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SIMULATION VERSUS TEXT: ACQUISITION OF IMPLICIT AND EXPLICIT INFORMATION*

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ABSTRACT

This study investigated potential differences in learning between two instructional activities: reading from a text and using a computer simulation. Participants were undergraduate students with limited knowledge of the domain topic (project management). Participants in both conditions (Simulation and Text) improved equally on a decontextualized, abstract knowledge assessment. In contrast, only the participants in the Simulation condition significantly improved on a contextualized case-based assessment. A propositional analysis revealed that participants in the Simulation condition acquired a significant amount of implicit domain information from pretest to posttest, whereas participants in the Text condition did not. These results suggest that educational computer simulations have the potential to significantly enhance the learning of implicit domain knowledge.

INTRODUCTION

Enabling individuals to acquire the knowledge necessary to successfully perform in complex domains, such as today's high performance workplaces, is a difficult instructional task (e.g., Berryman, 1993; Dede & Lewis, 1995; Gott, Hall, Pokorny, Dibble, & Glaser, 1993; Schank, 1997). For many students, the traditional approaches to this task, such as listening to a lecture or reading from a text, can be problematic. The information presented in the traditional approach to instruction is often intentionally simplified and decontextualized under the assumption that making the information more abstract will enhance transfer. In

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this approach the primary focus is on the presentation of explicit facts and abstract principles while much of the implicit contextual information is discarded and is never conveyed to the students. This can lead to a student who has "learned a subject" but cannot successfully perform real-world problems, in part because they do not know under what conditions an activity or a principle applies. Thus, while students might have gained information about a subject or topic, their knowledge may be "inert" and not readily accessible (e.g., Bransford, Franks, Vye, & Sherwood, 1989; Bransford & Schwartz, 1999; Gick & Holyoak, 1980, 1983; Lave, 1993; Mayer & Wittrock, 1996; Salomon & Perkins, 1989; Whitehead, 1929).

An alternative to the more traditional lecture or text-based approach is the use of instructional computer simulations. Some theorists have argued that use of such learning environments would allow users to learn the domain content in terms of its functions, and in multiple contexts, which will foster deeper understanding and make the information more accessible in appropriate problem-solving contexts (e.g., Cognition and Technology Group at Vanderbilt, 1990; Collins, Brown, & Newman, 1989; Resnick, 1987; Schank & Neaman, 2001).

This leads us to ask, what can be learned from such simulations and how does this acquired knowledge compare to that gained from more traditional methods of instruction? While existing literature has already established that the information presented explicitly by a workplace simulation (e.g., on-line text) can be learned (e.g., Jeong, Taylor, & Chi, 2000), the intriguing question regarding the extent to which students can learn the implicit, contextualized information presented by a simulation, has yet to be adequately investigated.

Simulation: Project Challenge

Given that, by definition, the implicit information presented by a simulation is not explicitly stated, how could one know if students had acquired this knowledge? A first step is to identify the implicit information embedded in a simulation. A high quality simulation called Project Challenge (Thinking Tools, Inc., 1996) that was designed to provide management training to junior-level management professionals was selected from among a large set of computer-based work simulations (Ferrari, Taylor, & VanLehn, 1999). One feature that made this simulation particularly well suited for this study was that it had been specifically designed based upon the influential management text—*The Guide to the Project Management Body ofKnowledge* (Project Management Institute, 1996), which had summarized and codified much of the project management domain knowledge. A content analysis of the simulation was undertaken to assess how much of the information provided was presented implicitly.

The content analysis ignored much of the information which is highly specific to that particular simulation. For instance, in the Project Challenge simulation, the user plays the role of a project manager and two of his main tasks are maintaining a balanced budget and keeping the project on schedule. Information such as the *specific cost* to the project for sending a team member off for training was considered *overly specific* and thus unlikely to be useful knowledge outside of the simulation, and therefore was not included in the coding of the content. In contrast, the information that *sending a team member off for training would negatively impact the project schedule in the short-term* (i.e., since the employee would not be working on the project while training) was held to be sufficiently general to be applicable and useful for situations beyond this specific simulation, and was therefore included in the coding of the content.

Information directly stated (i.e., textual materials) was categorized as *explicitly* presented. For example, when reviewing the qualifications of employees, the simulation directly listed the characteristics of a good technical architect, "Technical architect—requires very strong technology skills and a broad base of experience in designing and building technical systems. . . ." In contrast, information not directly stated, but that instead had to be inferred from the simulation was categorized as *implicitly* presented. For example, experience with the simulation could allow one to infer that many project problems dramatically increase with the passage of time (i.e., a snowballing effect) and that one needs to act quickly to solve problems before they become unmanageable. This implicitly presented information was captured as the proposition, "Small problems, left unattended, can quickly become big problems." In this article, information like this that is located in the *external* learning environment but is not explicitly stated will be referred to as being *implicit,* while implicit information that has been *learned* by a participant, will be referred to as *inferred.*

Media Comparison

One potentially useful way to conceptualize the comparison of learning about a domain from either reading a text (Text) or playing a simulation (Sim) is the comparison of two types of media. However, some researchers have found such comparisons to be problematic. Perhaps the strongest opposition comes from Clark (1983, 1994) who argued that *any* media comparison was inherently confounded. In Clark's view, instructional *methods* were the genuine causal factor influencing learning while the media used was "merely" a delivery system. Clark (1994) provided a medical analogy in which he claimed that instructional methods were like a medicine's "active ingredient," whereas the type of instructional media was comparable to the various delivery forms a medicine might take (i.e., tablets, injections, transdermal patches, etc.). Clark claimed that the different delivery systems were "often capable of delivering a necessary active chemical ingredient with *different levels of efficiency*" [emphasis added] but that the outcomes were essentially equivalent (1994, p. 26).

The appropriateness of Clark's medical/educational analogy is questionable. Furthermore, upon close examination, the analogy does not hold up when one comes to understand that the efficiency of a medical "delivery system" can be of paramount importance—in some cases it is literally a matter of life or death—hardly an inconsequential or equivalent outcome. Cobb (1997) critically examines this analogy and notes:

> While we educators debilitate ourselves worrying about how to separate method and message from medium, medical theorists accept that a medicine must enter a body through some means of delivery and that there is no neutral delivery that does not interact with the body to some degree. Medical research proceeds in the face of this problem . . . [it does not] close the hospital until clean variables are available. This is in the nature of an applied science (p. 27).

Thus, attempting to completely isolate the effects of media and instructional methods is an extremely difficult, if not impossible task (Jonassen, Campbell, & Davidson, 1994; Kozma, 1994). More importantly, it is fundamentally misguided. Such a comparison misses the main point—this article argues that it is precisely the unique representation affordances of various media that should be of primary interest to instructional researchers and designers.

