CAN ALL LEARNERS LEARN WITH COGNITIVE TOOLS? THE CASE OF COMPUTER MODELING TOOLS AND COGNITIVE STYLE

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Abstract

Two research experiments were designed to investigate the effects of field dependence/independence on learners' performance during complex problem solving with a computer modeling tool. Both experiments showed that field dependence/independence is not value-free because field independent learners were consistently associated with better problem-solving performance. The results also showed that well-designed instructional materials do not always lead to effective instruction and successful performance during problem solving with computer modeling tools for all learners.

Introduction

Socrates (469 BC–399 BC), the Classical Greek Athenian philosopher, has become renowned for his contribution to the field of ethics and the Socratic method through his portrayal in Plato's *Dialogues*, not his own books. Socrates not only never wrote a book but he was also well known for his opposition to the technology of writing and books. What Socrates failed to recognize back in his own time was that technologies can be used as tools or partners to learn with, and that their effects depend on how they are used, not on the tools per se (Jonassen & Reeves, 1996; Salomon, 1994). In fact, under optimal conditions humans and tools work together as effective joint cognitive systems to maximize the overall performance of the joint system (Dalal & Kasper, 1994).

The joint human-machine cognitive system may be treated as a single integrated cognitive system. In this context, cognition is viewed not as a property of the one or the other, but, as distributed or "stretched over" the extended cognitive system (Pea, 1993). Therefore, the emphasis is on the performance of the extended cognitive system (person plus environment) rather than on the performance of the individual (Salomon, 1993). In this theoretical framework, computer technologies are not considered as mere conveyors of information, but as cognitive tools. Cognitive tools are computer applications, such as modeling tools, spreadsheets, simulations, micro worlds, semantic networking tools, multimedia, and web tools, that allow learners to express themselves in different symbol systems such as linguistic, numerical, musical, and graphic (Jonassen & Reeves, 1996). Researchers have hypothesized that cognitive style would be a significant contributor to the efficacy of the partnership between humans and cognitive tools, but research findings are still conflicting, mixed, and inconclusive.

According to Jonassen and Reeves (1996), computer-modeling tools are perhaps the most powerful cognitive tools. Recently, many educational systems including the Cyprus educational system showed an interest in integrating computer modeling tools in teaching and learning. It becomes theoretically possible that students whose cognitive styles are incongruent with a learning context enhanced with computer modeling tools may experience high cognitive loads, increased frustration and low efficacy.

Thus, investigations regarding the role of cognitive style on learners' performance during problem-solving with computer-modeling tools become important as they can assist the process of effectively integrating them in teaching and learning for the benefit of all learners. For this purpose, the present study discusses the results of two experiments that were designed to investigate the effects of cognitive style on learners' performance during complex problem solving with a computer modeling tool.

Cognitive Style

Cognitive style describes the way or mode an individual perceives and processes information (Witkin, Moore, Goodenough, & Cox, 1977). There are different cognitive styles mentioned in the literature, but the most popular cognitive style, at least in the Educational Technology literature, is field dependence/ independence (FD/I) (Chinien & Boutin, 1992).

FD/I is a singular dimension that is based on the individual's reliance on the context to extract specific meaning (Witkin et al., 1977). FD/I describes learners along a continuum such that individuals on one end are considered to be Field Dependent (FD) and individuals on the other end Field Independent (FI). Individuals who fall in the middle of the continuum are characterized as Field-Mixed (FM) (Liu & Reed, 1994).

The key difference between FD and FI learners is visual perceptiveness. For example, when FD learners are asked to identify a simple geometric figure that is embedded in a complex figure will take longer to do so than FI learners, or FD learners may not be able to do it at all. The different characteristics of FD and FI learners also appear to have important implications for the instructional design of learning materials (Chinien & Boutin, 1992/1993). FI learners are more successful in isolating target information from a complex whole, and can process information with more accurate performance on visual search tasks. They are also more successful in analyzing ideas into their constituent parts, and reorganizing ideas into new configurations (Davis, 1991). Undoubtedly, "one picture is worth a thousand words" is a core idea of visualization and modeling, because appropriate visualizations can improve learner perception of the objects or the ideas the pictures represent (Kali, 2002). Nevertheless, learning from either textual or visual information is also directly associated with representational preferences and cognitive styles. Chinien and Boutin (1992/1993) also asserted that individual differences during learning with different instructional materials become important for researchers to consider when studying the performance of individuals interacting with technology to accomplish a task.

Therefore, on the basis of the above rationale, the present study sought to examine the extent to which type of instructional materials differentially affects learner achievement during problem solving with a computer-modeling tool, whether problem-solving performance with a computer-modeling tool relates to learner FD/I, and whether type of instructional materials interacts with learner FD/I to differentially affect their achievement during problem solving with a computer-modeling tool.

