving electrical circuits. The system offers a reference dictionary as well as various tools for on-line experimentation with the circuit being studied. A pretest and posttest were designed to measure domain-related declarative knowledge. In addition, the posttest included items that measured quantitative understanding and also included transfer items. There was a

main effect of tool use on learning outcome but not on efficiency. Optional tool use is associated with better learning outcomes, without costing more time. Thus, making optional tools available appears to be beneficial, even if the system cannot guide students in using the tools. The authors identified four groups of users based on the frequency of early and later tool use. They found that the patterns are stable over time and that some patterns are better than others in terms of learning outcomes. Students who had high tool use initially followed by low tool use later on fared best. Students who did not use the tools much early on but used them more frequently later fared the worst. Stable tool users had average results, with a slight advantage for those who used the tools frequently both early on and later.

To summarize, the studies discussed above show quite convincingly that effective use of the help facilities of ILEs is rare. They also provide evidence that on-demand help in an ILE leads to better learning. The studies by Renkl (2002) and Schworm and Renkl (2002a, 2002b) show that providing on-demand help *causes* better learning. A different study found that more frequent help use is related to better learning for students with lower prior knowledge, without establishing a causal connection (Wood & Wood, 1999). The study by Schworm and Renkl (2002a, 2002b) also uncovered a number of limitations on the effectiveness of providing on-demand help; doing so was not as effective as providing prompts for self-explanations. Moreover, on-demand help interfered with students' responses to such prompts, with a detrimental effect on learning. Additional studies are needed to establish more firmly the circumstances under which a causal relation exists between help seeking and learning and to establish both the value and the limitations of on-demand help for different types of ILEs, student populations, and subject matter.

System-Related Factors

If the use of on-demand help is a factor in determining learning results, what kind of help is most effective? A small number of studies have investigated what types of help work best under what circumstances or for what categories of learners. These "parametric studies" have compared learning results obtained with versions of the same ILE that differ only in some aspect of their help systems, for example, the content of the help messages. These studies have identified a number of relevant dimensions of help systems that make a difference with respect to learning outcomes. A number of the studies have found interactions with learner-related factors. We discuss the main findings on system-related factors in this section and discuss learner-related factors and interactions in the next section. We include a number of studies dealing with system-initiated feedback (i.e., messages volunteered by the system, usually in response to errors), since it is plausible that the results of these studies generalize to on-demand help. We discuss all relevant studies that we have come across in our literature searches.

Dutke and Reimer (2000) investigated what kind of help content most effectively helps subjects learn how to use a graphics software package by means of task-based exploration. They distinguished between *operative help* (a list of steps that have to be taken to achieve a goal, such as "Click left mouse button") and *function-oriented help* (explanations about how a function works, for example, "With this tool you can create a filled circle"). Sixty computer novices, undergraduate students with a mean age of 24 years, participated in the study. The participants completed a series

of drawing tasks with an experimental graphics software package that provided help on demand but had no other features designed specifically to support learning. All participants worked on a set of training tasks followed by a set of transfer tasks that were more difficult. Each subject worked with a version of the system that provided either operative help or functional help. During the training tasks the subjects could use the on-line help facilities freely, but during the transfer tasks they were no longer available. Dutke and Reimer measured performance as the number of commands the students needed to fulfill the task and the mean time per command. During training, the participants who received operative help needed fewer commands to complete the task than did the function-oriented group. Thus, operative help supports performance better than does function-oriented help. On the transfer tasks, however, which were more difficult and during which help could no longer be requested, the participants who had received function-oriented help did better. Therefore, in this case, function-oriented help supports learning better than does operative help. This study illustrates that some learning conditions enhance performance in transfer tasks, although they impair performance during training (van Merrienboer & De Crook, 1997).

Whereas the previous study investigated the effect of varying the content of on-demand help, a number of studies have investigated the effect of varying the content of *system-initiated feedback.* In a series of studies, Arroyo and colleagues investigated the (short-term) influence of the level of abstraction of the feedback messages and the degree to which the feedback is given in an interactive manner (Arroyo, Beck, Beal, Wing, & Woolf, 2001; Arroyo, Beck, Woolf, Beal, & Schultz, 2000). Her studies involved an ILE called Animalwatch, which deals with mathematical word problems related to endangered species of animals. Arroyo compared the effectiveness of system feedback with two different degrees of abstractness. *Concrete hints* made reference to concrete objects such as base-10 blocks and bars and made connections to real-life problems. *Abstract hints* used direct operations over numerals. The effectiveness of the hints was measured by analyzing the change in the number of errors immediately after receiving the hint (i.e., during the work with the ILE). The results showed a significant interaction between the abstraction level of the feedback and the students' level of cognitive development. Students high in cognitive development did better with more abstract hints, while students low in cognitive development did better with more concrete hints. This result suggests that the level of abstraction of help provided should be adapted to the learner's level of cognitive development.

In the same study, Arroyo et al. (2000, 2001) investigated the effect of level of interactivity of hints, comparing on the one hand highly interactive multimedia presentations where the students were asked for several kinds of input (e.g., drag and drop or textbox input) and on the other hand short messages where the student did not have to provide much input (e.g., just a single number). They found that with respect to self-confidence and performance, boys benefited more from the shorter, less interactive hints. Surprisingly, their self-confidence declined when they worked with the more highly interactive version. The level of interactivity did not affect girls' self-confidence, but girls did do better when supported by more interactive help. The influence of gender is discussed further below.

In addition to abstraction level and degree of interactivity, the *type of information* presented as feedback can make a difference in students' learning results.

McKendree (1990) investigated the impact of different kinds of feedback when learning geometric proofs with the Geometry Proof Tutor (Anderson et al., 1995). (This tutor is a predecessor of the Geometry Cognitive Tutor mentioned above. It focuses on teaching proofs.) McKendree distinguished among minimal feedback, condition violation feedback, goal statements, and a combination of condition violation and goal feedback. Minimal feedback let the student know that she or he made an error but provided no further information. Condition violation feedback pointed out an unsatisfied condition of the geometry rule that the student had selected for use in the next proof step. (The unsatisfied conditions are reasons that the rule cannot be applied as intended.) Goal feedback stated the correct subgoal on which the student should focus. Combined feedback, finally, stated both the subgoal and an unsatisfied rule condition. McKendree's results showed that goal feedback leads to better learning outcomes than feedback about the occurrence of an error or its cause (i.e., an unsatisfied condition of a rule that the student had selected). Learners who received goal feedback were better able to transfer their knowledge to tasks where feedback was no longer provided. Further, the learners more often corrected their errors after goal feedback than they did after any other type of feedback. Thus, in geometry proof tutoring, reminding students of their current goals supported both performance and learning more effectively than pointing out rule conditions that are not satisfied.

Luckin and du Boulay (1999) conducted a study to find out how best to implement the Vygotskian framework outlined above. They compared three versions of their Ecolab ILE in order to get a sense of how the system could best extend students in their ZPD (Vygotsky, 1986). These versions differed with respect to parameters related to the help facilities, namely, the number of help levels and the locus of control of the levels, as well as parameters related to the nature and content of the learners' task. Learning gains were measured by a written pretest and posttest as well as by a structured interview. The test and interview evaluated to what extent the children understood the relevant concepts of the Ecolab environment (e.g., food webs and food chains) as well as their awareness of what they had learned and their ability to transfer their knowledge to a different situation (i.e., an ecological environment different from Ecolab's). The results showed that the most consistent learning gains were made with the system version that exerted the greatest control along the dimensions mentioned above. However, this version was not optimal for all learners. For example, high-ability learners did better using the system version in which the control was shared (i.e., the system made suggestions but the learners were free to make their own choices). The users of the system version that exerted the most control took the greatest advantage of the system's help utilities. The users of the system version that offered students the most freedom basically ignored any offers for help (see also du Boulay et al., 1999). Thus, the study shows that directing learners toward activities that are beyond their ability while providing suitable help fosters learning; for high-ability learners, it is better if the system suggests what to do next. Although we cannot attribute the differences in learning outcomes to the differences in the help systems only, it is interesting that the design of the help system influenced the learners' help-seeking behavior.

In sum, the literature identifies a number of system-related factors that influence the effectiveness of help and feedback. In the context of task-based exploration, function-oriented help leads to greater transfer than operative help, although at the

expense of more training time (Dutke & Reimer, 2000). Function-oriented help abstracts from the surface of the task to be done and thereby helps to initiate knowledge transfer. In this respect, it is similar to help focused on problem-solving principles, which was also shown to lead to transfer (Renkl, 2002). These results seem to imply that help in ILEs should primarily be function oriented or principle oriented and that operative help should be given only as a last resort, as it is for example in the Geometry Cognitive Tutor (Aleven & Koedinger, 2000). Other interesting system-related factors are the number of help levels and who controls the level (student or system).

Certain findings that relate to system-initiated feedback seem relevant also to on-demand help, such as whether the feedback messages include goal information, whether the feedback is stated in abstract or concrete terms, and the degree to which the feedback is interactive (e.g., requires the user to answer questions correctly). As we have seen, these variables interact with learner characteristics such as gender and stage of cognitive development.

Even though the studies discussed in the current section do not show that providing facilities for on-demand help in an ILE improves learning, as compared to not providing such facilities, the fact that a number of factors related to help systems lead to differential learning outcomes provides further evidence that help seeking is an important influence on learning, Overall, the base of empirical results on the effect of help systems in ILEs is still quite small. At this point, not enough is known to be able to construct comprehensive theories of learning with help systems or to formulate empirically based design principles that provide guidance to the designers of help systems.

