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Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 23(23)

ISSN

1069-7977

Author

Chen, Mei

Publication Date

2001

Peer reviewed

A Potential Limitation of Embedded-Teaching for Formal Learning

Mei Chen (MeiChen@Vax2.Concordia.Ca)

Department of Education, Concordia University
1455 Maisonneuve Boulevard W., Montreal, Canada, H3G 1M8

Abstract

This paper presents a study that investigated the effects of two forms of “embedded teaching” on students’ formal learning of high-school-level algebra. The term “embedded teaching” here refers to the presentation modes in which algebraic concepts, procedures, strategies, and principles are taught within the context of solving specific problems. Two forms of “embedded teaching” (i.e., program control, and learner-control) were compared to a conventional presentation mode in which various forms of algebraic representations were taught as a coherent system before students were introduced to problems. The three instructional modes were implemented in three versions of a computer algebra tutor. Three groups of high-school students ($N=27$) were randomly assigned to one of the three experimental conditions. Pre- and posttests were administered to measure changes in students’ ability to construct different forms of algebraic representations, and their ability to make estimates using these different representations. A multivariate analysis of the pre- and posttest results indicates that overall student performance in all three conditions improved significantly on the two measures used ($F(2, 23) = 46.6, p < 0.01$). However, students in the conventional teaching condition achieved higher posttest scores (group mean = 86, and 93 on the measures of students’ ability to construct algebraic representations and their ability to make estimates, respectively) than students in the two embedded-teaching conditions did (group mean for the two measures = 65 and 57 for the program-controlled condition; and group mean = 67, 59 for learner-controlled condition, respectively). Furthermore, all students in the conventional teaching condition completed the posttest successfully, compared to only 56% of students did so in each of the two embedded teaching conditions. Despite an overall disadvantage, 3 out of 9 students in each of the two embedded-teaching conditions received perfect scores whereas only 1 student in the conventional teaching condition did so. It seems that the conventional presentation mode provided an instructional context that enabled the majority of students to succeed whereas the embedded-teaching modes offered the conditions for certain students to reach their greatest potential but left others far behind.

This paper presents a study that investigated the effects of two presentation modes of “embedded teaching” on students’ formal learning of high-school-level algebra. The term “embedded teaching” can be defined broadly or narrowly, depending on the purpose of the study. In the broad sense, most situated approaches that

emphasize the learning of domain knowledge through expert-like activities and authentic problem solving in rich social, cultural and functional contexts can be thought as “embedded teaching.” For example, the cognitive apprenticeship model (e.g., Collins, Brown, & Norman, 1989), problem-based learning (e.g., Barrows, & Tamblyn, 1980), goal-based scenarios (Collins, 1994; Schank, 1995), and case-based reasoning (Schank, 1995; Kolodner, 1994) can be all considered as “embedded teaching” (Hmelo, & Narayanan 1995). Although they can be characterized in many different ways and a wide array of features can be identified, situated approaches typically (a) focus on ill-defined, authentic problem solving tasks; (b) embed the learning of domain knowledge within a rich social and cultural context; (c) organize learning content and activities around problems or cases. Consequently, concepts, procedures, strategies, and principles are taught within the context of solving specific problems, as opposed to being taught as a coherent symbol system independently. Studies of “embedded teaching” in the past have often focused on the central role that social and cultural context played in learning, thus reflecting research traditions in anthropology and sociology.