Representational Affordances

Objects such as tools—or in our case, media—have different affordances. An affordance, as defined by Norman (1988, p. 9), is the ". . . perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. . . ." Thus, while a book and a computer both afford textual displays, it is not the shared affordances but rather the unique affordances that are of most interest.

As will be described in greater detail below, there are several such affordances of simulations. For instance, students can dynamically interact with and participate (at least partially) in a virtual workplace. In such a simulated environment, as in the real world, knowledge is highly contextualized—the complex and often ambiguous nature of such environments requires that individuals learn the specific contexts in which to apply their domain knowledge. Lastly, it should be noted that the affordances and instructional efficacy of a simulation (or a text) are also influenced by how well it has been designed for a particular situation.

Learning of Domain Knowledge

Domain knowledge pertaining to project management is represented quite differently in a simulation, as compared to that of a textbook. The text contains project management principles that have been decontextualized and abstracted. This information is sequentially ordered and then explicitly presented to students. In contrast, the simulation contains project management principles that remain contextualized. The information is not sequentially ordered, but instead is contingent upon the learners' decisions which then allow the information to be "implicitly" presented.

In other words, the simulation does not provide direct, explicit instruction to participants about principles of project management; instead, it only provides a virtual environment which provides individuals with the potential to experience different facets of managing a project. For instance, in the Project Challenge simulation, individuals were able to make a variety of management decisions and observe an array of time variant changes in project outcome measures (e.g., schedule, budget). It should be emphasized that the consequences of a management decision are often ambiguous. For instance, a decision to make a project team work a specific amount of unpaid overtime would generally improve the project schedule. However, after a certain period of time it will also decrease team morale, which leads to a decrease in productivity that in turn impedes progress, making it more difficult to keep the project on schedule. However, even this single action and its consequences are not straightforward—the outcomes are influenced by other factors. For example, there are interdependencies among the various project deliverables (i.e., work products such as system blueprint, prototype, etc.) such that assigning unpaid overtime to a team which is dependent upon another team's delayed deliverable, will be ineffective. Further complications include the fact that some deliverables are produced by multiple teams—each with differential impact on production. Thus, we can see that this simulated work environment is quite complex and, in many ways, approximates that of an actual workplace. However, this complexity and realism comes at a price—for it is not always clear to users how their management decisions (not to mention the interaction of multiple decisions) necessarily influence the project's outcome measures.

Learning about project management from a simulation such as this is therefore contingent upon multiple factors: 1) exploration of the virtual workplace; 2) attending to and correctly interpreting the project outcome measures; and 3) inferring the intricate causal relationships between a variety of project management decisions and the subsequent project outcome measures. Given the difficulty of these requirements, it was not clear if students would be able to successfully learn from such a complex workplace simulation.

Research Question

It has been proposed that computer simulations can serve as a useful alternative to the more traditional instructional approach of reading text based instructional materials. This experiment sought to help determine the extent to which a simulation's affordance of having the opportunity to experience a more contextualized presentation of information may result in differential learning compared to reading texts covering the same domain information.

METHOD

Participants

The participants were 20 undergraduate students (males = 8, females = 12) from a Psychology department subject pool at a large urban university.

Design

The experiment was a two-factor mixed-model repeated-measures analysis of variance (ANOVA) design: 2 (condition: Sim, Text) × 2 (time: Pretest, Posttest). The first factor was a between-subjects factor in which participants were randomly assigned either to the Simulation (Sim) condition, or the Text (Text) condition. In the simulation condition, the participants were given up to 2 hours to repeatedly play the same simulation episode. In the text condition, the participants were given up to 2 hours in which to read aloud the six sections on Project Management. Thus, the primary mode of information presentation was *implicit* for the simulation condition and *explicit* for the text condition. The second factor, time, was a pretest-posttest repeated measure.

Materials

The Simulation

In order to have a better understanding of the participant's experience with the simulation, a brief description of the simulation along with some accompanying screenshots will be provided. The user is depicted in the simulation as situated behind a desk in a virtual office (see Figure 1). A binder and folder lay on the desk. The office walls show several displays that present information about the status of the project (i.e., project outcome measures). The ship icon on the upper right is a real-time indicator of the project's status (sunny with "smooth sailing" if all project outcome measures are on target, and increasingly stormy weather to indicate the severity of project troubles). Clicking on a display icon opens up a window presenting that information in greater detail. If the user clicks on the ship icon, the Simulation Score window will open, displaying the simulation score as well as the four main project outcome measures: Budget, Schedule, Customer Satisfaction, and Team Morale (see Figure 2). As shown here, the project is under Budget and Customer Satisfaction is relatively high, which is good, but the project is running over Schedule and Team Morale has fallen, which is problematic.

Let's say the user closes the Sim Score window and decides to check the Project Plan by clicking on its binder (see Figure 3). After looking in the Project Plan, the user notices that there are no project meetings scheduled and chooses to set up weekly meetings with his team and with the sponsor by clicking in the appropriate boxes.

Figure 1. Project manager's office.

The user then closes the Project Plan and opens the Project Schedule window to check how each individual subtask or "deliverable" is progressing (see Figure 4). Near the bottom of the window is a horizontal calendar listing the months, with the thick vertical line labeled "Today" identifying the current date. This project began on January 1st, so we can see that the user is approximately 2 weeks into the project. On the left side of the screen is a list of six deliverables (e.g., Requirements Definition, System Blueprint, Prototype, etc.). The majority of these deliverables are on schedule, which is represented by the fact that the Projected Completion icons (light triangles) are to the left of—and are therefore projected to occur before—the Planned Completion icons (dark triangles). This is not the case for the first deliverable, the Requirements Definition, which has fallen behind schedule, as indicated by the Projected Completion icon being further to the right of the Planned Completion icon (i.e., the estimated completion is in mid-February versus the originally planned date set at the end of January).

The user is puzzled by this delay and decides to check on his team members (see Figure 5).