Learner-Related Factors

In previous sections, we discussed how aspects of system design influence help seeking. In this section and the next, we look at the influence of learner-related factors. Our goal is not to provide a comprehensive survey about all potential factors. Rather, it is to show the importance of developing help systems in relation to the characteristics of the target group and to give examples of how this might be achieved. In this section, we discuss factors that have been studied in the context of ILEs: prior knowledge, metacognitive ability, cognitive development, and gender. We discuss all empirical studies that we have found that relate to help use and help design in ILEs. In the next section, we discuss factors that have not been researched within ILEs but are promising candidates: students' goal orientation and epistemological beliefs.

Prior Knowledge

Prior knowledge is one of the most important factors influencing student performance (e.g., Dochy & Alexander, 1995; Weinert, 1996). It is a good predictor of learning and student success (Dochy & Segers, 1997; Glaser & De Corte, 1992). Prior knowledge has an indirect effect on learning through student behavior and study skills (Dochy & Segers, 1997). If one views learning as a process of integrating and structuring new information in existing knowledge structures, it seems clear that more developed prior knowledge provides a better basis for interpreting new material and for compensating for incoherence within this material (e.g., Kintsch, 1988, 1998).

With respect to help seeking, there are two domains of interest: effects of prior knowledge regarding the subject matter being learned and effects of prior knowledge regarding the ILE. We discuss each in turn.

Prior knowledge of the domain. As described in more detail earlier, Wood and Wood (1999) studied relations between prior knowledge and help seeking with a contingent tutoring system for algebra called QUADRATIC. Their results showed significant interactions among prior knowledge, the number of errors the students made, and their help-seeking tendencies. Overall, learners with less prior knowledge made more errors and sought help more frequently. They showed worse results in mastering and remembering the expansion of the quadratic function. Why is it that learners with less prior knowledge sought help more often and were provided with more specific help yet failed to show better results? Further analyses revealed that learners with higher prior knowledge exhibited more effective help-seeking behavior. Even though they made fewer errors than students with lower prior knowledge and were more likely to self-correct their errors, they were more likely to seek help after making errors. Learners with lower prior knowledge also fared better if they had a tendency to seek help after making an error. The authors concluded that students with lower prior knowledge apparently made less accurate judgments of their need for help.

Given the beneficial effect of prior knowledge on learning that has often been found, it may not be surprising that students with higher prior knowledge are better able to monitor and control their help-seeking behavior. On the other hand, prior knowledge can sometimes be detrimental to learning, as shown by a number of results in the field of comprehension monitoring. For example, learners with high prior knowledge may overestimate their understanding of learning material or may have a feeling of knowing when faced with a highly coherent text in a familiar domain. As a result of such overconfidence, they may process the text less deeply (Glenberg & Epstein, 1987; Kintsch, 1998). Similarly, a study by Scardamalia and Bereiter (1992) on question-asking behavior showed that children with less prior knowledge asked more appropriate questions. Thus, one might predict that higher prior knowledge would be associated with less appropriate help-seeking behavior. When learners working with an ILE are confident that they have the knowledge to solve a problem, they may not be inclined to seek help and may persist in trying to find the solution on their own. They may also process any help that is given in a more superficial way. Up to now, it is not known whether such phenomena can be found in help-seeking behavior.

It is surprising that, in the study by Wood and Wood, the learners with higher prior knowledge were more likely to seek help *after* an error than learners with low prior knowledge. The members of the group with low prior knowledge made more errors and were less likely to self-correct, so from an objective point of view it is clear that they needed more help. Then why did they not ask for help more often after committing an error? For reasons such as these, the interaction between prior knowledge and help seeking seems to be more complex than may be apparent at first sight. In the following, we describe some studies that examine these interactions in more detail.

In subsequent work, Wood (2001) investigated two possible explanations for the seemingly less proficient help-seeking behavior of students with lower prior

knowledge: These students may have weaker self-regulatory skills or they may only appear to be less adaptive help seekers than other students because they are faced with tasks that, given their low prior knowledge, are subjectively more difficult. Therefore, in the follow-up study, carried out with a contingent tutoring system called DATA, selection of problems was made contingent upon students' knowledge of the learning domain. Students took an on-line test prior to working with DATA. As they worked with DATA, they were offered tutoring in the classes of problems on which they had made errors. Under this "domain-contingent regime," there was no association between students' prior knowledge and any measures of the student-tutor interaction, such as probability of success, errors, or help seeking. In other words, the relation between prior knowledge and help seeking observed in the QUADRATIC study seems attributable to differences in problem difficulty, not in self-regulatory skills per se. If problems are too difficult, self-regulatory skills such as comprehension monitoring might break down more easily.

Further evidence for effects of prior knowledge on help seeking can be found in the work of Renkl (2002; see above). As mentioned, he compared two versions of an ILE for studying examples, one that offered on-demand help (minimalistic explanations and extensive explanations) and one without this help function. In order to identify patterns of help use and learning, Renkl analyzed the data using a cluster analysis, which yielded four types of users (as described in more detail earlier). Renkl's analysis suggests that all learners except those with high prior knowledge fare better if they seek help more often. Of the three clusters that comprise students with lower prior knowledge—the unsuccessful rare users, the successful users, and the mediocre users—the ones with more frequent help use tended to have higher learning gains. This result is consistent with those of Wood and Wood in the QUADRATIC study presented above.

The results of Wood and Wood (1998) and Renkl (2002) on help seeking with ILEs correspond to the results of studies in which learners request help from teachers or peers. These studies show that lower achieving learners, who have less prior knowledge and therefore should need help the most, seem less capable of adaptive help-seeking behavior (e.g., Miyake & Norman, 1979; Nelson-Le Gall, 1987; Nelson-Le Gall, Kratzer, Jones & DeCooke, 1990; Puustinen, 1998). Puustinen (1998) examined the influence of age and academic achievement in mathematics on three self-regulation aspects of help-seeking activities: (a) awareness of help, (b) capacity to restrict help to what is necessary, and (c) ability to reuse help in analogous tasks. In this study, second and fourth graders had to solve logical reasoning tasks and then self-evaluate their performance on the tasks. During the process, they could ask an experimenter for help. Her results showed that academic performance had a strong effect: High achievers (determined according to the children's grades in mathematics) were better self-regulators in all three self-regulation aspects. High-achieving fourth graders were best at self-regulation.

In sum, the studies discussed above indicate that learners with lower prior knowledge—those who need help the most—are the least likely to use help appropriately when help is under students' control. This situation presents a challenge for the designers of ILEs, especially since, as we have seen, there are good reasons for placing help under student control. The second study by Wood (2001) seems to suggest that ILEs that adapt very flexibly to learners with low prior knowledge—in other words, ILEs with a highly sensitive domain-contingent tutoring regime—

make lesser demands on students' help-seeking skill. If Wood's result can be replicated in studies of a larger scale, this may be good news. Many intelligent tutoring systems already implement some form of individualized problem selection based on their assessment of the student's knowledge state. To the extent that they provide a wide enough range of instructional units, they may already have the property that learning results are not related to students' help-seeking skill. On the other hand, it seems reasonable to prefer a system that helps students become better help seekers, as discussed below.

In addition, it might be possible to compensate for low prior knowledge by affecting variables that mediate the relations between prior knowledge and help seeking. For example, in classroom practice, high interest can compensate for low prior knowledge (Dochy & Segers, 1997). If it is possible to arouse interest in a domain, students may not only try harder to understand the domain, they might also try to use the help in a more adaptive way.

Prior knowledge of the learning environment. There is also strong evidence that prior knowledge about the learning system itself affects learning. For example, users' models of hypertext systems influence their information-seeking strategies and the appropriate use of links and tools (e.g., Bromme & Stahl, 1999, 2002; Gray, 1990, 1995; Stahl, 2001; Wallace, Kupperman, Krajcik, & Soloway, 2000). Users often compare unfamiliar systems such as hypertext with more familiar media such as conventional books. They prefer those tools that most closely mimic the familiar media and avoid unfamiliar tools (Leventhal, Teasley, Instone, Rohlman, & Farhat, 1993). Although little research is available about the influence of learners' prior knowledge of the system on their help-seeking behavior, it is plausible that users need to know about the help functions offered within an ILE before they can use them in an appropriate way. Hasebrock (1995) compared learners who worked for the first time in a hypertext system with learners who had experience using such a system. Only the experienced users were able to use the tools offered by the system (such as glossary, notepad, and content list) in an appropriate way. Further research should explore the hypothesis that students need a mental model of a help system and strategies for how to use it *before* they attempt to learn in a new learning environment.

Self-Regulation

In the following, we discuss empirical evidence that supports a view of help seeking as a self-regulatory skill. This issue has been studied primarily outside of the context of ILEs. Self-regulated learners are characterized by their control over learning processes and academic outcomes (Newman, 1998a). This includes activities such as appropriate preparation and control of one's own learning process, knowing how to learn, evaluating outcomes, and maintaining motivation and concentration (Simons, 1992). Self-regulated learners have useful learning strategies (Schunk, 1989; Thomas & Rohwer, 1986; Zimmerman, 1989; Zimmerman & Schunk, 1989).

Help seeking can be defined as a strategy of self-regulated learning (Newman, 1998a). Help seeking involves a sequence of steps, explicated in the Nelson-LeGall and Newman process model presented above, that require skills such as comprehension monitoring, formulation of the need for help, and evaluation of whether

the help received actually solves the problem. Such skills are typically considered to be in the realm of self-regulation. The work of Puustinen (1998) mentioned above shows that adaptive help seeking is related to such self-regulatory skills.

