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The Scaffolded Knowledge Integration Framework1 for the Design of Computer-Based Learning Environments in the Fields of Engineering and Computer Science

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ABSTRACT

It is an ongoing endeavor to develop curriculum that is both successful and incorporates technology tools for teaching complicated subjects. Synthesizing existing best practices is an essential step in promoting efficient design. Using examples from computer science and engineering, this article explains a paradigm termed scaffolded knowledge integration and shows how it influenced the development of two effective pedagogical tools. The LISP Knowledge Integration Environment is one improvement to the course that has led to better learning and more fair results for both sexes. The second addition, a spatial thinking environment, was made to help students with spatial reasoning in an introductory engineering course. This improvement made students' lack of previous spatial reasoning knowledge less of a hindrance by encouraging them to build a wider range of spatial reasoning skills. When considered as a whole, these studies of educational practice show how useful the scaffolded knowledge integration paradigm is and point the way for future reformers of educational programs.

KEYWORDS

Technologies for Education Curriculum Development for Spatial Reasoning in Computers a level of education above high school STEM Education Focused on Teaching Cognition

INTRODUCTION

This study details how scaffolded knowledge integration, an instructional design paradigm, was used to improve two courses at the university level. LISP Knowledge Integration Environment was developed as part of an introductory computer science course (LISP-KIE). The engineering discipline that first introduced students to graphical communication also established the spatial thinking environment. In both instances, the scaffolded knowledge integration architecture served as the basis for iterative cycles of trial and error culminating in a synthesis of the best available information. Informed by findings from studies of the Computer as Learning Partner curriculum, this framework served as the basis for the development of the two courses discussed in this study and shows potential as a guiding principle for the creation of similar courses in the future.

Many professionals in the field of education lament the fact that cognitive research, in particular, lacks the specificity needed to inform judgments on the design of complicated educational experiences. On the other hand, they gripe that many individual cases of successful teaching lack the generalizability needed for use as a basis for future research. While cognitive psychology tends to be more abstract, this study presents intermediate-level generalizations that are more relevant than discussions of individual design choices or creative courses. This research shows that it is possible to develop design guidelines and hypotheses via iterative trial and error, a process that has been proved to be useful in the creation of complicated pedagogical innovations.

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Norman (1988), Winograd and Flores (1987), and Hutchins (1989) have all pushed for a similar study paradigm to better understand how humans interact with complicated systems like flight control systems and nuclear reactors (in press). According to Hutchins, this is like studying intelligence "in the wild." Hutchins and Norman agree that the best way to discover patterns in human thought is to amass a database of natural history accounts, analyze those accounts using cognitive ideas, and then abstract patterns that extend beyond those examples. In this study, we use cognitive theory to the interpretation of a database of natural histories of pedagogical reforms. This investigation provides a structure for curriculum development.

Both of the novel courses presented in this study take their inspiration from the well-received Computer as Learning Partner (CLP) course (Lewis & Linn, 1994; Linn, 1992b; Linn & Songer, 1991). The CLP layout is the product of four stages of trial and error. We began by comparing and contrasting the viewpoints of subject matter experts and students in order to identify possible goals for the course and describe the range of participants' prior knowledge and interests. Second, we drafted a plan for the course that takes into account existing literature on the subject. This preliminary teaching was implemented and evaluated in a normal class. Third, the lesson was improved based on the findings of the pilot study. There were many rounds of testing and tweaking to ensure that the finalized curriculum satisfied all of the necessary standards. Four, the testing and refining procedure was synthesized and incorporated with relevant research. This fusion often prompted the development of updated CLP curriculum by suggesting new criteria (e.g., Linn et al., in press).

Taking elements from all four iterations of the Computer as Learning Partner (CLP) program, we were able to develop the scaffolded knowledge integration framework. The study was conducted at a middle school where the CLP curriculum is used in a semester-long thermodynamics subject (Linn, 1992b; Linn & Songer, 1991; Linn et al., 1993; Songer & Linn, 1991).