After looking through the various team member reports, the user identifies a likely cause of the scheduling problem—the technical architect appears to be

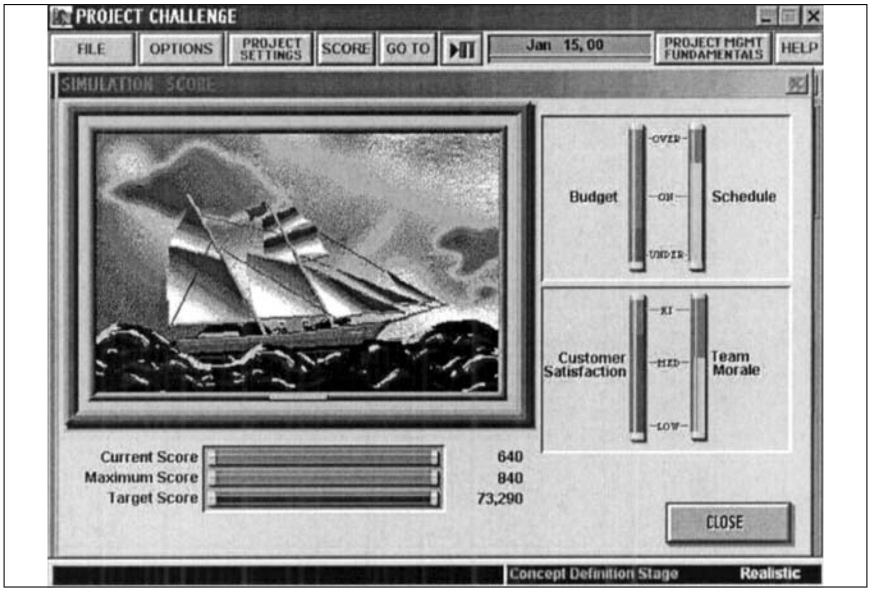

Figure 2. Simulation score.

deficient in his technical skills (i.e., "Tech" is only a 6 out of a maximum score of 10), which is what is probably the underlying cause of the projected deliverable delay. The user could then decide either to train or replace this employee.

The Text

The Text consisted of six sections from the influential management text, *The Guide to the Project Management Body of Knowledge* (Project Management Institute, 1996), which the simulation was based upon. The sections were: 1) Project Integration Management (4 pages), coordinating the various aspects of a project; 2) Project Time Management (8 pages), scheduling to assure timely project completion; 3) Project Cost Management (5 pages), budgetary processes; 4) Project Quality Management (2 pages), activities and policies for assuring quality processes and products; 5) Project Human Resources Management (5 pages), processes required for effective use of people involved with the project; and 6) Project Communications Management (2 pages), processes required to ensure effective collection and use of project information. These text sections were judged to best correspond with the information presented in the simulation.

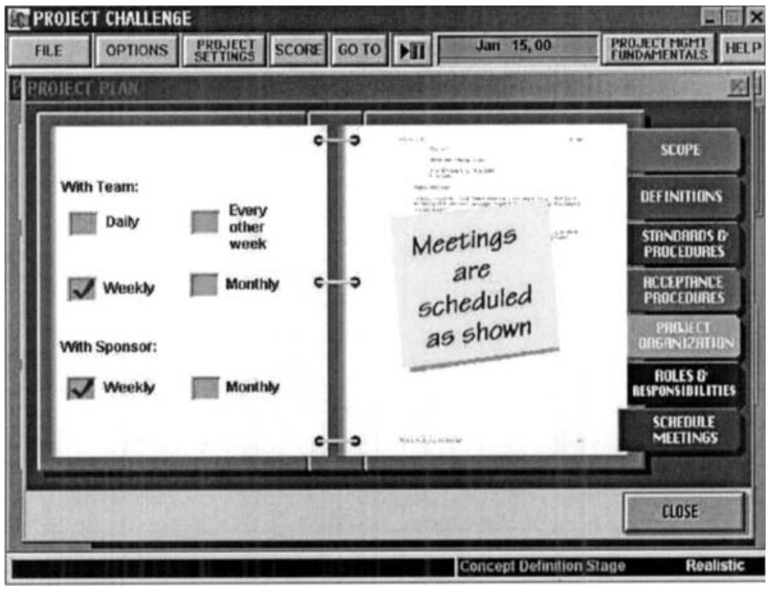

Figure 3. Project plan.

To give the reader a better sense of participants' experiences with the text, below is a brief passage from the human resources management section on Training (see Table 1).

In order to address concerns that any potential differences between the Simulation and Text conditions could be due to mere content difference, several modifications were made to the text. First, irrelevant material not covered in the simulation or assessments was minimized or eliminated from the text. For example, in the simulation the user begins the project with a Project Plan already in place but must actively work on its control and execution. This is in the text section on integration management which covers the project plan. The text material on project plan development was eliminated in order to place more emphasis on the relevant text covering project control and execution. Second, the format of the original text contained numerous references to other sections of the document that necessitated turning to various sections of the document. In order to improve the readability of the text, these links were replaced with the referenced information, and some minor modifications, such as the addition of bridging sentences were made to promote textual coherence. Care was taken to make sure no new information was introduced by these modifications.

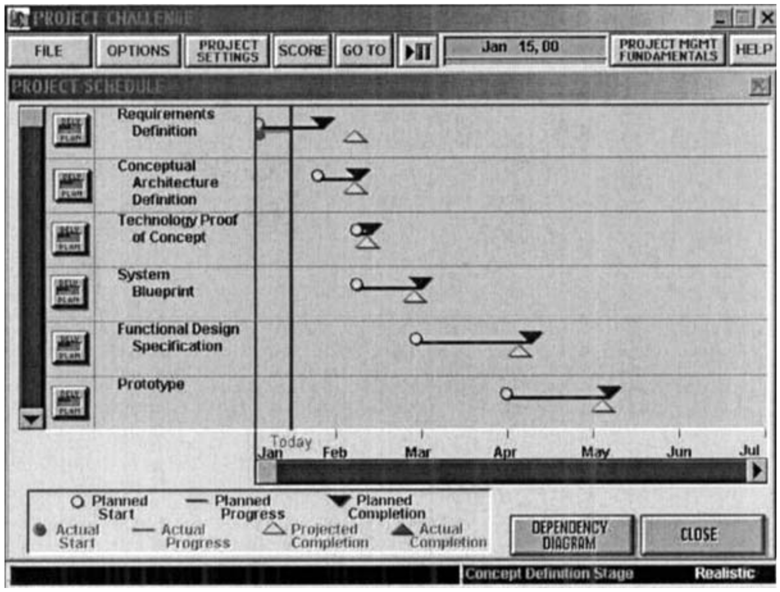

Figure 4. Project schedule.

Assessment

The Contextualized Question (CQ) and Decontextualized Question (DQ) assessments were based on a project management model (see Figures 6 and 7 for simplified model diagrams) that was constructed from a detailed task analysis of the Project Challenge simulation (Thinking Tools, Inc., 1996) and a content analysis of the Guide to the Project Management Body of Knowledge (Project Management Institute, 1996).

The project model consists of the four main project outcome measures—Schedule, Budget, Customer Service, and Team Morale—and their relationships (see Figure 6). The arrows indicate the direction of interaction, with the sign (+ or –) designating the direction of change. For example, if the project runs over schedule causing an increase in project duration, this will lead to increased expenses, likely putting the project over budget. Similarly, running over schedule also typically affects customer satisfaction and team morale, decreasing both factors directly and indirectly through budget overruns. The Contextualized and Decontextualized Questions each tried to assess participants' understanding of these relationships. The Contextualized Questions had a greater focus on assessing *implicit* information, while the Decontextualized Questions had a greater focus on assessing *explicit* information.