Further evidence that help seeking can be defined as a self-regulatory skill is given by Nelson-LeGall et al. (1990). They discussed how students' help seeking depends on their confidence in the answer they achieved (i.e., their own assessment of the need for help). They showed that objective item correctness did not account for as much variance in help-seeking rates as did self-assessment of performance. This type of assessment involves comprehension monitoring and can therefore be seen as a self-regulatory skill. Skills such as self-assessment of (future) performance might be a valuable factor to distinguish between adaptive and maladaptive help-seeking behavior.

It is an interesting and largely open question how self-regulatory skills and prior domain knowledge interact to affect learners' help-seeking behavior. As discussed, Wood (2001) found no relations between prior knowledge and the probability of help seeking when the system (DATA) selected problems adapted to learners' prior knowledge. He concluded that the previously observed relations between prior knowledge and help seeking were attributable to problem difficulty. This result seems to imply that within the given student population, differences in prior knowledge, mediated by subjective problem difficulty, had a far more pronounced effect on help seeking than differences in self-regulatory skill. More research is needed to study the relations between prior knowledge and self-regulatory skill.

In addition, it is an interesting open question how effective special training in help-seeking skills will be, administered perhaps prior to using an ILE. Generally, we cannot assume that learners will be able to become successful self-regulated learners without being trained to do so (e.g., Weinert & Schrader, 1997). Some studies show success in training students in such metacognitive skills (e.g., Bielaczyc, Pirolli, & Brown, 1995). If training in help-seeking skills turns out to improve help seeking, this will be an important practical result. It will also be important from a theoretical viewpoint, because it would establish a causal connection between self-regulation and help seeking. Rather than providing short introductory instruction in help seeking, it may be more effective to develop ways in which the system could monitor and evaluate students' help-seeking behavior and provide tutoring (Aleven, 2001; Luckin & Hammerton, 2002), as discussed further below.

Age and Gender

Constitutional factors such as age and gender have an effect on help-seeking behavior. The relation between age and help seeking is simple: Help-seeking abilities improve with age (Newman & Schwager, 1995). Adolescents, for example, show more appropriate help-seeking behavior than children because of improved metacognitive skills (e.g., Ryan & Pintrich, 1998); they are better able to monitor and reflect on their performance with increasing age.

The relation between gender and help-seeking behavior is more complex. Gender differences and their influence on learning processes and performance have been a popular topic in education policy over the years. Accordingly, there has been much research and many "analyses, re-analyses and meta-analyses" (Helmke & Weinert, 1997, p. 103). There exists a long controversy about the effects of gender on learning. At issue is whether there are inherent differences between the gen-

ders in, for example, intelligence, spatial imagery, or verbal skills, or whether differences in learning outcomes can best be explained in terms of gender-specific attitudes, socialization, and interest (e.g., Hannover & Bettge, 1993).

The relationship between help seeking and gender in social contexts has been examined extensively; within school contexts, boys are more likely than girls to avoid seeking help when they need it (e.g., Ryan, Gheen, & Midgley, 1998). Also, pupils with an ability-focused orientation (especially the boys in this subgroup)—meaning that they are intent on showing that they are competent—request the least amount of help (Butler, 1998). For such pupils, seeking help is thought to show incompetence. Newman and Goldin (1990) showed that gender differences depend on the domain: Girls in elementary school reported greater concern than boys that the teacher might think they were dumb when they asked for help in mathematics classes, but not reading classes. A possible reason for this might be seen in gender stereotyping of mathematics (Newman, 1998a).

Concerning help seeking in technology-based learning environments, especially those focused on individual learning, we find considerably less research. Arroyo and colleagues (2001) investigated learning of fifth-grade students with different versions of an ILE called Animalwatch. As described above, they compared hints that were classified as highly interactive with low interactive ones. They found that girls performed better in solving mathematical problems with highly interactive feedback and that boys performed better with less interactive feedback (see also Arroyo et al., 2000). In another study, the same authors found that boys spend significantly less time processing the system's feedback, offering a new answer sooner than girls do. The authors concluded that boys are less willing than girls to receive long periods of feedback. While the Arroyo studies focused on system-initiated feedback rather than on-demand help, it seems quite likely that the results apply as well to on-demand help.

These results indicate that help-seeking behavior is influenced by gender. Boys are less willing to seek and accept help from the system. It might be interesting to investigate whether students see help seeking as such as a masculine or a feminine activity (Ryan et al., 1998). Further, gender differences in help seeking seem to be domain specific and therefore may depend on interest. We can conclude that we know much more about the relation between help seeking and gender in social contexts than in the context of ILEs.

An interesting direction for future research is to examine not only the relation between gender and help seeking as such but also the factors that may determine gender differences. As described above, gender can be interpreted as a variable that integrates different factors such as interest, attitudes, self-confidence, desire for independence, and so on (e.g., Hannover & Bettge, 1993). It might be more productive to see gender as a moderating variable between such factors and help-seeking behavior than to see it as an independent variable. Results of such studies might make it easier to develop help systems that take into account gender-related individual differences.

Learner-Related Factors Not Yet Studied Within ILEs

In this section, we consider two more learner-related factors that have not been studied in the context of ILEs: students' goal orientation and their epistemological beliefs related to the domain of study. We consider these factors to be of major

interest to the study of help seeking in ILEs. This judgment may to some extent be subjective, but it is informed by a study of the literature. The influence of students' goal orientation on help seeking and learning has been studied quite extensively *outside* the context of ILEs. Although there is a significant literature on the relation between students' epistemological beliefs and their learning outcomes, to our knowledge, no studies have specifically addressed the influence of students' epistemological beliefs on their help-seeking behavior, with or without ILEs. We argue that it is quite plausible that epistemological beliefs exert an important influence on help-seeking behavior and outline research questions aimed at better understanding this influence.

Goal Orientation

Whether students are willing to seek help depends on motivational factors such as their interest in the subject matter, their academic goal orientation, and their self-perception of abilities (Newman, 1998a; Ryan & Pintrich, 1997). Motivational factors influence the ways in which students act within a learning setting. But the setting also has a reverse effect on motivation. For example, Schofield found increased motivation due to use of ILEs, namely Cognitive Tutors for geometry proofs and computer programming (Schofield, 1995; Schofield, Eurich-Fulcer, & Britt, 1994). An important motivational factor that is known to have an influence on help seeking is a student's goal orientation (Newman, 1998b). We first show evidence that a student's goal orientation affects help-seeking behavior and then discuss how it might be affected by contextual factors of the learning situation.

A student's academic goals determine his or her orientation toward achievement (Arbreton, 1998). Students with a more intrinsic orientation tend to focus on learning and understanding. They are interested in their work and in mastery. This *learning goal orientation* is assumed to lead to the use of more appropriate learning strategies such as monitoring comprehension and deep processing strategies such as relating new information to prior knowledge (Arbreton, 1998). In contrast, students with a more extrinsic orientation tend to focus on performance and on showing their abilities. They are mainly interested in being seen as better than others, impressing their teachers, and getting good grades. This *performance goal orientation* is assumed to be related to more surface processing strategies (Arbreton, 1998). There are other and more differentiated definitions of different kinds of goal orientations (e.g., Middleton & Midgley, 1997; Ryan, Pintrich, & Midgley, 2001), but we need not discuss them in order to illustrate the relation between help-seeking behavior and goal orientation.

Ryan and Pintrich (1997) showed both direct and indirect effects of motivational variables such as achievement goals on help seeking. In this study, 203 students (seventh and eighth graders) completed a survey about motivational and attitudinal factors and their help-seeking strategies. The direct effect was that students who wanted to understand the subject matter (i.e., students with a learning orientation) reported being more likely to seek help. Students with performance goals, on the other hand, tended to report that they avoid seeking help. The indirect effect was that achievement goals influenced attitudes toward help seeking. Students with learning goals tended to see the benefits of help seeking, while students with performance goals were more likely to perceive help seeking as a threat to self-worth.

Arbreton (1998) studied how students' goal orientation might influence the *kind* of help they request. She differentiated among learning goals, extrinsic goals (i.e., getting good grades), and relative-ability goals (i.e., demonstrating one's abilities compared to others). Also, she distinguished between *instrumental help* such as hints and *executive help* such as answers. She asked 384 fifth graders from 21 classrooms about their help-seeking behavior and measured their goal orientation with questionnaires. She found a significant correlation between goal orientation and help-seeking behavior: Students with learning goals reported that they asked more often for instrumental help, whereas students with extrinsic or relative-ability goals reported that they looked more for executive help.

It is plausible that help seeking in ILEs is affected by the learner's goal orientation in a similar way. For example, one would expect that students with performance goals would use help functions in an ILE to try to get the tasks done quickly without reflection or understanding. Such behavior was indeed reported by Aleven and Koedinger (2000), as discussed above. Aleven and Koedinger did not assess achievement orientation, but this is worth doing. Even without changing students' achievement orientation, ILEs may have a positive influence on help seeking, as compared to other environments. For example, ILEs offer the possibility of searching for help in a more anonymous way than is possible in the usual classroom situation. This greater anonymity might have a significant positive influence on help seeking, especially for students who tend to avoid seeking help because they fear demonstrating inability in front of others. Schofield (1995, p. 52) reports that students using an ILE are less concerned about such embarrassment. Therefore, learning with an ILE might help to overcome or at least reduce the effects of a strong ability-focused orientation.

The motivational characteristics of the classroom also play a role in shaping students' help-seeking behavior. For example, students' (self-reported) avoidance of help seeking is related to their perceptions of the classroom goal orientation, as shown by Ryan et al. (1998) in a survey study involving 516 fifth graders from 63 mathematics classrooms. Students who perceived the classroom goal as task focused (i.e., as learning oriented) reported lower levels of avoidance. On the other hand, students who perceived the classroom as focusing on relative ability (i.e., as performance oriented) reported higher levels of avoidance.