Experts in technology, education, and thought were all part of the study teams for both CLP and LISP-KIE, as well as spatial reasoning. Collaborative efforts between professionals from different fields are common in innovative ventures. The proliferation of such behavior on today's college and university campuses is often attributed to the accessibility of appropriate technical resources (Beshears, 1990; Kuo, 1988; Lan, 1989a; Lan, 1989b; Linn, 1989; McGrath, 1989a; McGrath, 1989b). The article then goes on to detail the scaffolded knowledge integration structure that resulted from the CLP encounter. Next, the iterative process of testing and improving both the LISP-KIE project and the spatial reasoning environment is outlined. In the last portion of the study, we analyze the consequences of this work and integrate these experiences into a revised version of the scaffolded knowledge integration paradigm.

SCAFFOLDED KNOWLEDGE INTEGRATION FRAMEWORK

In order to help students get an all-encompassing comprehension of a difficult topic, scaffolded knowledge integration is used. Students who are working toward an integrated knowledge do well to make connections between concepts. Students who have achieved integrated understanding may use their knowledge across disciplines to solve challenges having direct relevance to their lives. Students who have an integrated knowledge are not afraid to examine outliers and seek explanations for how they fit into their overall framework. However, there are situations when teachers actively discourage students from engaging in critical thinking and instead encourage them to just accept the instructor's viewpoints.

It is especially vital to build on students' ideas in the scientific fields, because students' instinctive notions are sometimes quite different from those of specialists (Carey, 1985; diSessa, 1988; Eylon & Linn, in press; McCloskey et al., 1980; West et al., 1984). Instead of seeing students' perspectives as roadblocks to comprehension, the scaffolded knowledge integration paradigm treats them as building blocks (Linn & Songer, 1991). Students are therefore pushed toward resolving discrepancies rather than just memorization. The scaffolded knowledge integration framework is indicative of the belief that students possess a variety of models for complex events and actively seek to develop, differentiate, reconcile, improve, and connect these models (see also Linn et al., 1994). Heuristics, algorithms, rules of thumb, formal mathematical systems, abstract representations, and processes are all considered models within this wide context. Here, adjustments to the existing set of models and the introduction of new ones constitute conceptual transformation. The objective of teaching is to have students thinking critically about other points of view and to help them find ways to incorporate such viewpoints into their own worldviews. Minimalism, practicality, and adaptability are all desirable qualities in a repertoire. In this work, we explore how to inspire learners to combine and contrast several models via the process of curriculum development.

The scaffolded knowledge integration technique first describes the range of models used by experts and students, and then pinpoints the steps that might help students acquire increasingly complex models. This isn't about getting kids to the point where they're experts; rather, it's about giving them the tools they need to continue learning. Rather than becoming specialists, this grounding will usually make students more educated members of society.

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Encouraging Autonomous Learning

The danger of making thought processes more transparent and apparent is that students will be persuaded to rely on memorization rather than active engagement with scientific concepts. Responsibility for comprehending is shifted from teacher to student as a central tenet of the scaffolded knowledge integration paradigm. To achieve this goal, most classrooms will need to renegotiate their hierarchy of power so that students learn to critically assess evidence rather than blindly accept the teacher's word as gospel. On the other hand, guided exploration programs have shown that pupils are more likely to fail than to integrate their ideas when given responsibility without the abilities required to perform that authority (e.g., Duschl, 1990; Raizen, 1991). As a result, fostering students' ability to study on their own accord requires not just transferring responsibility but also guaranteeing that students can competently execute that duty.

Students that are actively engaged in learning generate and evaluate their own ideas. They evaluate their development, then plan and carry out initiatives to strengthen and broaden their knowledge. Expert self-directed learners keep pushing for more comprehensive and convincing explanations of events. Still, these self-directed students keep tabs on their development and make sound choices about whether to keep at it and when to give up on their efforts at synthesis. The practice of reflecting on one's own learning—also known as metareasoning—is characteristic of autonomous learners. Students develop competence as self-directed students when they are (a) provided with opportunity to behave as

investigators and critics devising standards for assessing evidence, (b) invitations to think on alternative interpretations of phenomena and on how scientific concepts evolve and advance, and (c) chances to participate in persistent reasoning and build competence in a confined domain.