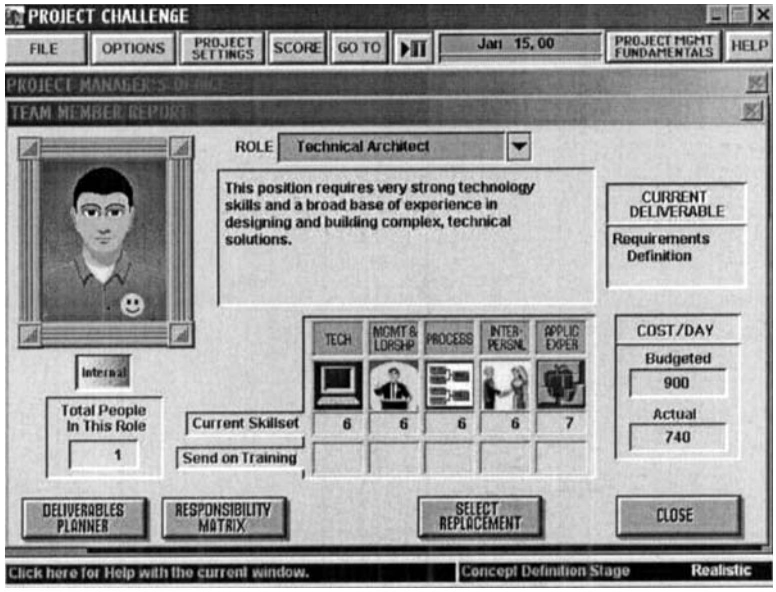

Figure 5. Team member report.

Table 1. Passage from Human Resources Section of Text

Training

Training includes all activities designed to enhance the skills, knowledge, and capabilities of the project team. Training may be formal (e.g., classroom training, computer-based training) or informal (e.g., feedback from other team members). There is a substantial body of literature on how to provide training to adults.

If the project team members lack necessary management or technical skills, such skills must be developed as part of the project, or steps must be taken to restaff the project appropriately. Direct and indirect costs for training are generally paid by the performing organization.

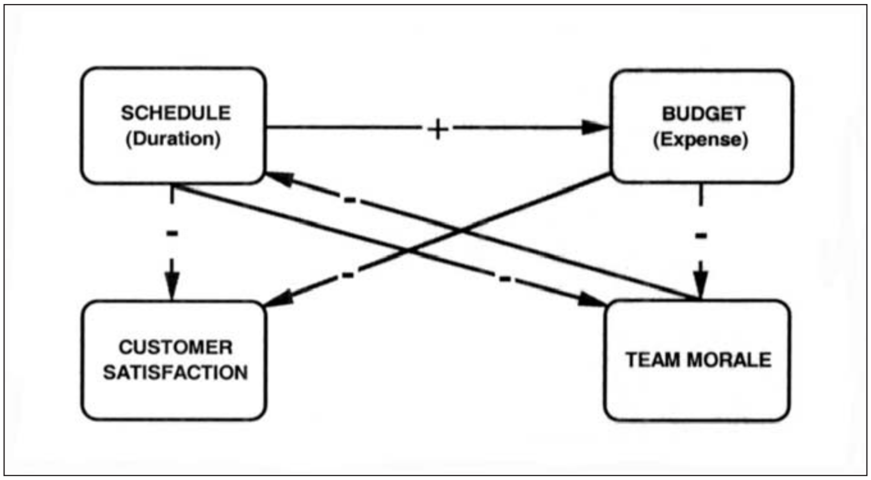

Figure 6. Model of interactions between main project management factors.

There are many different actions the project manager can take which may influence the four main outcome measures. Figure 7 displays a diagram of how some of these actions influence the project schedule. For instance, increasing the amount of overtime and staffing tends to decrease the project duration, while increasing employee training typically delays projects in the short-term (while employees are away from work at training) but tends to decrease project duration in the long-term. This is a concrete example of the kind of relationship knowledge that can potentially be inferred.

Decontextualized Questions

The Decontextualized Questions (DQ) assessment was designed to measure the participants' abstract knowledge of the four main project outcome measures (Schedule, Budget, Team Morale, and Customer Satisfaction) that were covered in both the simulation and the text, and which are believed to determine success in project management. Knowledge of each outcome measure was assessed with two open-ended questions.[1]

[1] A third question asked how one might prevent or fix a project with a problem with the outcome measure in question. These data were not included here because of difficulties establishing content and coding parity between the domain information in the Simulation and Text.

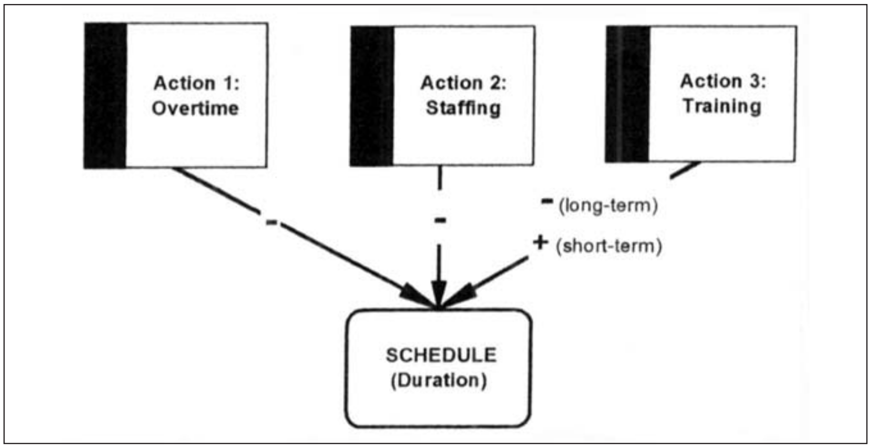

Figure 7. Some of the factors influencing the project schedule.

The first question in each set assessed whether participants knew how to identify specific parameters for a given outcome measure. For example, one item asked, "What are some ways to tell if a project is ahead of, behind, or on schedule?" Given that there could be many reasons why a participant might not make adjustments to the project schedule, it was important first to establish that they could at least *properly interpret* the charts and diagrams displaying the relevant information. The second question for each outcome measure asked participants to explain how a project might come to experience problems with the outcome measure in question. For example, participants were asked, "What are some *reasons why* a project could fall behind schedule?"