While Ryan et al.'s (1998) study leaves open the possibility that the students' perception of the classroom goal orientation merely reflected their own personal goal orientation, a study by Newman (1998b) suggests an independent impact of contextual (or classroom) goals on students' help-seeking behavior. He examined the relationships among personal goal orientations, contextual goals, and help-seeking behavior. The contextual goals were experimentally induced goals that were used to simulate classroom goals. A total of 78 fourth- and fifth-grade students were asked to solve mathematics puzzles. Some students were told that doing these puzzles would greatly help them improve their skill in mathematics (learning goal). Other students were told that the experimenter wanted to assess how smart they were in mathematics and how they compared to other children (performance goal). The results showed that when both contextual and personal goals emphasized performance, students were most reluctant to seek help. For students with personal performance goals, contextual learning goals helped them to overcome their personal tendencies, resulting in more help seeking. In a study with a

similar design, Newman and Schwager (1995) examined the relation between help seeking and contextual goals. They also found that students (118 students in Grades 3 to 6) with contextual performance goals showed more maladaptive help seeking.

Although these results were obtained outside the context of ILEs, they certainly *suggest* that students working with ILEs in learning-oriented classrooms may make more effective use of the system's help facilities than students in performance-oriented classrooms. Further, it may be beneficial to give students a contextual learning goal orientation. Students with performance orientations would be expected to profit most from these kinds of instructions. It does not appear likely, however, that simple manipulations such as those used in the studies discussed above will be very effective in inducing a permanent learning orientation in actual classroom settings. Much may depend on the teacher. Creating a classroom culture focused on learning may be one of the greatest challenges that teachers face. The use of ILEs may have some advantages in this regard. In training sessions related to the use of the ILE in their classrooms, teachers could be encouraged to emphasize to their students that the ILE is a tool meant to foster learning. Further, some "symptoms" of a performance orientation may be readily observable when students work with an ILE, such as students' focusing on hints that give answers rather than explanations. Perhaps teachers could be encouraged to be alert for such symptoms and, when they observe them, to explain and demonstrate a more productive way of using help to their students. In addition, some success may be had by thinking carefully about the kinds of help functions that should be offered to the learner. For example, perhaps ILEs should not offer help that gives away answers, as a way of communicating (albeit implicitly) to students that a performance orientation might not be helpful. Such measures are not likely to result in a radical shift in students' performance orientation, especially in classes where such an orientation is dominant, but perhaps small changes may lead to better help seeking.

Epistemological Beliefs

There is growing evidence that learning processes and outcomes are strongly influenced by the epistemological beliefs of learners and their teachers. As mentioned, we are not aware of any studies showing that these beliefs might influence students' help-seeking behavior. We discuss why it is plausible that they do. We give a short introduction to the research area of epistemological beliefs before we discuss possible effects on help seeking. A number of detailed overviews about research on epistemological beliefs provide further information (Buehl & Alexander, 2001; Duell & Schommer-Aikins, 2001; Hofer, 2001; Hofer & Pintrich, 1997).

Epistemological beliefs are beliefs about the nature of knowledge. Theories changed over time from the assumption that epistemological beliefs are unidimensional (e.g., Ryan, 1984) to the assumption that these beliefs are multidimensional (Elby & Hammer, 2001; Hofer & Pintrich, 1997; Schommer, Calvert, Gariglietti, & Bajaj, 1997). Depending upon the theory, epistemological beliefs include beliefs about the structure and stability of knowledge, about sources and justification of knowledge (e.g., Hofer, 2001), about learning and abilities (e.g., Schommer, 1990), or about the relation of knowledge and beliefs (e.g., Alexander & Dochy, 1995; Souterland, Sinatra, & Matthews, 2001). It is generally assumed that epistemological beliefs change during educational processes from more naive

views (e.g., knowledge is absolute, knowledge is an accumulation of facts) to more sophisticated beliefs (e.g., knowledge is relative and contextual, knowledge is a complex network). Further, it is widely believed that a more sophisticated belief system has positive effects on learning processes (for a critique of this view, see Elby & Hammer, 2001).

There is growing empirical evidence that learners' epistemological beliefs have an influence on their processing and interpretation of information and their comprehension monitoring (Schommer, 1990; Schommer, Crouse, & Rhodes, 1992), on academic performance (Schommer, 1993), on conceptual change learning (Qian & Alvermann, 1995), and on cognitive processes (Kardash & Howell, 2000). Therefore, one of the goals of education should be to help students develop more sophisticated beliefs.

Only a few studies exist on the effects of epistemological beliefs during learning with new technologies. Concerning learning with hypertext, Jacobson and Spiro (1995), as well as Jacobson, Maouri, Mishra, and Kolar (1996), found that learners with more sophisticated epistemological beliefs were better able to learn and apply their knowledge after using a complex hypertext system than students with simpler epistemological beliefs. Jacobson et al. (1996) asked 69 students (17 to 19 years) to read a hypertext about effects of technology on society. They were asked to complete short answer tests on factual information contained in the hypertexts and had to write problem-solving essays. Epistemological beliefs were measured with the EBP (epistemological beliefs and preferences instrument; Jacobson & Jehng, 1999). Learners with more sophisticated epistemological beliefs showed better results in knowledge transfer, measured with the problem essays. Macneal (2001) reported a relationship between learning activities in a complex hypertext system and epistemological beliefs. Concerning learning with other new media, Windschitl and Andre (1998) found interesting effects of epistemological beliefs on learning with computer simulations of the human cardiovascular system, in an experiment involving 250 university students. Learning outcomes were measured with a pretest-posttest design using multiple-choice tests focusing on common misconceptions concerning the topic. Students with more sophisticated beliefs learned more with constructivist simulations that allowed them to create and test hypotheses on their own, while students with less sophisticated epistemological beliefs learned more with confirmative simulations that guided them through the information. There is also evidence that epistemological beliefs influence how students access information on the Internet and how they evaluate what they find (Hofer, 2001; Wallace et al., 2000).

Empirical evidence exists of mutual influences between epistemological beliefs and learning processes in traditional as well as technology-based learning environments. Epistemological beliefs might influence the standards and goals that determine students' learning strategies (Schommer et al., 1992) and their engagement in learning (Hofer & Pintrich, 1997).

The relation between help seeking and epistemological beliefs appears not to have been examined in prior research. But it is likely that epistemological beliefs influence help-seeking activities as a part of learning strategies. For example, students with simpler beliefs might overestimate their understanding of information (see Schommer, 1990; Schommer et al., 1992). Thus, their epistemological beliefs might influence students' awareness of whether they need help, their engagement

in help-seeking activities, and their interpretation of the value of the help offered. Epistemological beliefs may influence the *type* of help that students seek when working with an ILE. For example, students' preoccupation with the bottom-out hints in the Geometry Cognitive Tutor, discussed above, might at least in part be a result of students having an impoverished epistemological view of mathematical inquiry—they may think that mathematics is about getting answers, not about proof or logical deduction.

When designing an ILE, it might be useful to think about the epistemology inherent in the subject matter content of the system. At least early on in the learning process, this epistemology needs to be aligned with the epistemological beliefs of the learners. Further, it may be useful if the system is designed to help students develop more sophisticated domain-specific epistemological beliefs. Exactly how that can be achieved is unclear at this point. At minimum, it seems, the system should make explicit the domain-specific epistemological beliefs of experts. Students' improved epistemological beliefs might help them use the help functions of an ILE in a more appropriate way. Depending on the epistemological beliefs of individual learners, different features of help may be appropriate. In short, the influence on help seeking of students' epistemological beliefs promises to be an interesting and important area of research.

Conclusions and Future Research

We have argued that help seeking in ILEs is an interesting field of research with important educational implications. Our review of the literature indicates that a number of interesting results have been found. As can be expected in a young research field, there are also many open questions. In this section, we present six conclusions based on our review of the existing literature and discuss the most promising trajectories for future research.

1. *Different instructional goals result in different types of ILEs whose help systems provide different types of information.* Researchers who have looked at the role of on-demand help in ILEs from different theoretical perspectives provide a number of reasons why such systems should give help primarily at the student's request. The system may not know enough about the nature of the student's difficulties to volunteer appropriate help (Anderson, 1993), in part because it does not have access to visual or verbal cues that experienced human tutors take advantage of (Wood & Wood, 1999). Further, when students control the timing of help provided by the system, there is a greater likelihood that the help messages are received at the right time to be maximally useful for knowledge construction (Renkl, 2002). Both Anderson and Wood and Wood have stressed that providing help on demand may well be an imperfect solution, due in part to limitations of the technology but due mainly to the fact that it is not possible (fortunately!) for humans or machines to know everything about a student's cognitive state at any point in time.

Different types of ILEs are rooted in different theoretical perspectives on learning and/or instruction and hence aim at fostering different teaching and learning processes. Consequently, the help systems in these different ILEs may have different tasks assigned to them. As an illustration, consider two groups of instructional approaches dominating theory-based design in recent times, the cognitive approach and the situated learning approach (Wilson & Myers, 2000).

These approaches determine to a large degree the role of the learner as well as the role of technology and, therefore, the role of an additional help system (Bransford, Brown, & Cocking, 2000). They imply fundamentally different roles of the help system. Approaches based on cognitive models of learning, such as the Cognitive Tutor technology described in earlier sections (e.g., Anderson et al., 1995), are aimed at giving the learner information and feedback at just the right point in time during the learning process (usually, learning by doing). ILEs built according to this approach use a cognitive model of the learner to assess the learner's knowledge or skill level and to select individualized instructional trajectories to help the learner acquire new skills and knowledge. From this perspective, suboptimal help may be due to an incorrect diagnosis of the learner's knowledge state or to inadequate selection of the trajectory of follow-up instruction. Providing help may mean (a) accurately defining the knowledge base to be acquired by the learner, for example in terms of production rules; (b) defining possible or frequently occurring incorrect models or misconceptions of the content to be learned; (c) finding appropriate ways to diagnose these misconceptions in the learning process; and (d) identifying specific instructional interventions that guide the learner from the misconception to the scientifically correct model.