Through their involvement in the CLP project, students get experience in both the roles of investigator and critic, and they learn to critically assess scientific data. After students have conducted their first experiments, they may discuss and evaluate a class experiment that incorporates data from many studies. As they go through experiments in the ELB, students are often challenged to ponder their experiences. Students are asked to discuss the relationship between their own experiences and the results of classroom experiments, such as how they kept an item warm or cold.

CLP has pilot tested a number of exercises meant to teach students about the nature of scientific evidence and the processes that lead to conflicting interpretations (e.g., Linn & Songer, 1993; Songer & Linn, 1991). Students, for instance, compare and contrast several explanations for the extinction of the dinosaurs, assess the reliability of supporting data, and develop an understanding of the nature of competing explanations. In another exercise, they compare and contrast two hypotheses on the nature of light's journey: one holds that it lasts forever, while the other posits that it eventually fades away.

CLP has used student projects to have pupils thinking critically and for longer periods of time (e.g., Linn & Clark, in press). These assignments may call for students to conduct their own experiment, evaluate the methods and outcomes of others' studies, combine data from many experiments, or create curriculum for a specific area of science. Mentors are available to answer students' questions and guide them toward self-directed learning.

The focus of a number of recent studies has been to find ways to foster independent learning while still offering many opportunities for feedback. Chi & Bassok (1989) and diSessa (1992) have highlighted features of independent learners, while Schoenfeld (1983) has tried to teach self-monitoring.

Providing Social Support

Educationists and philosophers have agreed for some time that learning takes place through interactions with others (e.g., Dewey, 1901; Dewey, 1929). Depending on the social setting, knowledge integration may either be facilitated or hindered. Vygotsky (1978) defined the "zone of proximal development" as the area where children may learn the most provided they get positive social reinforcement. Researchers have shown that when students are part of a learning community, they get the encouragement and structure they need to study independently, and they are able to tackle more complicated issues than they could on their own (Scardamalia & Bereiter, 1993). In addition, a number of organizations maintain that students may benefit from seeing and learning from experts in their field by joining communities of practice (Brown & Campione, 1990; Lave & Wenger, 1991; Newman et al., 1989; Pea, 1992).

Social support for knowledge integration requires programs to both facilitate productive social contacts and prevent those that can serve to reinforce stereotypes or otherwise impede the process (Linn & Burbules, 1993). Our early research for the CLP project revealed barriers to collaboration. For instance, (a) groups of 3 or 4 excluded members while crowded around the computer screen (b) men routinely interrupted and insulted females (c) natural leaders received more experience than others (d) rather than sharing ideas, students often separated the activity into portions and each worked alone (Burbules & Linn, 1991; Madhok, 1992 April 4 & 5). CLP paired students up, created tools to facilitate group work, and retooled exercises to encourage collaborative problem solving to ensure that students could build

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upon and learn from each other's ideas and feedback (Linn, 1992b).Thus, taking advantage of the social context of learning requires considerable trial and refinement. Students are typically inexperienced in collaborative problem solving and techniques for fostering such learning require further research (e.g., Cohen, 1994; Hawkins *et al.*, 1993; Webb, 1989; Webb & Lewis, 1988). In sum, the knowledge integration scaffolding architecture may be used as a reference for those working on future curricula. Two separate initiatives were launched with the goal of bettering education and developing the scaffolded knowledge integration architecture. The following several paragraphs will detail LISP's Knowledge Integration Environment and the spatial reasoning setting respectively.