Contextualized Questions

The Contextualized Questions (CQ) assessment was also designed to measure the participants' situational knowledge of the four main project outcomes. This assessment consisted of a set of four case study scenarios created by the experimenter in which the participant read about different fictional players who'd made a series of common project management decisions. The participants were also able to view the simulation status (i.e., various informational diagrams and charts) of the fictional players, and they were then asked to evaluate the fictional players' performances. In each scenario the fictional player had made several typical decisions—some of which were correct, and some that were incorrect—as determined by both the simulation and text. For example, in the first scenario the participant judged the appropriateness of the actions taken by a fictional player named Bob. If the participant agreed with Bob's (correct) decision to appoint a Steering Committee and disagreed with Bob's (incorrect) decision to skip defining project Roles and Responsibilities, he or she was coded as having given two correct answers.

Simulation Performance

In order to better understand the process of implicit knowledge acquisition, analyses were conducted on the participants' use of the simulation during the training or intervention phase (Sim condition only). Performance was defined as the Implementation Score (IS), a weighted performance metric that is built into the simulation. The score is a ratio of the user's actual score divided by the maximum possible score for the simulation episode. Thus, a perfect Implementation Score would be 100%. The simulation can also run without the user making any decisions (i.e., on "auto-pilot"). If the user pursues this extreme laissez-faire management approach, the Implementation Score would be 65%, which can be taken as a rough measure of chance performance.

Inferred Knowledge

Inferred Knowledge (IK) was operationally defined as participants' giving verbal utterances or engaging in management actions that were determined a priori as a key subset of implicit information that could be inferred by the participant from either the simulation or the text. As discussed earlier, this information was derived from a content analysis of both the Project Challenge simulation (Thinking Tools, Inc., 1995) and project management literature (Project Management Institute, 1996), and was coded as sets of propositions (Ferrari et al., 1999). A subset of the most important and applicable propositions was then selected and used in coding (see Appendix A for a list of these implicitly presented, inferable knowledge propositions).

This coding was used in conjunction with the process measure of Simulation Performance. Each pass though the simulation of each participant (in the Sim Condition) was evaluated in terms of the actions performed and the verbal statements generated. This allowed a rough measure of the degree of Inferred Knowledge (IK) throughout the use of the simulation.

Procedure

The study consisted of three sessions: Pretest, Intervention, and Posttest. Each session took place on separate days. All of a participant's sessions were completed within 2 weeks' time.

Pretest

The pretest session was identical for all study participants, regardless of condition, and began with a brief overview of the study and general instructions. Due to the complexity of the subject matter, in order for the participants to possess enough basic information to answer the subsequent assessment questions, a familiarization procedure was performed in which the basic aspects of project management were explained and then a 10-minute "movie" reviewed the simulation user-interface layout. According to the standard practice for obtaining talk-aloud verbal protocols (Ericsson & Simon, 1993), the experimenter explained that the participant was to express his or her thoughts while reading the text or playing the simulation. The experimenter first demonstrated the talk-aloud procedure and then had the participant talk aloud while solving a practice problem. If necessary, feedback was provided to the participant until he or she was able to successfully perform the talk-aloud procedure.

After this preliminary material was completed, the participants began the first of two assessments (see Table 2).

The first assessment, Contextualized Questions (CQ), targeted *implicit* information and involved four different case study scenarios. Each involved a description of a fictional player who had made a series of management decisions (e.g., "After Mark began using the simulation he noticed that the project was slightly over budget so he decided to cut expenses by reducing the support staff"). The participants were required to evaluate the quality of these decisions and then provide justification for their answers. The participants' answers were electronically recorded.

Table 2. Schedule of Data Collection

Session	Activity
Pretest	Familiarization
	Talk-Aloud Demo & Practice
	Contextualized Questions
	Decontextualizded Questions
	Background Questionnaire
Intervention	Sim Condition: Participants Play Sim
	Text Condition: Participants Read Text
Posttest	Familiarization
	Contextualized Questions
	Decontextualized Questions

The second assessment, Decontextualized Questions (DQ), targeted *explicit* information and consisted of four questions, each of which was focused on one of the four major project outcome measures covered by both the simulation and the text: Schedule, Budget, Team Morale, and Customer Satisfaction. For example, one question was, "what are some reasons why a project could fall behind schedule?" Again, participants' answers were electronically recorded. The participants were then asked to complete a background questionnaire on prior computer, academic, and work experiences, which concluded this session.

Intervention

In the Intervention session, participants were randomly assigned to one of two conditions: Playing the Simulation (Sim) or Reading the Text (Text). In the simulation condition, the participants were told to imagine that they were the project manager for a software company and that they needed to keep their team motivated to manage the project so that it was finished on time, within budget, and to the customer's satisfaction. The participants had up to 2 hours in which to repeatedly play and master the same simulation episode. While playing, each participant's verbal talk-aloud protocol and simulation performance (i.e., their history of decisions and actions) was electronically recorded through the use of screen capture software. Participants in the text condition had up to 2 hours in which to read aloud the six sections from *The Guide to the Project Management Body of Knowledge* (Project Management Institute, 1996).

Posttest

The posttest session was identical for all study participants, regardless of condition. Participants were re-familiarized with the simulation and were given the Contextual Questions (CQ) and Decontextualized Questions (DQ) assessments once again.

Data

Pretest and posttest outcome measures were taken for the Contextualized Questions (CQ) and Decontextualized Questions (DQ) assessments. Performance was measured in terms of the number of correct responses given in their answers and justifications. A process measure was taken of participants' (Sim condition only) use of the simulation over time. Coding of all assessments was carried out by the first author, who was blind to the participant's condition and the temporal sequence (i.e., pretest/posttest). The assessments will be described in greater detail below.

RESULTS

Baseline Equivalence between Conditions

Baseline levels of both domain-related knowledge and ability of participants were statistically compared across both conditions. An alpha level of .05 was used for all statistical tests. No significant differences between conditions were found on any pretest measure.

Knowledge Gains—Contextualized Questions

Performance on the Contextualized Questions (CQ) was assessed by scoring the number of correct answers to case-based scenario questions about project management (maximum score = 38). This was examined via a one-way (Condition) repeated measures (Time) ANOVA. There were significant gains in knowledge over time, $F(1, 18) = 10.69$, $p < .01$. The interaction of Time × Condition (Sim, Text) was significant, $F(1, 18) = 9.87$, $p < .01$.

There was a significant improvement for the participants in the Simulation condition from pretest ($M = 7.70$, $SD = 4.40$) to posttest ($M = 12.70$, $SD = 3.59$), $F(1, 9) = 15.00$, $p < .01$. However, there was no significant improvement for subjects in the Text condition from pretest ($M = 9.80$, $SD = 3.23$) to posttest ($M = 9.90$, $SD = 1.79$), $F(1, 9) = 0.01$, $p > .05$ (see Figure 8).