On the other hand, instructional approaches based on situated learning and constructivist ideas emphasize the learners' engagement in open-ended activities with authentic learning material (e.g., Cognition and Technology Group at Vanderbilt, 1997) and therefore imply other kinds of help systems. Here the role of the ILE is not to diagnose cognitive states and provide specific tasks together with feedback, as in the cognitive approaches described above. Rather, the main role of the ILE is to provide authentic contexts that the learner can explore, for example, presentations and simulations of real or near-to-real cases or phenomena of the domain under consideration. To do so, learners are supposed to use different tools that reflect important domain strategies and concepts. An additional help system might have the function of linking and referring to background knowledge required to deal with the case or exploring the phenomenon (e.g., in textbooks, in lecture manuscripts, or on Web sites outside of the ILE per se). From this perspective, providing information and strategies that support learners engaged in an authentic task might be regarded as adequate help. There is some research on how to provide additional information and strategies in problem-oriented learning environments, suggesting for example that presenting an audiotaped or graphically represented teaching expert solution may improve help-seeking strategies (e.g., Mandl et al., 2000).

2. *Learners often use help systems ineffectively or ignore them altogether. However, when they do use help, learning processes and outcomes may be substantially improved.* The main empirical findings on help seeking presented in the literature show that help facilities of ILEs often are ignored or used in ways that are not conducive to learning. Ineffective help use seems to occur independent of the instructional goal pursued with the help system. In other words, cognitive approaches as well as more situated approaches are struggling with this phenomenon. Moreover, the problem is not restricted to ILEs. Inadequate help-seeking behavior seems quite widespread in all kinds of learning environments, including, for example, classrooms.

There is also evidence, however, that help systems and help seeking can be effective and can have a positive influence on learning with an ILE. First, a few

studies have demonstrated a *causal* connection between providing on-demand help and better learning outcomes. For example, Renkl (2002) showed that adding on-demand help to an ILE leads to better transfer performance. Second, a number of studies have shown a positive correlation between help seeking and learning in ILEs, often for learners with lower prior knowledge (Renkl, 2002; Shute & Gluck, 1996; Wood, 2001; Wood & Wood, 1999). These positive correlations suggest that providing on-demand help in an ILE leads to better learning, even if they do not definitively establish a causal relation. Third, studies that show that varying the type of on-demand help leads to different learning outcomes (e.g., Dutke & Reimer, 2000) also indicate that on-demand help influences learning, although they do not show that it causes *improved* learning. All in all, these studies strongly suggest that on-demand help can be a positive influence on learning. However, much is still to be learned about when and under what circumstances on-demand help is most likely to be useful.

In particular, the correlation between help-seeking behavior and learning outcomes is complicated. A positive correlation would be expected when students are more likely to underuse help than to overuse it, which seems to happen frequently (see, e.g., Aleven & Koedinger, 2000; Wood, 2001). A negative correlation does not necessarily imply that the system-provided help is dysfunctional (e.g., distracts learners, requires too much time to process by the learner, or tramples learning opportunities by readily providing answers). It may mean instead that the less able learners are using the help functions most frequently (although the opposite phenomenon was reported by Wood & Wood, 1999). Similarly, a low correlation does not necessarily indicate that there is no relationship at all, just that the relation is not linear. For example, if some learners are overusing help (i.e., relying on help even when a problem or step is within their independent capability), the result might be the absence of a correlation. Further, the heuristic that learners with low cognitive learning prerequisites will benefit more from help than high prerequisite learners also seems to be too simple to explain the relationship. Recent studies (e.g., Renkl, 2002) indicate that there are different types of learners with different profiles of help-seeking activities. These types may be described best using more than one dimension of learner characteristics.

In terms of future research, more studies are needed to establish under what circumstances a causal connection exists between the provision of on-demand help and better learning outcomes. Further, more research is needed to establish when one might expect to see a positive correlation between help seeking and learning.

One way to address the problem of inadequate help use is to design systems so that they are able to detect obvious instances of help underuse or overuse and volunteer or withhold help accordingly. Although the various proponents of theoretical frameworks for help use have stressed that it is difficult for the system to know enough about the nature of the learner's difficulties, more can be done. For example, certain strong patterns of ineffective help use are relatively easy to detect, such as students' frequent use of bottom-out hints in the Geometry Cognitive Tutor (Aleven & Koedinger, 2000). In such instances, the ILE could withhold the bottom-out hint, at least when the system is used in a classroom and a teacher is present to help students who get stuck. Also, it seems straightforward to detect certain instances of help underuse that are likely to be detrimental to learning (see also Wood, 2001), for example, when students make multiple errors on a step. In such

instances, the ILE could volunteer help. More generally, it is a good idea to try to find a better balance between system-initiated help and feedback and student-initiated help. The study by Luckin and du Boulay (1999) was in part an attempt at figuring out where this balance should reside. As this study made clear, the balance may well be different for different kinds of students.

However, in general it may be difficult to say exactly when unusually frequent help use indicates that the student may not be learning. Wood and Wood (1999) describe an example of a student who used help much more than seemed appropriate yet ended up with large learning gains. Thus, in general, it may be very difficult to come up with good criteria for when an ILE should withhold help. Also, withholding help may be unacceptable to learners or at least frustrating, as reported by du Boulay, Luckin, and del Soldato (1999).

The use of new technologies such as eye tracking and natural language processing may eventually enable systems to strike a better balance between student-controlled and system-controlled help. These technologies may provide more information from which the system can infer what the student's difficulties are. For example, the use of eye tracking in a Cognitive Tutor can help in disambiguating student strategies and even predict errors before students make them (Gluck, Anderson, & Douglas, 2000). Also, many researchers are involved in developing tutorial dialogue systems (Aleven, Popescu, & Koedinger, 2002; Evens et al., 2001; Graesser, VanLehn, Rose, Jordan, & Harter, 2001), capitalizing on the advancement of natural language and dialogue management technologies. In many domains, it is useful to study the pedagogical content knowledge (Shulman, 1986b) of experienced human tutors, who often have good strategies to communicate difficult concepts to students. Tutorial dialogue systems are an attempt to implement some of these strategies (Heffernan & Koedinger, 2002), and they will possibly be better able than current ILEs to adapt to students' prior knowledge and to volunteer help at appropriate times. How well they can be made to work, however, and whether they work best for all students are still largely open questions.

3. *A variety of learner characteristics influence help seeking, individually or in combination.* A number of studies of help seeking both with ILEs and in other contexts show that prior knowledge is an important factor influencing students' help-seeking behavior. Generally, students with lower prior knowledge seek help less effectively (Puustinen 1998; Renkl, 2002; Wood & Wood, 1999). An unfortunate consequence of this finding is that if ILEs provide help only at the student's request, those students who need help the most are the least likely to receive it in time.

There also seems to be a relation between help seeking and self-regulatory skills such as self-assessment. The theoretical argument in support of this relation is quite strong. There is empirical evidence as well (Nelson-Le Gall et al., 1990). On the other hand, Wood (2001) found that when the difficulty of problems is adjusted to the students' prior knowledge, students with lower prior knowledge do not exhibit less appropriate help-seeking behavior than students with higher prior knowledge. Therefore, he concluded, differences in metacognition are not likely to account for other studies' finding of a lower tendency to seek help among students with lower attainment.

Moreover, poor help seeking has much to do with motivational factors: Students often are oriented toward performance rather than toward learning. That is, they may be inclined to focus on finishing problems quickly and not be concerned with

gaining an understanding of the task domain. This performance orientation leads to an overuse of executive help (i.e., help focused on getting the right solution quickly). In classroom situations, a performance orientation also seems to lead to an avoidance of help seeking (so as to avoid the embarrassment of having to ask for help); in ILEs, however, one would expect that this danger is less acute, since help is more anonymous.

We have argued that learners' epistemological beliefs are likely to be an important influence on their help-seeking behavior. Evaluating the impact of this factor appears to be a promising area for future research. Further, the impact of students' achievement orientation on help seeking with ILEs has not been studied as of yet.

It is an interesting open question to what extent it will be possible to improve students' help-seeking skills by means of dedicated instruction. One might provide initial instruction prior to the use of an ILE or even between sessions with the ILE, for example, by discussing (videotaped) examples of good and bad help-seeking behavior with the ILE. A more effective approach may be to develop an ILE that helps students to become better help seekers. Aleven and Koedinger (2000, 2001) propose equipping a Cognitive Tutor with a model (implemented as production rules) of desired help-seeking behavior, to enable the system to follow students' help-seeking behavior and provide guidance on help seeking. This approach goes beyond the approach described above, in which the system volunteers or withholds help at appropriate times, in that the system now is capable of demonstrating appropriate help-seeking behavior. Luckin and Hammerton (2002) are pursuing similar ideas in developing an ILE capable of "metacognitive scaffolding." This line of research may also cast some light on the question of to what extent help-seeking behavior is a function of self-regulatory skills and to what extent it is determined by prior knowledge.

4. *Different types of help may cause different types of help-seeking activities and result in different learning outcomes.* The literature discussed in this article identifies many system-related factors that may influence the effectiveness of learners' help-seeking behavior. Some of these factors have been shown to influence the learning outcomes of ILE users, such as whether help is function oriented or operative (Dutke & Reimer, 2000), whether it is principle oriented (Renkl, 2002), or whether system feedback includes information about problem-solving goals (McKendree, 1990). Other system-related factors, such as the level of abstractness and the degree of interactivity of system feedback, interact with characteristics of the learner in their influence on learning results (Arroyo et al., 2000, 2001). Still other factors, such as whether the help is context sensitive, whether it might impose too much cognitive load, the length of the help sequences and of the help messages, the use of different types of representations (e.g., verbal/graphical), and whether the system or student controls the level of help, have not yet been investigated systematically.