THE LISP KNOWLEDGE INTEGRATION ENVIRONMENT (LISP–KIE)

Undergraduates learning to code in Common LISP may benefit from the LISP Knowledge Integration Environment (LISP-KIE), which was developed with them in mind. Complex problem-solving is a particularly challenging skill to impart to students in beginner programming courses (Linn, 1985; Linn & Clancy, 1992b). Typically students understand the syntax of the language and the procedures for handling basic issues, but are unable to apply their knowledge to the design and solution of complicated programming challenges. Through (a) utilizing case studies to explain the skills students require and (b) using LISP, a language that is well-suited to addressing a large variety of programming issues, the LISP-KIE aimed to educate beginning programming students to solve complicated programming problems.

The process of building this curriculum began with an examination of the beliefs held by both novice programmers and industry veterans with regards to the learning and use of LISP. The second stage was developing a draft syllabus that would promote independent study while also highlighting the need of critical thinking. This prototype curriculum was developed using (a) programming research, (b) cognitive process research, and (c) speculations from literature meant to teach complicated problem-solving. The final phase was to apply these concepts and develop methods to give social assistance. The developed strategy was analyzed and tweaked until a workable layout was created. In this study, we begin the fourth phase, which is combining the data into a design framework for the future.

Encouraging autonomous programming.

Oftentimes, students in the field of programming need targeted instruction in problem-solving evaluation and idea-connection. Students often guarantee the correctness of their programs. A viewpoint like this discourages pupils from learning to evaluate and improve their own work. Paraphrase and citation lessons centered on analyzing and evaluating various approaches (Davis et al., in press-b). Students who were adept at finding answers to issues sometimes lacked the critical thinking skills necessary to evaluate the merit of the alternatives proposed by their peers. The LISP-KIE included CodeProbe into its case studies as a means of fostering critique-related expertise. CodeProbe helps students build a complete collection of test cases for their programs and requires students to anticipate outcomes for particular scenarios, both of which enhance students' debugging efforts and promote good trouble-shooting procedures (Bell et al., in press) (see Figure 3).

SPATIAL REASONING ENVIRONMENT

Objectives for the spatial reasoning environment in the context of an engineering course in graphical communications were more modest than those of the LISP-KIE (Hsi & Linn, 1994). Many people feel that spatial reasoning is a necessary talent for engineers to have. Engineers, while creating new artifacts, often have to envision the interaction of pieces that do not yet exist. Engineers often imagine what a finished product might look like in order to judge how well it will perform. It's important to be able to "translate" two-dimensional graphics into the third dimension.

Many women avoid studying engineering because they struggle with spatial thinking, while many male engineering students also struggle with spatial reasoning (Agogino & Linn, 1992 May-June; Shepard & Metzler, 1971). Even though spatial thinking is crucial in the engineering field, it is seldom covered in elementary through high school education. Not enough pre-college experience in spatial thinking is often a barrier for many aspiring engineers (Newcombe, 1981). In addition, studies have shown that practice makes perfect, therefore when pupils are given opportunities to develop their spatial reasoning abilities, they do so (Lohman, 1988).

The hypothesis that talented students may be dissuaded from pursuing engineering due to a lack of spatial reasoning expertise was a major impetus for developing the spatial reasoning environment. In instance, if students' spatial reasoning abilities are proportional to their prior experience in this area, those who lack this background may be dissuaded from continuing in the subject (Newcombe, 1981). If students were given more support to improve their spatial reasoning, this tendency may be reversed.

The LISP-development KIE's procedure was used as a blueprint for creating spatial reasoning curriculum for engineering students. The first step was to compare and contrast the ways in which professionals and students thought spatially. Then, preliminary teaching was prepared and evaluated based on the findings of the study and analyses of both expert and student comprehension. After many rounds of design and testing, a successful intervention was achieved. Similar to the LISP-KIE, a number of technology tools were developed to provide users real-world practice in

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spatial reasoning. After compiling all of these observations, we are able to provide recommendations for enhancing the scaffolding used in the framework for integrating information.

How Do Experts Solve Spatial Reasoning Problems?

There has not been a lot of research done on the abilities of skilled spatial reasoners. So, we had several engineering professors and expert designers go through some spatial reasoning challenges and write up how they did it (Bell & Linn, 1993). Engineering activities that are likely to be faced in the workplace and standard inventories for measuring spatial aptitude were mined for problems.