The examination of social context is necessary for forming theories and good practice of situated learning. However, the focus of the study presented in this paper was placed on investigating the effects of “embedded teaching” from an instructional design perspective. That is, “embedded teaching” is defined as a narrow term that signifies the instructional techniques by which concepts, procedures, strategies, and principles are taught within a specific problem-solving context. The “embedded teaching” examined in this study represents merely an instructional feature but not the social and cultural characteristics of the situated learning approaches described above. The exclusive focus on the instructional feature of the “embeddedness” of the situated approaches in a study is justified for the following two reasons. First, as human beings and life-long learners, we have to complete a large part of our learning under solitary conditions due to the many practical limitations of getting together and learning with other people. Therefore, it is important to investigate what characteristics of instructional applications can effectively support the development of the individual knowledge in situations where rich social interaction and resources are lacking. Secondly, there is a formal system of symbols, or a structured body of scientific knowledge in a formal knowledge domain such as mathematics, physics, or chemistry. Therefore,

it is necessary to find out whether teaching concepts, procedures, strategies, and principles within the context of solving specific problems is more effective than teaching such knowledge as a coherent, representational system before introducing students to problems, as teachers often do in classroom teaching. The answer to this question is needed in order to design instructional applications, especially computer tutoring systems that effectively foster individual learning in formal knowledge domains.

The Theoretical Background

A primary focus of analysis in cognitive science over the past three decades has been the processing structures of the brain and the symbolic representations of mind (Norman, 1993). Norman further characterizes such a research paradigm as studies of *symbolic representations* (Norman, 1993). Cognitive researchers have shown that structured, principle-based knowledge representation is a function of expertise (Chi, Feltovich, & Glaser, 1981). Therefore, one important goal of instruction is to help students form coherent and structured knowledge representations of the domain being studied (Glaser, 1989). Although they specify neither the elements of which instruction should be composed, nor the sequence in which the different instructional elements should be arranged, some cognitive theories seem to support an instructional approach by which the knowledge elements are structured and coherent, preferably proceeding from a declarative stage to a procedural stage. Kintsch's Construction-Integration (CI) model of discourse comprehension (Kintsch, 1988, 1998) and Anderson's ACT-R theory of cognitive skills represent two central tenets of this research paradigm.

It is apparent that Kintsch's CI model is a cognitive model of discourse comprehension rather than an instructional model, however, this model explains the ways that the mental representations are constructed when learning from text. According to Kintsch, comprehension (i.e., an important form of learning) is an interactive process between the learning materials and the mental models that learners formed on the basis of their prior knowledge. Kintsch suggests that the process of building a coherent mental representation from text depends on the learner's ability to recognize the structure of the text (Kintsch, 1998). Many studies have shown that the structural features of a text (e.g. coherence, the use of the outlines, headings) can help learners identify the structure of the text thus having a significant impact on learners' memory, comprehension, problem solving, and transfer (Kintsch, 1997, in Kintsch 1998; Mayer, 1989; 1997). It is postulated that the structural features of a text may enable learners to form a coherent knowledge representation of the material to be studied, the coherent representation formed, in turn, can guide the processes of selecting, interpreting, organizing, and integrating

the subsequent information to be studied (Mayer, 1989). As a result, the structure feature of text can have impact on learning, especially for learners who lack prior knowledge of the domain (Kintsch, 1997, in Kintsch 1998).

Furthermore, Anderson's ACT-R theory asserts that the acquisition of cognitive skills proceeds from a declarative stage to a procedural stage (Anderson, 1983, 1993). Although both Kintsch and Anderson state that learning should be embedded in the context of meaningful activities, their theories seem to support a pedagogical approach in which learning proceeds from instruction that focus on the structured knowledge representations, to problem-solving activities that emphasize the use of the knowledge learned — a method that is frequently employed by teachers in their classroom teaching.