It appears, however, that many help systems are still being designed without much guidance from this empirical work or from psychological theory. What is needed is a broader base of empirical results that will guide the construction of adequate theories that address the observed aptitude-treatment interactions and will help in formulating design principles upon which the developers of help systems can draw.

Future research concerning system characteristics and help design should focus on investigating what features of help lead to better help use, with what kinds of learners and for what kind of subject matter, to determine to what extent the results reported in the literature generalize. Many if not all of the factors related to help systems listed above are interesting candidates for further investigation. The following factors are of particular interest:

Context sensitivity—this factor is interesting especially since it relates to crucial differences between two technologies for developing ILEs, namely CAI and ITSs. For example, to what extent is the context-sensitive help offered by ITSs worth the extra development costs of these systems, as compared to CAI systems?

Cognitive load—in particular, to investigate the effectiveness of help systems that minimize cognitive load, possibly at the expense of other seemingly desirable characteristics of good help.

Whether the learner controls the level of help—this factor is interesting since the different theoretical frameworks take different points of view on this issue.

Whether the learner should be able to freely access help or whether there should be some kind of cost associated with help.

The value of specialized domain-specific representations. The study of Gräsel et al. (2001) can be regarded as a pilot study in this context.

The psychological quality of text and multimedia information in help systems. Good starting points may be the theoretical concepts provided by Kintsch (1998) on discourse comprehension and Mayer (2000) on the processing of multimedia information.

As Arroyo et al. (2001) point out, the space of possible experiments studying the effects of different help characteristics on different categories of learners is vast. One approach to alleviate this problem may be to instrument ILEs to do within-subjects experiments, where the type of help is varied across students and skills (but kept constant for any particular pairing of student and skill). This type of experiment fits well within the architecture of ILEs that have an explicit representation of the skills targeted in the instruction.

5. *Design- and learner-related factors interact in their effect on help seeking and learning.* A number of studies provide evidence that, as far as the design of help systems is concerned, "one size fits all" is not likely to be a good strategy. Different types of learners seem to need different types of help. For example, abstractness of help has been shown to interact with cognitive development: Learners with higher cognitive development learn better when receiving abstract hints, and learners with low cognitive development benefit most from concrete hints (Arroyo et al., 2000). Moreover, high ability learners have been shown to learn better with help systems providing low guidance, whereas help systems with higher guidance seem to be useful for most other learners (Luckin & du Boulay, 1999). However, as we are still far away from a systematic approach to either design characteristics or learner characteristics, we are even further away from a systematic approach to analyzing the interactions between them.

6. *Depending on the learning context, the same type of help may trigger different help-seeking behavior, which in turn is related to different effects on learning outcomes.* The literature suggests that classroom goals, as important parts of the culture of learning, exert considerable influence on students' help-seeking

activities. This factor thus adds an additional layer of complexity to the (already complex) set of relationships among learner-related factors, system-related factors, instructional approach, and help-seeking activities. We are led to shift emphasis from the question of what kind of help is effective for learning to the question of which type of help is helpful in which context and for whom. This question clearly calls for higher complexity in theory building as well as in empirical research paradigms (Fischer, Bouillion, Mandl, & Gomez, in press). Most of the approaches to help design and help seeking reviewed in this article have not explicitly described the process of contextual implementation of the ILE. A specific help system may be described as helpful or unhelpful without paying attention to the specific physical, social, and institutional context in which it is placed. It could make a difference, for example, whether each learner has individual access to the help system or computers are shared among a group of students. Similarly, one can expect to see differences in help system use depending on the "institutional vision" of technology's role in instruction (Gräsel & Fischer, 2000) within a given school or university.

In terms of future research, the main questions concerning help design are as follows: How is a given help system used in different contexts (laboratory, classroom, at home, etc.)? To what extent do specific help-seeking activities in ILEs generalize across increasingly inclusive contexts (classroom, school, school district, etc.)? And, maybe most important, if there is no generalization across different contexts, what are the reasons for that? Answers to these questions can make a major contribution to the understanding of help-seeking activities.

There are several ways in which these questions could be addressed. For example, test bed design (Gomez, Fishman, & Pea, 1998) is a methodology intended to compare effects of ILEs at different levels of the context. The basic idea is to implement the system in test beds of different sizes (classroom, multiple classrooms in one school, many schools of the same district, schools of different districts, etc.) and to analyze any differences in effects. Further, an approach focusing on theory-guided experimental laboratory research and its interplay with practice is the *integrative research paradigm* described by Stark and Mandl (2001). This approach prescribes a systematic "bouncing strategy" between field studies (carried out, for example, in actual classrooms) and laboratory research with the goal of improving both theory and practice. This kind of combined research strategy may improve our knowledge about help seeking and at the same time improve the practice of help design and use.

To conclude, even though the literature on help seeking in ILEs is still quite small, it provides important insights into the effects of various system characteristics, student behaviors, student characteristics, and the interactions among these factors. In addition, there are important links to the literature on help seeking in other arenas as well as to psychological research on cognition, motivation, and instruction. Bringing all of these factors together in a comprehensive program of theory building and empirical research is a challenging task, but one that is filled with possibilities for important research. Not only will this research lead to a deeper understanding of help design and help seeking in ILEs, it will likely spur improvements in educational practice. It will help to make ILEs more effective, not just in fostering domain-specific skills and knowledge but quite possibly also in helping students become more skilled at seeking help judiciously. Help-seeking

skills are likely to be instrumental when learners face new learning goals, as many people do continuously in today's society.

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References

Aleven, V. (2001, October). *Helping students to become better help seekers: Towards supporting metacognition in a Cognitive Tutor.* Paper presented at the 1st NSF-DFG Workshop on Learning Technologies, Tübingen, Germany.

Aleven, V., & Koedinger, K. R. (2000). Limitations of student control: Do students know when they need help? In C. F. G. Gauthier & K. VanLehn (Eds.), *Proceedings of the 5th International Conference on Intelligent Tutoring Systems, ITS 2000* (pp. 292–303). Berlin: Springer-Verlag.

Aleven, V., & Koedinger, K. R. (2001). Investigations into help seeking and learning with a Cognitive Tutor. In R. Luckin (Ed.), *Papers of the AIED-2001 Workshop on Help Provision and Help Seeking in Interactive Learning Environments.* Available: http://www.hcrc.ed.ac.uk/aied2001/workshops.html

Aleven, V., & Koedinger, K. R. (2002). An effective meta-cognitive strategy: Learning by doing and explaining with a computer-based Cognitive Tutor. *Cognitive Science, 26,* 147–179.

Aleven, V., Popescu, O., & Koedinger, K. R. (2002). Pilot-testing a tutorial dialogue system that supports self-explanation. In S. A. Cerri, G. Gouardères, & F. Paraguaçu (Eds.), *Proceedings of the Sixth International Conference on Intelligent Tutoring Systems, ITS 2002* (pp. 344–354). Berlin: Springer-Verlag.

Alexander, P. A., & Dochy, F. J. R. C. (1995). Conceptions of knowledge and beliefs: A comparison across varying cultural and educational communities. *American Educational Research Journal, 32,* 413–442.

Ames, R. (1983). Help-seeking and achievement orientation: Perspectives from attribution theory. In B. DePaulo, A. Nadler, & J. D. Fisher (Eds.), *New directions in helping* (Vol. 2, pp. 165–186). New York: Academic Press.

Anderson, J. R. (1993). *Rules of the mind.* Hillsdale, NJ: Erlbaum.

Anderson, J. R. (1999). *Cognitive psychology and its implications* (5th ed.). New York: Worth.

Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive Tutors: Lessons learned. *Journal of the Learning Sciences, 4,* 167–207.

Arbreton, A. (1998). Student goal orientation and help-seeking strategy use. In S. A. Karabenick (Ed.), *Strategic help seeking: Implications for learning and teaching* (pp. 95–116). Mahwah, NJ: Erlbaum.

Arroyo, I., Beck, J. E., Beal, C. R., Wing, R., & Woolf, B. P. (2001). Analyzing students' response to help provision in an elementary mathematics intelligent tutoring system. In R. Luckin (Ed.), *Papers of the AIED-2001 Workshop on Help Provision and Help Seeking in Interactive Learning Environments.* Available: http://www.hcrc.ed.ac.uk/aied2001/workshops.html

Arroyo, I., Beck, J. E., Woolf, B. P., Beal, C. R., & Schultz, K. (2000). Macro-adapting Animalwatch to gender and cognitive differences with respect to hint interactivity and symbolism. In G. Gauthier, C. Frasson, & K. VanLehn (Eds.), *Proceedings of the*

5th International Conference on Intelligent Tutoring Systems, ITS 2000 (pp. 574–583). Berlin: Springer-Verlag.

Bielaczyc, K., Pirolli, P. L., & Brown, A. L. (1995). Training in self-explanation and self-regulation strategies: Investigating the effects of knowledge acquisition activities on problem solving. *Cognition and Instruction, 13,* 221–252.

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

Bromme, R., & Stahl, E. (1999). Spatial metaphors and writing hypertexts: Study within schools. *European Journal of Psychology of Education, 14,* 267–281.

Bromme, R., & Stahl, E. (Eds.). (2002). *Writing hypertext and learning: Conceptual and empirical approaches.* London: Elsevier.