According to the outcomes of LISP-KIE, there were large variations in spatial thinking ability even among the most seasoned of engineers. Most specialists have a collection of techniques they could draw upon when solving spatial problems. These included the "holistic" approach, in which an object as a whole is rotated, the "pattern" approach, in which familiar parts of the object are rotated and then connected, and the "analytic" approach, in which specifics like the lengths of lines or the size of angles between lines are used to rotate the object. Sometimes experts would utilize a set of heuristics to determine which approach was best, and they might switch approaches midway through solving an issue. The inclination of experts to choose a certain tactic was also variable. The use of analytical or pattern-based approaches was reserved for cases when holistic approaches had failed by certain specialists. Others tended to use analytical methodologies, sometimes using descriptive geometry methods, and lacked an emphasis on holistic methods. Some individuals depended on a wide variety of previously learned patterns, and they could swiftly recognize these patterns even in complicated items, using holistic and analytical approaches only as a last option.

What's more, when polled on the importance of spatial thinking in engineering, experts' opinions were all over the map. People generally agreed that spatial thinking was useful in many contexts, but that it was seldom used independently. That is, they relied on spatial reasoning abilities with other abilities while doing tasks like plan analysis or design creation. Students may be overestimating the significance of spatial thinking.

Both experienced engineers and LISP programmers have mostly honed their craft outside of formal education. Many engineers said they had never received training or direction in spatial reasoning, and they had no recollection of ever been taught the topic. The specialists thought it was strange that we were talking about spatial thinking. Few were able to articulate their thought processes when working through spatial reasoning issues. Some respondents said they didn't think highly of their own spatial reasoning abilities. A female professor in engineering once lamented that she had never been taught how to think in a more integrative way. This self-perceived flaw prompted her to focus on a particular branch of engineering and continues to give her pause. It came as a shock to her to hear that many seasoned engineers, even mechanical engineers, had similar experiences.

difficulties. She hadn't gone into mechanics since she struggled with holistic thinking. None of the polled engineers and designers admitted to having had a conversation on spatial thinking with anybody else.

Evaluation of the spatial reasoning environment

Multiple metrics point to the Spatial reasoning environment being a success. The students who were given the chance to use their spatial reasoning skills said they much appreciated it. In addition, the majority of students felt that their understanding of and competence in spatial thinking improved as a consequence of the laboratory exercises. Students that attended the tutoring session said they learned a lot and felt like it helped them succeed in the class. There were far more women than men in the tutoring session, and they were especially grateful for the chance to talk about how to improve their spatial reasoning. In addition, girls improved more than men did in spatial thinking after receiving coaching (see Table II and Figure 8). (Hsi & Linn, 1994).

Intriguing correlations were found between students' academic performance and their spatial thinking abilities. This course's emphasis was on visual communication, and a significant portion of the curriculum was devoted to the completion of design projects in which students conceptualized and then produced their own solutions to real-world problems.

use of a CAD (computer-aided design) program to arrive at their answer. So, it stands to reason that being good with spatial thinking will aid academic performance.

Indeed, there was found to be no correlation between spatial reasoning ability and performance on the midterm, final, or overall grade for the course (Hsi & Linn, 1994). The course's heavy focus on analytical methods may help to explain the disconnect. It would be possible for students to do well in the class even if they never ever considered the course as a whole. If students wanted to take a more comprehensive approach, however, they were given the chance to do so.

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Finally, contrasting the graphical communication course between the Spatial reasoning environment version and the prior version revealed various advantages for the spatial reasoning environment. Before anything else, there was a marked decrease in the number of students who voluntarily withdrew from the course. When compared to earlier iterations of the course taught by the same teacher, significantly fewer students dropped Spatial thinking environment. Second, although men historically fared better than women in this area, recent iterations of the spatial reasoning course have produced equivalent results for both sexes in terms of grades and test scores (Figure 8). In engineering, women tend to outperform their male counterparts, and the recent revisions to the project have helped one class catch up to the others (Kimball, 1989; Linn, 1992c; Linn & Kessel, in press).