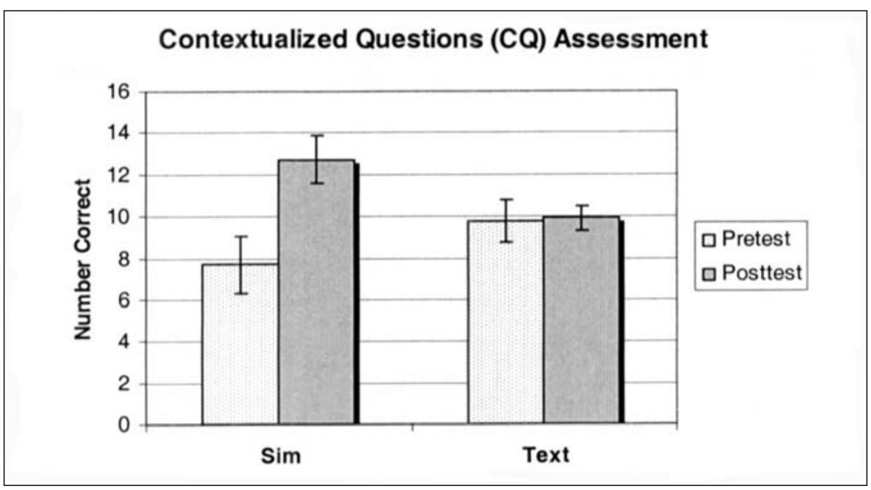

Figure 8. Contextualized Question assessment performance.

A supplemental coding of the contextualized questions (CQ) was also included to identify any increase in the number of potentially inferred knowledge (IK) propositions used when answering the contextualized questions. This analysis demonstrated that there was a significant increase in the number of inferred knowledge (IK) propositions displayed by the participants in the Simulation condition from pretest ($M = 4.70$, $SD = 2.98$) to posttest ($M = 7.7$, $SD = 2.83$), $F(1, 9) = 15.58$, $p < .01$. There was no significant difference for subjects in the Text condition from pretest ($M = 5.5$, $SD = 2.64$) to posttest ($M = 6.0$, $SD = 2.21$), $F(1, 9) = 0.37$, $p > .05$ (see Figure 9).

Knowledge Gains—Decontextualized Questions

Performance on the Decontextualized Questions (DQ) was assessed by scoring the number of correct answers to decontextualized questions about project management (maximum score = 50). This was examined via a one-way (Condition) repeated measures (Time) ANOVA. There were significant gains in knowledge over time, $F(1, 18) = 23.27$, $p < .001$. The interaction of Time × Condition (Sim, Text) was not significant, $F(1, 18) = 2.45$, $p > .05$.

There was significant improvement for subjects in the Simulation condition from pretest ($M = 16.30$, $SD = 3.83$) to posttest ($M = 18.90$, $SD = 4.31$), $F(1, 9) = 5.41$, $p < .05$. Similarly, there was significant improvement for subjects in the

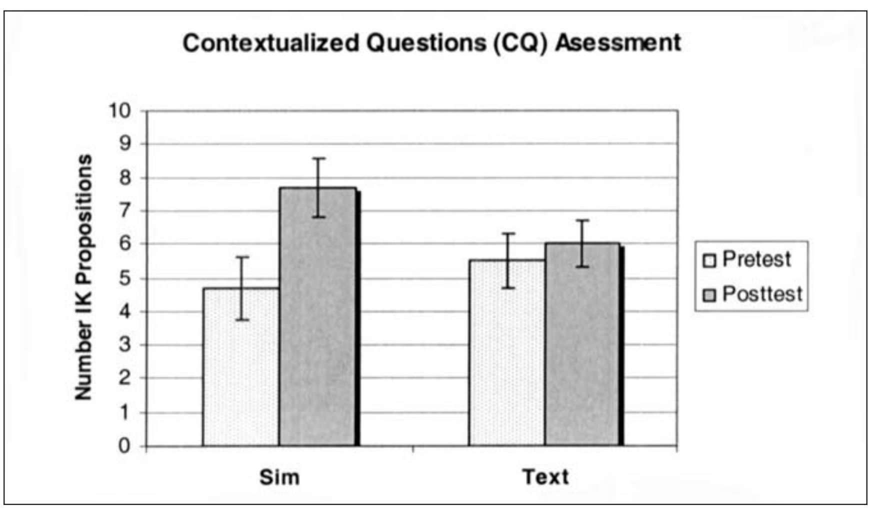

Figure 9. Contextualized Question assessment—Inferred Knowledge.

Text condition from pretest ($M = 17.70$, $SD = 4.42$) to posttest ($M = 22.80$, $SD = 4.13$), $F(1, 9) = 20.03$, $p < 0.01$ (see Figure 10).

As noted earlier, the decontextualized questions (DQ) were designed to capture the more abstract, deep structural knowledge of project management. The nature of this assessment, therefore, prevented the use a supplemental coding of inferred knowledge.

Knowledge Gains—Simulation Usage

As discussed earlier, participants' performance with the simulation was assessed by a weighted metric that was determined by the simulation. An Implementation Score (IS) of 100% would indicate an optimal performance, while a score of 65% would indicate that the participant was essentially performing at mere chance level. During the 2 hours participants had available to use the simulation, they all made several "passes" through the game—following a variety of available exploratory paths—repeatedly playing the same management "episode." There was a significant improvement in participants' Implementation Score (IS) from their First Pass (analogous to pretest) ($M = 0.67$, $SD = 0.08$) to their Last Pass (analogous to posttest) ($M = 0.77$, $SD = 0.10$), $F(1, 9) = 6.23$, $p < .05$

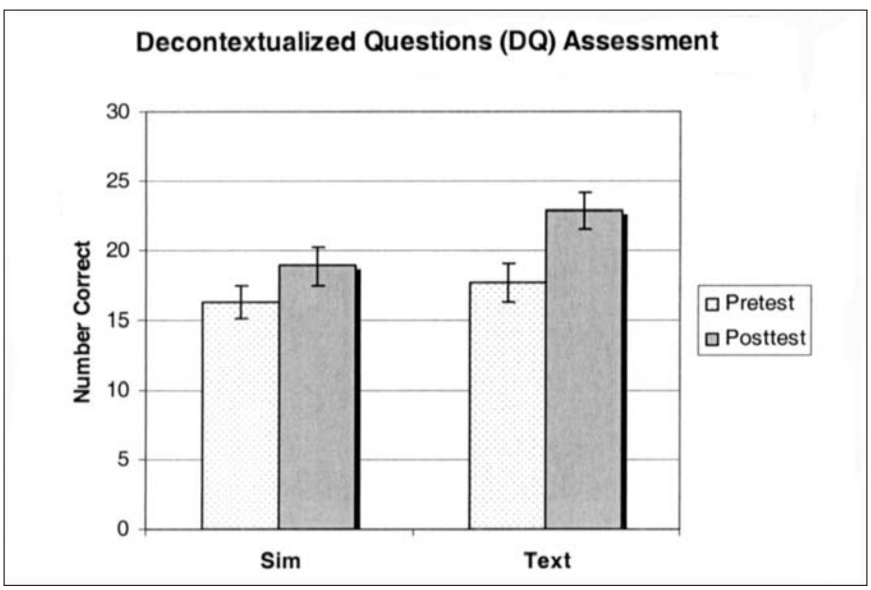

Figure 10. Decontextualized Question assessment performance.