Brophy, J., & Good, T. (1986). Teacher behavior and student achievement. In M. Wittrock (Ed.), *Handbook of research on teaching.* New York: Macmillan.

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology, 20,* 493–523.

Brusilovsky, P. (2001). Adaptive hypermedia. *User Modeling & User-Adapted Interaction, 11,* 87–110.

Buell, M. M., & Alexander, P. A. (2001). Beliefs about academic knowledge. *Educational Psychology Review, 13,* 385–418.

Butler, R. (1998). Determinants of help seeking: Relations between perceived reasons for classroom help-avoidance and help-seeking behaviors in an experimental context. *Journal of Educational Psychology, 90,* 630–643.

Chi, M. (1996). Constructing self-explanations and scaffolded explanations in tutoring. *Applied Cognitive Psychology, 10,* 33–49.

Cognition and Technology Group at Vanderbilt. (1997). *The Jasper Project: Lessons in curriculum, instruction, assessment, and professional development.* Mahwah, NJ: Erlbaum.

Corbett, A. T., Koedinger, K. R., & Anderson, J. R. (1997). Intelligent tutoring systems. In M. Helander, T. K. Landauer, & P. Prabhu (Eds.), *Handbook of human-computer interaction* (2nd ed., pp. 849–874). New York: Elsevier.

De Bra, P., Brusilovsky, P., & Houben, G. J. (1999). Adaptive hypermedia: From systems to framework. *ACM Computing Surveys, 31*(4), 1–6.

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,* 322–349.

Dochy, F. J. R. C., & Alexander, P. A. (1995). Mapping prior knowledge: A framework for discussion among researchers. *European Journal of Psychology of Education, 10,* 225–242.

Dochy, F. J. R. C., & Segers, M. S. R. (1997). *The effect of prior knowledge and its assessment on learning in classroom practice.* Keynote address presented at the Deutsche Gesellschaft für Psychologie Conference on the Role of Prior Knowledge in Learning, Frankfurt.

du Boulay, B., Luckin, R., & del Soldato, T. (1999). The plausibility problem: Human teaching tactics in the 'hands' of a machine. In S. P. Lajoie & M. Vivet (Eds.), *Artificial intelligence in education, open learning environments: New computational technologies to support learning, exploration, and collaboration, proceedings of AIED-99* (pp. 225–232). Amsterdam: IOS Press.

Duell, O. K., & Schommer-Aikins, M. (2001). Measures of people's beliefs about knowledge and learning. *Educational Psychology Review, 13,* 419–449.

Dutke, S., & Reimer, T. (2000). Evaluation of two types of online help information for application software: Operative and function-oriented help. *Journal of Computer-Assisted Learning, 16,* 307–315.

Eberts, R. E. (1997). Computer-based instruction. In M. Helander, T. K. Landauer, & P. Prabhu (Eds.), *Handbook of human-computer interaction* (2nd ed., pp. 825–847). New York: Elsevier.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. *Science Education, 85,* 554–567.

Evens, M. W., Brandle, S., Chang, R. C., Freedman, R., Glass, M., Lee, Y. H., et al. (2001). CIRCSIM-Tutor: An intelligent tutoring system using natural language dialogue. In *Twelfth Midwest AI and Cognitive Science Conference, MAICS 2001* (pp. 16–23). Oxford, OH: Miami University.

Fischer, F., Bouillion, L., Mandl, H., & Gomez, L. (in press). Bridging theory and practice in learning environment research—Scientific principles in Pasteur's Quadrant. *International Journal of Educational Policy, Research, and Practice.*

Floden, R. E. (2001). Research on effects of teaching: A continuing model for research on teaching. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed.). Washington, DC: American Educational Research Association.

Gibbons, A. S., & Fairweather, P. G. (1998). *Computer-based instruction: Design and development.* Englewood Cliffs, NJ: Educational Technology.

Glaser, R., & De Corte, E. (1992). Preface of the assessment of prior knowledge as a determinant for future learning. In F. J. R. C. Dochy (Ed.), *Assessment of prior knowledge as a determinant for future learning.* London: Jessica Kingsley.

Glenberg, A. M., & Epstein, W. (1987). Inexpert calibration of comprehension. *Memory & Cognition, 15,* 84–93.

Gluck, K. A., Anderson, J. R., & Douglas, S. A. (2000). Broader bandwidth in student modeling: What if ITS were "eye" TS? In G. Gauthier, C. Frasson, & K. VanLehn (Eds.), *Proceedings of the 5th International Conference on Intelligent Tutoring Systems, ITS 2000* (pp. 504–513). Berlin: Springer-Verlag.

Gomez, L. M., Fishman, B. J., & Pea, R. D. (1998). The CoVis project: Building a large-scale science education testbed. *Interactive Learning Environments, 6,* 59–92.

Graesser, A. C., VanLehn, K., Rosé, C. P., Jordan, P. W., & Harter, D. (2001). Intelligent tutoring systems with conversational dialogue. *AI Magazine, 22*(4), 39–51.

Gräsel, C., & Fischer, F. (2000). Information and communication technologies at schools: A trigger for better teaching and learning? *International Journal of Educational Policy, Research, and Practice, 1,* 327–336.

Gräsel, C., Fischer, F., & Mandl, H. (2001). The use of additional information in problem-oriented learning environments. *Learning Environments Research, 3,* 287–305.

Gray, S. H. (1990). Using protocol analyses and drawings to study mental model construction. *International Journal of Human Computer Interaction, 2,* 359–378.

Gray, S. H. (1995). Linear coherence and relevance: Logic in computer-human 'conversations.' *Journal of Pragmatics, 23,* 627–647.

Hannover, B., & Bettge, S. (1993). *Mädchen und Technik* [Girls and technology]. Göttingen, Germany: Hogrefe.

Hasebrook, J. (1995). *Multimedia-Psychologie: Eine neue Perspektive menschlicher Kommunikation* [Multimedia psychology: A new perspective of human communication]. Heidelberg: Spektrum.

Heffernan, N. T., & Koedinger, K. R. (2002). An intelligent tutoring system incorporating a model of an experienced human tutor. In S. A. Cerri, G. Gouardères, & F. Paraguaçu (Eds.), *Proceedings of the Sixth International Conference on Intelligent Tutoring Systems, ITS 2002.* Berlin: Springer-Verlag.

Helmke, A., & Weinert, F. E. (1997). Bedingungsfaktoren schulischer Leistungen [Requirements of school achievements]. In F. E. Weinert (Ed.), *Psychologie des Unterrichts und der Schule: Enzyklopädie der Pädagogischen Psychologie* (pp. 71–153). Göttingen, Germany: Hogrefe.

Hofer, B. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review, 13,* 353–383.

Hofer, B., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67,* 88–140.

Hofer, M., Niegemann, H. M., Eckert, A., & Rinn, U. (1996). Pädagogische Hilfen für interaktive selbstgesteuerte Lernprozesse und Konstruktion eines neuen Verfahrens zur Wissensdiagnose [Instructional help for interactive self-directed learning processes and construction of a new procedure for knowledge diagnosis]. *Zeitschrift für Berufs- und Wirtschaftspädagogik Beiheft, 13,* 53–67.

Jacobson, M. J., & Archodidou, A. (2000). The design of hypermedia tools for learning: Fostering conceptual change and transfer of complex scientific knowledge. *Journal of the Learning Sciences, 9,* 145–199.

Jacobson, M. J., & Jehng, J.-C. (1999). Epistemological beliefs instrument: Scales and items. Available: http://emergentdesigns.com/mjjacobson/publications/Epist_Beliefs_Instrument98.pdf

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

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

Kardash, C. M., & Howell, K. L. (2000). Effects of epistemological beliefs and topic-specific beliefs on undergraduates' cognitive and strategic processing of dual-positional text. *Journal of Educational Psychology, 92,* 524–535.

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

Kintsch, W. (1998). *Comprehension: A paradigm for cognition.* New York: Cambridge University Press.

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

Larkin, J. H., & Chabay, R. W. (Eds.). (1992). *Computer-assisted instruction and intelligent tutoring systems: Shared goals and complementary approaches.* Hillsdale, NJ: Erlbaum.

Leventhal, L. M., Teasley, B. M., Instone, K., Rohlman, D. S., & Farhat, J. (1993). Sleuthing in HyperHolmes: An evaluation of using hypertext vs. a book to answer questions. *Behaviour & Information Technology, 12,* 149–164.

Luckin, R., & du Boulay, B. (1999). Ecolab: The development and evaluation of a Vygotskian design framework. *International Journal of Artificial Intelligence in Education, 10,* 198–220.

Luckin, R., & Hammerton, L. (2002). Getting to know me: Helping learners understand their own learning needs through metacognitive scaffolding. In S. A. Cerri, G. Gouardères, & F. Paraguaçu (Eds.), *Proceedings of the Sixth International Conference on Intelligent Tutoring Systems, ITS 2002* (pp. 759–771). Berlin: Springer-Verlag.

Macneal, L. G. (2001). Epistemic beliefs and comprehension in a hypertext system. *Dissertation Abstracts International, 61,* 12A.

Mandl, H., Gräsel, C., & Fischer, F. (2000). Problem-oriented learning: Facilitating the use of domain-specific and control strategies through modeling by an expert. In W. J. Perrig & A. Grob (Eds.), *Control of human behavior, mental processes and consciousness* (pp. 165–182). Mahwah, NJ: Erlbaum.

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

McKendree, J. (1990). Effective feedback content for tutoring complex skills. *Human Computer Interaction, 5,* 381–413.

Middleton, M., & Midgley, C. (1997). Avoiding the demonstration of the lack of ability: An underexplored aspect of goal theory. *Journal of Educational Psychology, 89,* 710–718.