In conclusion, LISP-KIE and the spatial thinking environment have a lot in common, as shown by the trial-and-error method of improvement. Experts in both fields resorted to a variety of tactics, rather than favoring just one particular strategy, when faced with complex issues. Both situations benefited from the use of visualization tools to teach students how professionals solve problems. Both LISP and spatial reasoning specialists were found to lack insight into the problem-solving process, and in the instance of engineering, a female professor's career choices had been influenced by her incomplete comprehension of the spatial reasoning techniques employed by other expert engineers. Further, in both situations, the most successful intervention required elaborating on components of problem resolution that are often glossed over or miscommunicated in everyday settings. Tutoring sessions, for example, conveyed individual variations in problem-solving in a manner that may be disregarded in a traditional engineering course, while case studies conveyed problem-solving methods that might be overlooked in a course focused on results.

THE SCAFFOLDED KNOWLEDGE INTEGRATION FRAMEWORK REVISITED

Many of the principles in the scaffolded knowledge integration framework are supported and refined by research into the spatial reasoning environment and LISP-KIE. These two developments have a number of similarities that highlight the benefits of this approach for teaching and studying computer science and engineering.

Providing New Goals for Learning, Revisited

Analyzing the habits of experts and amateurs inspired both the spatial reasoning environment and LISP-KIE to develop new learning objectives. Research conducted in such settings has shown that it is beneficial to expand on concepts that pupils already understand. Furthermore, they argued against giving kids the opportunity to use tactics that mesh well with their own innate understanding. Several students, for instance, struggled to understand the material and failed to integrate their concepts when obscure uses of applicative operators were stressed. In its place, they attempted to remember some illustrative issues in the hopes that their solutions might apply to similar difficulties in the future. By shifting the focus of the LISP-KIE course from the intricate properties of applicative operators to their basic applications, students were able to acquire a deeper grasp of LISP (Katz, 1991). This result is similar to

heat flow is more effective than molecular kinetic theory in helping pupils make the difference between heat and temperature, according to a CLP study.

Knowledge integration and coherence are fostered via LISP-LISP KIE's Evaluation Modeler and the spatial reasoning environment's Display Object, both of which enable the entire repertory of methods typical of experts. Both also provide students the freedom to choose the models they like best, rather than forcing any particular set of beliefs or practices on them.

As an alternative to a model of LISP evaluation at the machine level, the LISP Evaluation Modeler supports both recursive and applicative operator-based patterns, and so lays a solid groundwork for further study. This simple model of LISP evaluation is provided by the LISP Evaluation Modeler. It works well for both recursive and applicative operator issues, and it is straightforward to grasp. The LISP Evaluation Modeler may be used to analyze not just the challenges that students face in the first course, but also the problems that they address in subsequent courses and throughout their careers as programmers. The modeler is useful for both professionals and novices (Mann et al., in press).

In a similar vein, Display Object bridges the gap between pattern analysis, data-driven decisions, and holistic approaches. Display Object's distinctive emphasis is on teaching students when to use various tools for spatial thinking. This research broadens the scope of the scaffolded knowledge integration framework by showing how several approaches may be equally successful and guiding students to identify when each approach is most suitable.

Do All Experts Have the Same Repertoire of Models?

As these studies showed, however, specialists use a wide variety of approaches to tackling difficult situations, each with its own strengths and weaknesses. In the cognitive community, there is debate about whether or not professionals have a common knowledge of their fields, or whether there are instead significant individual variances in the way different experts perceive the same information. As a result, Chi, Feltovich, and Glaser (1981) conjectured that specialists shared common approaches to categorizing

and retrieving information. After showing that professionals used free body diagrams, Reif and Larkin (1991) found that beginners relied on iterating over existing formulae. However, in each of these trials, experts were given challenges that were more suited to amateurs. Furthermore, the majority of the investigated specialists had a teaching position.
Teachers may use the same approaches when discussing the kind of issues often given to students in their first courses, but they may employ a variety of techniques when tackling difficult problems themselves. Experts in tackling complicated issues show far greater variation than previously thought, according to research (Clement, 1991; Nersessian, 1991).