In contrast to the emphasis on the structured knowledge representations and rigid instructional sequence, situated learning approaches give great importance to the functional use of knowledge thereby the learning materials and activities are organized around problems or cases. The theoretical assumption underlying such approaches can be referred to as situated theory. From the situated perspective, thinking, knowing, and learning are situated within a particular context of intentions, social partners, and tools (Resnick, Levine, & Teasley, 1991; Greeno, 1997). Therefore, internal cognitive activities such as perceiving, understanding, remembering and reasoning are shaped and given significance within the context of activities (Greeno, Collins, & Resnick, 1996). The situative view challenges standard pedagogical practice for paying too little attention to the processes employed by experts to solve complex, realistic problems (Collins et al., 1989; Resnick et al., 1991). Situative theorists criticize learning opportunities provided to students within the scope of typical school activities as mostly involving memorization of factual knowledge and the rote manipulation of symbols and equations. As a result, the kind of knowledge that students acquire in conventional teaching often remains "inert" and can't be applied to other relevant problem-solving situations (Collins et al., 1989; Resnick et al., 1991). It is asserted that "embedded teaching" can facilitate students' development of problem-solving skills and reasoning strategies more effectively. It can also enhance students' conceptual understanding because knowledge is immediately used within a relevant context (Collins et al., 1989). A variety of pedagogical approaches that have been developed emphasize such situative nature of learning and cognition (e.g., Collins et al., 1989; Collins, 1994; CTGV, 1993; Schank, 1995; Kolodner, 1994).

An interesting phenomenon occurred in the debate over symbolic representations versus situated action is that, as Norman points out, the cognitive and situative researchers find different sets of observations to be

interesting and important (Norman, 1993). The same statement may also apply to the argument over conventional school teaching versus situated approaches to learning. Conventional teaching normally focuses on the understanding of symbolic representations and the command of symbolic manipulations whereas situated approaches typically places their focus on the development of students' ability to formulate and solve ill-structured, authentic problems. It is important to keep in mind that, in a knowledge domain such as mathematics, physics, or chemistry, there is a formal system of symbols, or a structured body of scientific knowledge. Therefore, an expert model of knowledge in such domains may consist not only of the strategies that are used in expert-like performance, but also of structured, principle-based knowledge representations of symbolic systems. Correspondingly, students should be encouraged and required to develop the full range of knowledge and skills in the domain, including the ability to understand the symbol systems correctly and manipulate symbols intelligently, the ability to communicate ideas scientifically, the ability to formulate and solve ill-structured problems proficiently and, ultimately, the ability to participate in expert practice in the real world. Therefore, an important question concerning "embedded teaching" is to understand whether it is indeed a more effective technique than the conventional method for teaching formal knowledge. The study presented in the paper attempts to find out whether the embedded teaching as a presentation mode is more effective than conventional teaching for computer-assisted learning of high-school-level algebra.

Methods

This study compared the effects of two presentation modes of "embedded teaching" (i.e., program control, and learner-control) to that of a conventional presentation mode. The three experimental modes were implemented in three versions of a computer tutor that was designed to teach linear functions to grade ninth students. Several features of the computer tutor are important for interpreting the results of the study. First, a cognitive task analysis was conducted to identify the specific elements of knowledge that students need in order to (a) construct multiple forms of algebraic representations (i.e., tables of values, graphs, and equations), and (b) make estimates using such representations (e.g., finding the price of ordering a given number of music CDs based on the relations expressed in a graph of linear functions). Second, the computer tutor employed a basic instructional model that consisted of instruction, demonstration, and practice. In addition, everyday-life scenarios were incorporated into the instruction, demonstration, and practice whenever possible, to help students make connections between their knowledge of the everyday life and the formal algebraic representational system

that they were to learn. Furthermore, various media formats (text, graphics, and animations) were combined to describe some complex concepts, principles, and procedures. Finally, all three versions of the computer tutor utilized the same instructional materials, practice exercises, and media formats, varying only in terms of the "embeddedness" and "learner control". The following is a brief description of these conditions.

The first version of the tutor was designed as a base line for making the comparison (Condition 1). In this version, the computer tutor first presented instruction about the different forms of algebraic representations, explaining what are tables of values, graphs, or equations, and the relationship between the different forms of representations. After the instruction, the computer tutor then provided examples illustrating how to construct each of the different forms of algebraic representations and how to convert these representations from one form to another.