(see Figure 11). Thus, the participants, on average, got better at playing the simulation over time.[2]

Based upon the verbal protocols and pattern of simulation behaviors, each pass was coded for the presence of Inferred Knowledge (IK) propositions (see Appendix A). As with the Implementation Score (IS), there was also a significant improvement in participants' Inferred Knowledge (IK) score from their First Pass (M = 1.8, SD = 1.87) to their Last Pass (M = 6.1, SD = 2.75), $F(1, 9) = 42.88$, $p < .001$ (see Figure 12).

DISCUSSION

This experiment examined the degree to which individuals can acquire domain knowledge from a computer simulation, and how this knowledge may differ from the domain knowledge gained from reading a comparable text. It was found that the participants who used the computer simulation performed significantly better on a contextualized, case-based assessment (CQ), whereas participants who read the text did not significantly improve. This is hypothesized to be due to the increased implicit information that was inferred by participants in the simulation condition.

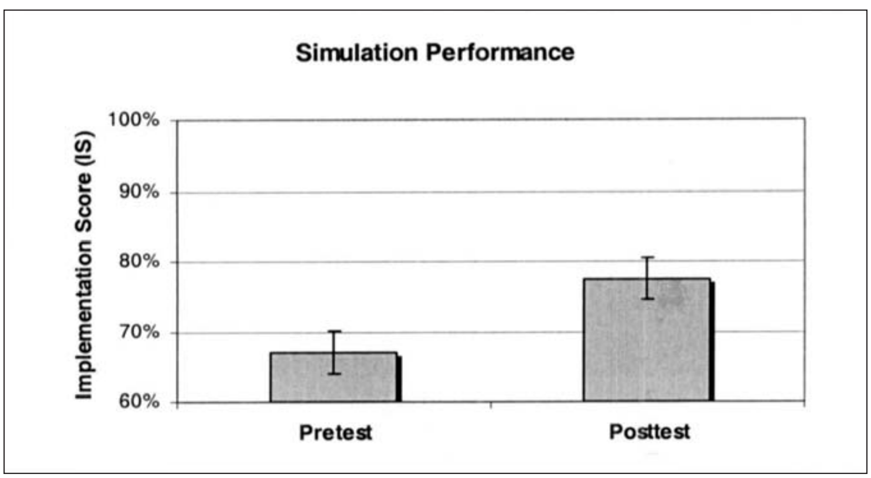

Figure 11. Simulated performance assessment.

[2] However, one \softlineparticipant consistently performed below chance level.

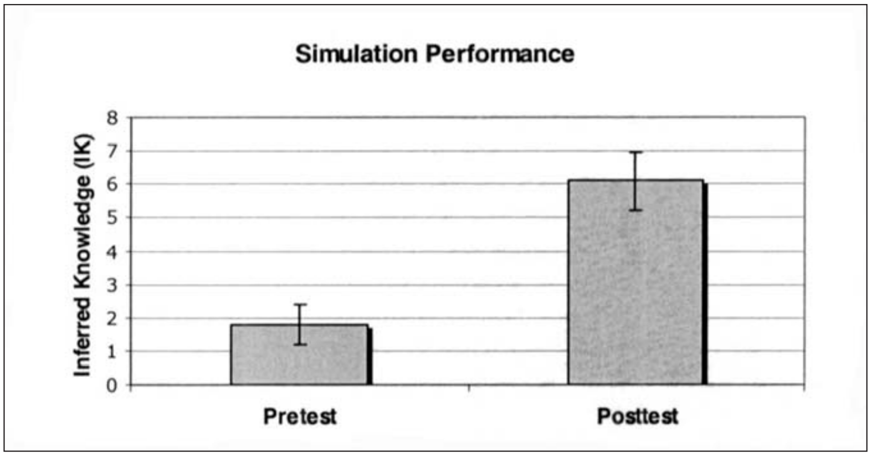

Figure 12. Simulated performance assessment—Inferred Knowledge.

It was also found that the participants in both the simulation and text conditions performed significantly better on an abstract, decontextualized assessment (DQ). Most importantly, there was no significant difference in learning between the conditions. The equivalent gains of the two conditions suggest that there was no significant handicap for individuals who experienced the more contextualized simulation condition.

Another important finding was that despite the complexity of the domain (project management) and a lack of experience among the participants, those in the simulation condition significantly improved their performance over time. Furthermore, the participants were shown to have gained significant amounts of inferred knowledge during the course of playing the simulation. We speculate that use of the simulation may have resulted in increased acquisition of implicitly presented information, which in turn lead to increased performance on the more contextualized performance assessments (i.e., CQ and Sim Usage).

As discussed earlier in terms of a medical research model, one inherent limitation of this type of research is that one can never cleanly separate the factors of instructional content and media representation. However, several actions were taken to make the comparison between the conditions as fair as possible. As noted earlier, the chosen simulation was specifically designed based on the seminal text of project management, *A Guide to Project Management Body of Knowledge* (Project Management Institute, 1996), which served as the basis of the text used in this experiment. Furthermore, this text was modified, eliminating irrelevant sections and rewriting portions to improve readability, in order to make both conditions as equivalent as possible with respect to the comprehensibility of the content presented. Lastly, as a final safeguard, only answers that could be inferred from both the simulation and the text were included in the assessments.

This investigation produced several noteworthy contributions. First, it presented a more sophisticated method of instructional media comparison—namely that of representational affordances. Given the widespread and ever increasing use of diverse instructional media, there is a great need for additional, theoretically grounded, empirical research in this area. Second, this research presented methodological techniques and empirical results on the role of implicit domain knowledge acquisition from simulation. This is of note, we argue, because this area of research is still poorly understood, particularly in the realm of educational implementation. Lastly, the results from this research are germane to educational policy and administration in that they provide strong empirical support for the implementation and utilization of instructional computer simulations, particularly in complex domains that are rich in implicit knowledge.