In their 1992 research, Linn et al. posed issues to LISP specialists that were actually difficult for them to solve. Teachers in higher education and professionals in the field were analyzed. Therefore, it is possible that (a) experts were tackling difficult issues, (b) experts were engaged in a wide range of activities, and (c) experts were using patterns of thought that they had created independently. Similar to how we wouldn't anticipate a bunch of English literature scholars to all produce identical dissertations on, say, "Jane Austen's feminism," we should anticipate a range of approaches when it comes to addressing difficult programming and engineering challenges.

A Second Look at "Making Thinking Visible"
Students often want guidance in integrating their concepts, and a dynamic model may prove to be the most helpful tool available. With the help of the LISP Evaluation Modeler and the Display Object tool, students are able to more easily see how they are using and choosing among several approaches to addressing a problem.

Experts and students alike recognize the LISP Evaluation Modeler's usefulness due to its many features and functionality. Although the replacement model is simple in concept, it may be challenging to put into practice. Programming newcomers and veterans alike may find their mental resources taxed while attempting to follow this model's breadcrumbs.
The LISP Evaluation Modeler is a key component of the LISP-KIE, since it makes rational thought processes more apparent and so facilitates knowledge sharing.

Display Item works in a similar way by presenting an object in all conceivable orientations and allowing pupils to rotate it to see details they may otherwise miss. The ability to watch holistic rotation is useful in helping students differentiate their analytic methods from their holistic strategies and in encouraging a holistic approach for simple items, even if students are typically unable to do such rotation on their own. In the tutoring session, students often noted that they were hesitant to adopt a holistic technique before using Display Object because it gave them the confidence to reason holistically and then test their expectations against the findings. In this way, Display Object helps students build their capacity for spatial reasoning and makes whole-brain thinking more explicit.

By elaborating on the process followed to arrive at a solution rather of focusing just on the final product, case studies make the rationale behind such solutions more transparent. Students seldom get constructive criticism or instruction on how to approach addressing an issue. The LISP-KIE implementation of interactive case studies is superior to paper-based case studies because it allows students to get the immediate and accessible help they may need as they go through the process of problem-solving techniques.

It has been widely agreed that one of the most productive ways to provide students the direction and explicit problem-solving procedures they need to succeed in today's competitive academic climate is via tutoring, which is stressed in the spatial reasoning environment (Bloom, 1984). For students who joined the course with less expertise than their colleagues, it was especially helpful to provide advice and clear problem solving support throughout these two assignments. Particularly helpful to students at the outset of the LISP course was advice on how to handle difficulties with parenthesis and quotations.
When first beginning the spatial reasoning course, students benefited just as much from direction about the variety of tactics suitable for tackling problems in this area.

Encouraging Autonomous Learning, Revisited

These studies show the need for students to be accountable for their own knowledge integration via the promotion of self-monitoring and autonomous learning. It turns out that LISP-KIE and spatial reasoning specialists are quite different from one another, yet they all have the ability to think creatively, critique others' work, and keep tabs on their own growth. Students will need to practice self-monitoring skills to help them make sense of the many tactics available to them given the wide range of teachers' levels of experience. Learners may tailor their approaches to problem-solving in these multifaceted fields to their own conceptual growth. In addition, they require certain heuristics for choosing the best approach to a problem. These are two facets of self-monitoring that need the aforementioned abilities. Both LISP-KIE and spatial reasoning enable students to think critically about their own approach to addressing problems. They both aid pupils in understanding that there is a wide range of approaches to any given situation.

CodeProbe and Display Object's ambiguous objects inspire students to assume active roles as investigators and critics as they work to master difficult topics. Both roles show the need of self-monitoring and encourage students to consider methods they may have previously disregarded.