Two forms of "embedded teaching" were examined: a program-control instruction (Condition 2), and learner-control instruction (Condition 3). Both conditions presented the instruction about the different forms of algebraic representations (i.e., what are tables of values, graphs, or equations) within the context of constructing these representations. Because it was the instructional designer of the computer tutor who decided the occasions to introduce the relevant algebraic concepts and principles, students had to follow a fixed sequence imposed by the computer tutor in the program-controlled instruction (Condition 2). The ways that the computer tutor presented various types of algebraic knowledge might not meet the needs of individual students. Therefore, a learner-controlled hypermedia environment (Condition 3) was developed to enable students themselves to determine what, and when to consult a particular type of knowledge. In the learner-controlled hypermedia environment, students engaged directly in problem-solving activities without receiving any prior instruction or demonstration, but they could receive relevant instructions and demonstrations using hyperlinks. It is necessary to indicate that for both Condition 2 and 3, the instruction on algebraic representations was broken into small independent chunks to enable the computer tutor or students to access the relevant knowledge elements in the context of solving specific problems. This might create stronger links between particular knowledge chunks and their applications, but weaker links between the different forms of algebraic representations.

All three conditions included a practice session in which two problems similar to the one used in the demonstration were presented. Students could check their answers, or get the correct answers if they failed to provide the correct answers.

Participants

A public English school in suburban Montreal was

selected as the setting of the experiment. An effort was made to recruit as many participants as possible. As a result, two types of students constituted the sample pool for the experiment: (a) ninth graders in a below-average class, who had just finished learning linear functions one week prior to the pretest, but who had difficulties in math classes; and (b) eighth-graders from two regular math classes who had some knowledge of algebra, but hadn't explicitly learned about linear functions. A pretest was administered to assess the prior knowledge that students had on linear functions. Twenty-seven students who scored under 60 on a scale of 100 were selected to participate in the experiment.

Procedures

The twenty-seven students were divided into three groups based upon their pre-test scores, the grades and gender were balanced in each group. Each group was then randomly assigned to one of the three experimental conditions. Some adjustments were made to accommodate the schedules of the participants. The experiment consisted of two 45-minute learning sessions over a two-week period in the school computer lab. The algebra tutoring program was used as the sole source of instruction and each student learned alone with one version of the computer program. Instruction on the use of a particular version of computer program was presented by the computer at the beginning of the learning sessions. In order to understand types of learning activities in which students engaged, student-computer interaction was recorded during the experiment. To conclude the experiment, a posttest was administered one week after the last learning session. The posttest consisted of (a) two word problems to assess students' algebraic skills and the transfer of such skills, and (b) questions designed to assess students' understanding of algebraic concepts and rules. After students had completed the posttest, they were asked to complete an attitude questionnaire concerning their learning experience with the computer tutor. In addition, three students who received the best posttest scores were interviewed one week after the posttest. They were asked first to orally answer some structured questions in attempt to understand their conceptual knowledge, problem-solving and reasoning strategies, then to translate the algebraic representations from one form to the other in "backward" fashion in order to determine whether student performance was based on the execution of a set of "rote" procedures or on the understanding of the algebraic relations.

Results

The independent variable of this study is the presentation modes: two forms of "embedded teaching" were compared to a conventional teaching mode. The dependent variables include the pretest and posttest measures that reflect the development of students'

algebraic knowledge and skills: (a) the measure on the ability to construct different forms of algebraic representations; and (b) the measure on the ability to make estimates using the relationships expressed by such representations. In addition, several other dependent variables were measured in the posttest but not in the pretest: (c) the measure of the transfer of algebraic knowledge and skills to the solution of a problem in an unfamiliar situation, (d) the measure of understanding of the relationships between different forms of algebraic representations by asking students to construct the various forms of algebraic representations that they had learned in "backward" fashion, and (e) the assessment of students' conceptual understanding of the key algebra concepts and principles by asking them to fill in the answers to some conceptual questions. In addition, students offered their opinions about their learning experience by answering an attitude questionnaire.

Two types of "process" data were also collected to determine how the three different teaching modes affected students' learning of well-structured algebraic tasks: (a) the "dribble" file recordings of the history of student-computer interaction; and (b) the explanations that the selected students provided in response to structured interview questions.