This research raises a number of exciting questions. How would such a simulation compare with a text that contained embedded examples? Also, given that self-explanation has been shown to be a powerful method for enhancing learning (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, De Leeuw, Chiu, LaVancher, 1994; McNamara, Levinstein, & Boonthum, 2004), how might asking participants to self-explain, particularly in the text condition, influence learning?

Other intriguing questions for future research are whether there are specific types of *strategies* employed by individuals using instructional computer simulations? If so, how do they affect learning? Similarly, are there any general patterns of *exploration* of the virtual environments in instructional computer simulations? If so, how do they impact learning? These questions help to underscore the need for further research in this important area.

APPENDIX A
Table A
Inferred Knowledge (IK) Propositions

Proposition

1. Small problems left unattended, can quickly become big problems.
2. Visits to the staff improves team morale.
3. It is best to meet with team members regularly (i.e., daily or weekly vs. biweekly or monthly).
4. Check the completion dates for deliverables, paying particular attention to those that are behind schedule.
5. If projected completion date is slipping take corrective action immediately.

6. If there is only a short time left between planned completion and current time, then to eliminate slippage, need to assign high level of overtime.

7. If there is a long time left between planned completion and current time, then to eliminate slippage, only need to assign a low level of overtime.

8. Delays on one deliverable can put everything else connected to it, behind schedule.

9. Dependent deliverables require the completion of earlier deliverables before work can begin on them.

10. There is usually a trade-off between the skill of the employee and their employment cost.

11. Replacing less skilled worker with more skilled worker typically costs more, and negatively affects budget, at least in the short-term.

12. If you cut facilities too much, individuals will find it hard to work in cramped working conditions reducing productivity and team morale.

13. Bonuses improve Team Morale.

14. Bonuses negatively impact Budget, at least in the short term.

15. Check to see if employee is working for less than budgeted (expected) because this is tip that the employee may be under-qualified.

16. Make sure that managers have higher skills (in key areas) than those working below them.

17. Replacing under-skilled workers improves scheduling.

18. If you decide to train/replace worker, do so early to make most use of added skills.

19. Make sure that employees' roles are well-defined so that they do not duplicate each other's work, leading to wasted effort, lost time, and demoralization.

20. Schedule regular meetings with the team members to hear about potential problems soon after they arise.

21. Informal meetings with team members allow you to find out what is really happening with the project.

22. Make sure standards and procedures are well-defined, early in project.

23. Ask to have a project steering committee set up to make the project more efficient in the long run.

Note: Propositions 1–18 are embedded in both the Contextualized Questions (CQ) assessment and Simulation. Propositions 19–21 are only embedded in the CQ assessment. Propositions 22 and 23 are only embedded in the Simulation Performance assessment.

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REFERENCES

Berryman, S. E. (1993). Learning in the workplace. In L. Darlin-Hammond (Ed.), *Review of research in education* (Vol. 19, pp. 343-401). Washington, DC: AERA.

Bransford, J. D., Franks, J. J., Vye, N. J., & Sherwood, R. D. (1989). New approaches to instruction: Because wisdom can't be told. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 470-497). New York: Cambridge University Press.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education, 24,* 61-100.

Brown, S. B., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13,* 145-182.

Chi, M. T. H., De Leeuw, N., Chiu, M., & La Vancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18,* 439-477.

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research, 53*(4), 445-459.

Clark, R. E. (1994). Media will never influence learning. *Educational Technology Research and Development, 42*(2), 21-29.

Cobb, T. (1997). Cognitive efficiency: Toward a revised theory of media. *Educational Technology Research & Development, 45*(4), 21-35.

Cognition and Technology Group at Vanderbilt. (1990). Anchored instruction and its relationship to situated cognition. *Educational Researcher, 19*(6), 2-10.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and arithmetic. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum.

Dede, C. J., & Lewis, M. (1995). *Assessment of emerging technologies that might assist and enhance school-to-work transitions.* Contractor report to the Office of Technology Assessment, Washington, DC, National Technical Information Service, Springfield, Virginia.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data.* Cambridge, MA: MIT Press.

Ferrari, M., Taylor, R., & VanLehn, K. (1999). Adapting work simulations for schools. *Journal of Educational Computing Research, 21*(1), 25-53.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*(3), 306-355.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology 15*(1), 1-38.

Gott, S. P., Hall, R. A., Pokorny, E., Dibble, E., & Glaser, R. (1993). A naturalistic study of transfer: Adaptive expertise in technical domains. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 258-288). Norwood, NJ: Ablex.

Jeong, H., Taylor, R., & Chi, M. (2000, August). Learning from a computer workplace simulation. *Proceedings of the 22nd annual meeting of the Cognitive Science Society* (pp. 705-710). Mahwah, NJ: Lawrence Erlbaum Associates.

Jonassen, D. H., Campbell, J. P., & Davidson, M. E. (1994). Learning with media: Restructuring the debate. *Educational Technology Research and Development, 42*(2), 31-39.

Kozma, R. (1994). Will media influence learning? Refraining the debate. *Educational Technology Research and Development, 42*(2), 7-19.

Lave, J. (1993). Word problems: A microcosm of theories of learning. In P. Light & G. Butterworths (Eds.), *Context and cognition. Ways of learning and knowing* (pp. 74-92). Hillsdale, NJ: Erlbaum.

Mayer, R. E., & Wittrock, M. C. (1996). Problem-solving transfer. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 47-62). New York: Macmillan.

McNamara, D. S., Levinstein, I. B., & Boonthum, C. (2004). iSTART: Interactive strategy trainer for active reading and thinking. *Behavioral Research Methods, Instruments, and Computers, 36,* 222-233.

Norman, D. A. (1988). *The psychology of everyday things.* New York: Basic Books.

Project Management Institute. (1996). *A guide to the project management body of knowledge.*Sylva, NC: PMI Publishing.

Resnick, L. (1987). Learning in school and out. *Educational Researcher, 16*(9), 13-20.

Salomon, G., & Perkins, D. N. (1989). Rocky road to transfer. Rethinking mechanisms of a neglected phenomenon. *Educational Psychologist, 24*(2), 113-142.

Schank, R. (1997). *Virtual learning: A revolutionary approach to building a highly skilled workforce.* New York: McGraw Hill.

Schank, R., & Neaman, A. (2001). Motivation and failure in educational simulation design. In K. D. Forbus & P. Feltovich (Eds.), *Smart machines in education: The coming revolution in educational technology* (pp. 37-69). Menlo Park, CA: AAAI Press/MIT Press.

Thinking Tools, Inc. (1996). *Project Challenge* [Computer software].

Whitehead, A. N. (1929). *The aims of education and other essays.* New York: Macmillan.

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