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Students benefit from the combination of spatial reasoning and LISP-KIE in their exploration of the epistemological foundations of their respective disciplines. Thus, rather than assuming that there is a single right answer or a single best path for solving a problem, these two approaches emphasize the diversity of methods and paths to solution, the importance of contrasting alternatives, and the value of considering different methods for solving the problem. In the long run, pupils who are able to see that there may be several viable explanations for a phenomenon are more likely to shift their perspective from one of a single, perfect solution to one in which they know that all theories have benefits and drawbacks.

LISP-KIE and the spatial reasoning environment both provide opportunities for students to evaluate their own methods in comparison to those of professionals via the use of case studies and one-on-one tutoring. These exercises are meant to help students improve their ability to monitor their own problem-solving activities and reflect on their own learning processes.

Monitoring progress and allocating time efficiently are two of the most important actions for specialists while handling complicated and tough challenges. Some LISP students end up with disjointed knowledge bases, favoring one area of study over another. Self-regulation help is obviously needed by these kids. This issue has been investigated in LISP-KIE, however finding a workable solution remains difficult.

Providing Social Support, Revisited

Both LISP-KIE and the Spatial Reasoning Environment sought to capitalize on the social nature of learning by supporting group learning in laboratory and tutoring sessions. In both projects these experiences has strengths and drawbacks. Working in groups often helped students expand their repertoire of strategies or refine understanding of a familiar strategy. Often students expressed strategies in new ways so that other students could understand them for the first time. At the same time, group members also discouraged their peers by criticizing on the basis of normative views. For example, in both projects, females sometimes experienced disrespectful and unwarranted treatment based on the normative view that computer science and engineering are male domains.

Capitalizing on the social nature of learning requires careful analysis of the learning environment. Normative views, based on the population of males and females and of underrepresented minorities can mitigate against benefits gained from appropriating problem solving practices refined by others. This aspect of the framework requires further investigation.

IMPLICATIONS

The Computer as Learning Partner project served as inspiration for the scaffolded knowledge integration architecture (Linn, in press). The CLP project spent 10 years perfecting a method for instructing middle schoolers on the topics of heat, temperature, light, and sound. The work presented here is an application of these principles to the improvement of programming and spatial reasoning curriculum in higher education. Many new studies that emphasize learning in complex, cumulative domains are congruent with this concept as well (Collins et al., 1991; Spiro & Jehng, 1990; Spiro et al., 1987; Torney-Purta, 1993 Aug 22). The scaffolded knowledge integration technique is applicable to both high school and college-level curricula in complicated fields.

Across all three experiments, researchers have found evidence supporting the idea of the learner as constructing and improving the collection of models introduced in the introduction. Experts in all three fields were found to draw from a variety of tactics, tailoring their solutions to each unique challenge. To aid in the development of pupils' skills and

Identifying differences in approaches has great promise. Many different, and sometimes more or less accurate, methods are used by experts. Expert problem-solving relies heavily on the meta-cognitive abilities required to strike a balance between speed and precision. Each project's new learning objectives were based on this guiding idea.

The framework places emphasis on the student's obligation to link and develop this information by making problem-solving procedures clear. Self-directed learning is often met with resistance from students, particularly when teaching methods do not prioritize the development of students' independent skills. Some pupils are resistant even when prodded, arguing that memorization has always produced the desired results in the past. In order to build and differentiate a repertory of models, students' mindsets must be shifted to prioritize integration and refinement.

Students who have difficulty with independent study may benefit from group study. When newcomers to a community of academics are encouraged and supported as they try out new ways of linking and integrating ideas, they are more likely to develop an inclination toward integration. Future academics will have a problem when it comes to the development of effective communities, particularly those that rely heavily on computer technology.

Implementing the ideas, conjectures, rules-of-thumb, and heuristics proposed by the scaffolded knowledge integration framework is an effective strategy for designing advanced courses. By putting these hypotheses to the test, design teams may develop a toolkit of pedagogical approaches and specify the circumstances in which they work best.

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