The data-analysis strategy consists of two steps: The first step is comparing the learning outcome measures to determine whether the three different presentation modes have different effects on students' learning outcomes. A multivariate analysis (MANOVA) is employed to analyze the pre- and posttest scores on students' ability to construct different forms of algebraic representations and their ability to make estimates using these representations. This is followed by a qualitative analysis of the learning process measures to understand what may have contributed to the effects observed. The results of this study were reported in details elsewhere (Chen, 2000). This paper only highlights the findings concerning the following questions:

(1) did the three versions of computer tutor improve student performance on well-structured algebraic tasks?

The population mean scores on the measure of students' ability to construct algebraic representations was raised from 22.5 to 72 on a scale of 100. Similarly, the population mean score on the measure of students' ability to make estimates using these representations was raised from 27.1 to 70. Table 1 presents the pre- and post-test scores of these two variables for all three conditions. A multivariate analysis (MANOVA) of the pre- and posttest scores indicates a significant overall effect on the two measures used ($F(2, 23) = 46.6, p < 0.01$). Therefore, it seems that students improved not only their ability to construct algebraic representations, but also their ability to make estimates using the different forms of algebraic representations. However, it

Table 1: The pre- and post-test scores of two measures of students' algebraic abilities (N=27).

Presentation Modes	Constructing Representations		Making Estimates	
	Pre-test	Post-test	Pre-test	Post-test
C1: Conventional	17.9	86.4	25.9	92.6
C2: Program-control	29.8	64.8	33.3	57.4
C3: Learner-control	19.9	67.3	22.2	59.3
<i>M</i>	22.5	72.8	27.1	70
<i>SD</i>	21.4	31.6	33.4	37.2

should be noticed that the standard deviations are considerably large in both the pre- and post-test scores (*SDs* range from 21 to 37), reflecting big individual differences in the participants' initial algebraic abilities, as well as the improvement of such abilities.

(2) *Did "embedded teaching" modes promote better learning outcomes than conventional teaching?*

The MANOVA rejects the hypothesis of no difference between the conventional teaching mode and the program-controlled embedded-teaching mode on students ability to construct algebraic representations and their ability to make estimates using these representations ($F(2, 23) = 3.7, p < 0.05$). Similarly, the hypothesis of no difference between the conventional teaching and the learner-controlled embedded-teaching on the same two dependent variables is rejected ($F(2, 23) = 4.1, p < 0.05$). Therefore, students' learning outcomes in the embedded teaching modes differ significantly from that in the conventional teaching mode. However, contradicting the hypothesis that the embedded teaching is more effective than conventional teaching, this study reveals that students produced better learning outcomes in the conventional teaching mode. Students in conventional teaching mode also showed superiority in terms of their performance on transfer task, and measure on conceptual understanding. It is important to indicate that all students in the conventional teaching condition (including those who had difficulty in the regular math classroom) successfully passed the posttest, whereas only 56% of students passed the post-test in the other two conditions. However, three out of nine students in each of the embedded teaching modes received the perfect scores whereas only one out of nine students in the conventional teaching mode was able to do so. It seems that the conventional teaching provides an instructional context that enables the majority of students to succeed whereas the embedded-teaching conditions offer the conditions for certain students to reach their greatest potential.

(3) *Did "learner-controlled" instruction enhance student learning in a "embedded-teaching" mode?*

No difference is found between the learner-controlled and the program-controlled embedded-teaching modes on the measures of students' ability to construct algebraic representations and their ability to make accurate estimates ($F(2, 23) = 0.46, p > 0.05$). Thus, the level of student control (i.e., being able to determine whether or when to consult the different types of knowledge available) did not influence students' learning outcomes. However, the examination of student-computer interaction reveals what differentiates the high achievers from the low achievers is the navigation strategies that they employed when they were given control over the navigation paths. The high achievers tended to complete each topic that they reviewed whereas the low achievers tended to switch from topic to topic, indicating a lack of mindful engagement.