Miyake, N., & Norman, D. A. (1979). To ask a question, one must know enough to know what is not known. *Journal of Verbal Learning and Verbal Behavior, 18,* 357–364.

Nelson-Le Gall, S. (1981). Help-seeking: An understudied problem-solving skill in children. *Developmental Review, 1,* 224–246.

Nelson-Le Gall, S. (1987). Necessary and unnecessary help-seeking in children. *Journal of Genetic Psychology, 148,* 53–62.

Nelson-Le Gall, S., Kratzer, L., Jones, E., & DeCooke, P. (1990). Children's self-assessment of performance and task-related help seeking. *Journal of Experimental Child Psychology, 49,* 245–263.

Newman, R. S. (1994). Adaptive help seeking: A strategy of self-regulated learning. In D. H. Schunk & B. J. Zimmerman (Eds.), *Self-regulation of learning and performance: Issues and educational applications* (pp. 283–301). Hillsdale, NJ: Erlbaum.

Newman, R. S. (1998a). Adaptive help seeking: A role of social interaction in self-regulated learning. In S. A. Karabenick (Ed.), *Strategic help seeking: Implications for learning and teaching* (pp. 13–37). Mahwah, NJ: Erlbaum.

Newman, R. S. (1998b). Students' help seeking during problem solving: Influences of personal and contextual achievement goals. *Journal of Educational Psychology, 90,* 644–658.

Newman, R. S., & Goldin, L. (1990). Children's reluctance to seek help with schoolwork. *Journal of Educational Psychology, 82,* 92–100.

Newman, R. S., & Schwager, M. T. (1995). Students' help seeking during problem solving: Effects of grade, goal, and prior achievement. *American Educational Research Journal, 32,* 352–376.

Puustinen, M. (1998). Help-seeking behavior in a problem-solving situation: Development of self-regulation. *European Journal of Psychology of Education, 13,* 271–282.

Qian, G., & Alvermann, D. (1995). Role of epistemological beliefs and learned helplessness in secondary school students' learning science concepts from text. *Journal of Educational Psychology, 87,* 282–292.

Quentin-Baxter, M. (1999). Quantitative evidence for differences between learners making use of passive hypermedia learning environments. *ACM Computing Surveys, 31*(4).

Renkl, A. (2002). Learning from worked-out examples: Instructional explanations supplement self-explanations. *Learning & Instruction, 12,* 529–556.

Ryan, A. M., Gheen, M. H., & Midgley, C. (1998). Why do some students avoid asking for help? An examination of the interplay among students' academic efficacy, teachers' social-emotional role, and the classroom goal structure. *Journal of Educational Psychology, 90,* 528–535.

Ryan, A. M., & Pintrich, P. R. (1997). "Should I ask for help?" The role of motivation and attitudes in adolescents' help seeking in math class. *Journal of Educational Psychology, 89,* 329–341.

Ryan, A. M., & Pintrich, P. R. (1998). Achievement and social motivational influences on help seeking in the classroom. In S. A. Karabenick (Ed.), *Strategic help seeking: Implications for learning and teaching* (pp. 117–139). Mahwah, NJ: Erlbaum.

Ryan, A. M., Pintrich, P. R., & Midgley, C. (2001). Avoiding seeking help in the classroom: Who and why? *Educational Psychology Review, 13,* 93–114.
Ryan, M. P. (1984). Monitoring text comprehension: Individual differences in epistemological standards. *Journal of Educational Psychology, 76,* 248–258.
Scardamalia, M., & Bereiter, C. (1992). Text-based and knowledge-based questioning by children. *Cognition and Instruction, 9,* 177–199.
Schofield, J. W. (1995). *Computers and classroom culture.* Cambridge, England: Cambridge University Press.
Schofield, J. W., Eurich-Fulcer, R., & Britt, C. L. (1994). Teachers, computer tutors, and teaching: The artificially intelligent tutor as an agent for classroom change. *American Educational Research Journal, 31,* 69–97.
Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82,* 498–504.
Schommer, M. (1993). Epistemological development and academic performance among secondary students. *Journal of Educational Psychology, 85,* 406–411.
Schommer, M., Calvert, C., Gariglietti, G., & Bajaj, A. (1997). The development of epistemological beliefs among secondary students: A longitudinal study. *Journal of Educational Psychology, 89,* 37–40.
Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology, 84,* 435–443.
Schunk, D. H. (1989). Social cognitive theory and self-regulated learning. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theory, research, and practice.* New York: Springer.
Schworm, S., & Renkl, A. (2002a). Learning by solved example problems: Instructional explanations reduce self-explanation activity. In W. D. Gray & C. D. Schunn (Eds.), *Proceedings of the 24th Annual Conference of the Cognitive Science Society* (pp. 816–821). Mahwah, NJ: Erlbaum.
Schworm, S., & Renkl, A. (2002b). Lernen effektive Lösungsbeispiele zu erstellen: Ein Experiment zu einer computer-basierten Lernumgebung für Lehrende [Learning to design worked-out examples: Study about a computer-based learning environment for teachers]. *Unterrichtswissenschaft, 30,* 7–26.
Shulman, L. S. (1986a). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. Wittrock (Ed.), *Handbook of research on teaching* (pp. 3–36). New York: Macmillan.
Shulman, L. S. (1986b). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15,* 4–14.
Shute, V. J., & Gluck, K. A. (1996). Individual differences in patterns of spontaneous online tool use. *Journal of the Learning Sciences, 5,* 329–355.
Shute, V. J., & Psotka, J. (1996). Intelligent tutoring systems: Past, present, and future. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 570–600). New York: Macmillan.
Simons, P. R.-J. (1992). Lernen, selbständig zu lernen-ein Rahmenmodel. In H. Mandl & H. F. Friedrich (Eds.), *Lern- und Denkstrategien—Analysen und Interventionen* (pp. 251–264). Göttingen, Germany: Hogrefe.
Slotta, J. D., & Linn, M. C. (2000). The Knowledge Integration Environment: Helping students use the Internet effectively. In M. J. Jacobson & R. B. Kozma (Eds.), *Innovations in science and mathematics education: Advanced designs for technologies of learning* (pp. 193–226). Mahwah, NJ: Erlbaum.
Souterland, S. A., Sinatra, G. M., & Matthews, R. (2001). Belief, knowledge, and science education. *Educational Psychology Review, 13,* 325–351.

Stahl, E. (2001). *Hyper-Text Schreiben: Die Auswirkungen verschiedener Instruktionen auf Lernprozesse beim Schreiben von Hypertext* [Hypertext writing: Effects of different instructions on learning processes during the writing of hypertext]. Münster, Germany: Waxmann.

Stark, R. (in press). Experimetelle Untersuchungen zur Überwindung von Transferproblemen in der kaufmännischen Erstausbilding [Experimental studies on overcoming the transfer problem in primary vocational education]. *Zeitschrift für Pädagogik.*

Stark, R., & Mandl, H. (2001). *Die Kluft zwischen Wissenschaft und Praxis—ein unlösbares Problem für die pädagogisch-psychologische Forschung?* [The gap between theory and practice—An unresolvable problem for educational psychology?] (Research Report 118). München, Germany: Ludwig-Maximilians-Universität, Institut für Pädagogische Psychologie und Empirische Pädagogik.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12,* 257–285.

Sweller, J. (1999). *Instructional design in technical areas.* Camberwell, Victoria, Australia: Australian Council for Educational Research.

Thomas, J. W., & Rohwer, W. D. (1986). Academic studying: The role of learning strategies. *Educational Psychologist, 21,* 19–41.

van Merrienboer, J. J. G., De Crook, M. B. M., & Jelsma, O. (1997). The transfer paradox: Effects of contextual interference on retention and transfer performance of a complex cognitive skill. *Perceptual and Motor Skills, 87,* 784–786.

Vygotsky, L. S. (1986). *Thought and language.* Cambridge, MA: MIT Press.

Wallace, R. M., Kupperman, J., Krajcik, J., & Soloway, E. (2000). Science on the Web: Students on-line in a sixth grade classroom. *Journal of the Learning Sciences, 9,* 175–204.

Weinert, F. E. (1996). Lerntheorien und Instruktionsmodelle [Learning theories and models of instruction]. In F. E. Weinert (Ed.), *Psychologie des Lernens und der Instruktion: Enzyklopädie der Psychologie, Serie Pädagogische Psychologie* (pp. 1–48). Göttingen, Germany: Hogrefe.

Weinert, F. E., & Schrader, F. W. (1997). Lernen lernen als psychologisches Problem [Learning how to learn as a psychological problem]. In F. E. Weinert (Ed.), *Psychologie der Erwachsenenbildung: Enzyklopädie der Psychologie, Serie Pädagogische Psychologie* (pp. 295–335). Göttingen, Germany: Hogrefe.

Wenger, E. (1987). *Artificial intelligence and tutoring systems: Computational and cognitive approaches to the communication of knowledge.* Los Altos, CA: Morgan Kaufmann.

Wilson, B. G., & Myers, K. M. (2000). Situated cognition in theoretical and practical context. In D. Jonassen (Ed.), *Theoretical foundations of learning environments.* Mahwah, NJ: Erlbaum.

Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of Research in Science Teaching, 35,* 145–160.

Wood, D. (2001). Scaffolding, contingent tutoring, and computer-supported learning. *International Journal of Artificial Intelligence in Education, 12,* 280–292.

Wood, H., & Wood, D. (1999). Help seeking, learning and contingent tutoring. *Computers and Education, 33,* 153–169.

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology, 81,* 329–339.

Zimmerman, B. J., & Schunk, D. H. (Eds.). (1989). *Self-regulated learning and academic achievement: Theory, research, and practice.* New York: Springer.

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