(4) *What factors may have contributed to different learning outcomes observed?*

The analysis of the interview protocol reveals that the strategies that students employed to solve problems are linked to the types of conceptual understanding that they developed. The interview also indicates that successful task performance is associated with conceptual knowledge that is retrievable and, more importantly, that is coupled with appropriate reasoning strategies.

The examination of student-computer interaction and students' self-reports indicates that students' posttest performance relates to neither the amount of time that students spent on tasks, nor to the amount of instructional materials that they reviewed. However, the navigation strategies that students used in the learner-controlled condition seem to relate to the outcomes of learning. The surfer's strategy (i.e., switching from topic to topic without completion) is directly linked to poor posttest performance. The "learning curve" derived from the dribble file recordings further indicates that (a) significant learning had took place through instruction and demonstration and, (b) a certain amount of learning took place through practice, however, the role of practice was not as predominant as what is usually believed. The questionnaire and interview data indicate that student attitudes toward their learning with the computer tutor program are very positive, irrespective of the teaching conditions. Therefore, the superior posttest performance of the students who learned under the conventional teaching condition seem primarily due to the characteristics of this presentation mode rather than any other factor.

Discussion

This section will discuss briefly two important findings of this study. First, this study shows that students' algebraic knowledge and skills have improved significantly over time. Such a finding suggests that

computer-based learning environments that employ an adequate instructional model, incorporate authentic problem scenarios, provide rich learning activities, and use multimedia to illustrate abstract concepts and procedures, can effectively enhance student learning of algebra. Second, this study indicates that students in the conventional teaching condition generally learned better than students in both program-controlled and learner-controlled embedded teaching conditions did. It is speculated that the conventional teaching condition may enable the majority of students to develop a coherent mental model of the algebraic representations. The coherent knowledge representations that students developed, in turn, may help them better interpret the goals and functions of the subsequent procedures and effectively direct their attention to the key task elements in the step-by-step demonstration performed by the tutor, as well as in their own problem-solving exercises. Furthermore, this study shows that significant learning had taken place through instruction and demonstration prior to the practice of the exercises. The findings of this study seem to support the notion that learning is a sense making process that involves construction and integration of mental representation of the materials being studied, as explained by Kintsch's CI model (Kintsch, 1989, 1998). The findings of this study suggest that instructional designers need to consider the coherence of the symbolic representations when applying "embedded teaching" and "learning by doing" principles to design instruction applications for formal learning. This study also showed that the percentage of students who received perfect posttest scores is higher in the embedded teaching conditions than that in the conventional teaching condition. It seems that the problem-solving context and the higher level of learner control enables some students to reach their greatest potential. Therefore, problem-solving context may indeed more effectively facilitate the development of conceptual understanding, problem-solving skills, and reasoning strategies for some students. In addition, some students are able to focus on their own weaknesses when they have control over what to learn.

Some limitations of this study include the use of a small sample of the participants and a lack of aptitude and learning strategy measures prior to the experiment. A further direction of this research is to incorporate other features of successful "embedded teaching" approaches (e.g., using diversified and contrasting cases to enable students to generate the "rules of thumb") into the computer algebra tutors described here to investigate how these features can support both collaborative inquires and individual learning. The goal is to understand the pedagogical requirements for implementing particular instructional approaches and to explore their limitations and strengths for teaching in a given domain. The findings of such studies will certainly have important implications for the

development of instructional theories and applications. However, precautions are in order when discussing the pedagogical approaches taken by teachers in classroom situations. This is because good teachers adjust their teaching techniques according to their assessment of students and their monitoring of the on-going instructional processes—they rarely use an instructional technique exclusively even though they may firmly believe in a particular pedagogical approach.

Acknowledgements

The research was supported in part by Fonds FCAR. Special thanks to my husband Michel Décary for his contributions and support. The author would also like to thank Dr. Frederiksen, Dr. Breuleux and Dr. Lajoie for their thoughtful comments and suggestions.

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