Context of the Experiments

Model-It, a computer modeling tool and two sets of (different) instructional materials, were used in each experiment. Participants in both experiments were asked to solve a complex problem about immigration policy using Model-It. An assessment rubric with three levels that was developed inductively using the constant comparative method (Strauss & Corbin, 1990) was used to assess participants' problem-solving performance. The Hidden Figures Test (French, Ekstrom, & Price, 1963) was used to classify participants into a field type (FD, FM, or FI).

Model-It

The researchers used Model-It®, a computer modeling tool (Metcalf, Krajcik, & Soloway, 2000), to create the model about immigration dynamics. With Model-It®, the user first creates the entities of the model followed by the variables for each entity. These variables are designated as independent or dependent, depending upon the direction of the relationship between them. Model-It® supports a qualitative, verbal description of relationships between variables. Changes in a relationship may be defined in terms of two orientations (i.e., increases or decreases) and different variations (e.g., about the same, a lot, a little, more and more, less and less). After defining the relationships between the variables, the user may run the model. During run time, a timer counts time steps which may represent whatever time interval the user conceptualizes, while a simulation graph, displayed at the bottom of the computer screen, shows how variables affect each other over a series of time steps. In addition, the value of an independent variable can be manipulated during run time to show how it can affect the value of a dependent variable.

Instructional Task

Participants had to individually explore a computer model using Model-It® for solving a problem about immigration policy regarding a problematic situation at the USA-Mexico border and suggest a solution to the problem. Participants were given four possible policies to explore: (a) Open Border, (b) Closed Border, (c) Job Export, and (d) Immigration. Students were asked to form hypotheses based on these policies and test them using Model-It®. Then, they were asked to propose one of the four policies for the purpose of regulating, as optimally as possible, the situation at the USA-Mexico border.

Assessment Rubric

Participants' problem-solving performance was measured on the basis of an inductively constructed rubric, using the constant comparative analysis method developed by Glaser and Strauss (1967; Strauss & Corbin, 1990). The problem-solving scoring rubric, as shown in Table 1, was developed with three mutually exclusive levels with scores ranging from 1 (low performance) to 3 (high performance). The researcher and a rater specifically trained to use the rubric, independently evaluated students' problem-solving performance using the rubric in Table 1. Pearson's correlation between the two raters for Experiment 1 was found to be $r = .87$, and for Experiment 2, $r = .84$. The raters and the researcher discussed the observed disagreements and easily resolved the differences.

Table 1: Problem-solving Performance Scoring Rubric

3
a. Reaches a decision by correctly interpreting the simulated outcomes of the model.
b. Examines the consequences of all policies and identifies pros and cons of each policy.
c. Considers possible long-term effects of the full impact of each policy and recognizes that ramifying may take a long time.
2
a. Reaches a decision by correctly interpreting the simulated outcomes of the model.
b. Examines the consequences of all policies and identifies pros and cons of each policy.
c. Does not consider possible long-term effects of the full impact of each policy and does not recognize that ramifying may take a long time.
1
a. Reaches a decision, which is not based on accurate interpretations of the simulated outcomes of the model.
b. Does not consider pros and cons of each policy and shows biased thinking.
c. Does not consider possible long-term effects of the full impact of each policy and does not recognize that ramifying may take a long time.

Hidden Figures Test

The Hidden Figures Test (HFT; French, Ekstrom, & Price, 1963) has 32 questions and it is group administered. It consists of two parts and 12 minutes are allowed for answering each part. One point is assigned for each correct answer to a test item, so the total test scores range from 0–32.

Experiment 1

Participants: 65 first-year undergraduates from a teacher education department volunteered to participate in the study. Initially, participants were screened using the HFT and based on their HFT scores, they were classified into 22 FD, 22 FM, and 21 FI learners. Participants from each group of FD, FM, and FI learners were randomly assigned into two groups, namely, Text-Only (T-O) and Text-Visual (T-V).

Instructional materials. Two sets of instructional materials, the Text-Only (T-O) set and the Text-and-Visual (T-V) set were used in Experiment 1. The sets differed in how the structure of the model was explained. In the T-O set the model was described in textual form. In the T-V set the model was decomposed in four smaller diagrams and each one of the diagrams was presented along with its description in narrative form. Diagrams and texts appeared in alternate format. Participants in the T-O group received the T-O set and participants in the T-V group received the T-V set of materials.

Research procedure. The research session lasted two hours. The researchers demonstrated Model-It for 20 minutes and showed how to run and test a model using the software. Then each participant received the instructional materials (T-O or T-V). Every 15 minutes, the participants were prompted to write on the last page of their materials the current time, and next to it the word Materials or Model-it.

Research questions.

- Do text-only (T-O) and text-and-visual (T-V) instructional materials differentially affect learner achievement during problem solving with Model-It?

- Does problem-solving performance with Model-It relate to learner FD/I?
- Do T-O and T-V instructional materials interact with learner FD/I to differentially affect their achievement during problem solving with Model-It?

Results. A 3 (FD, FM, FI) X 2 (T-O, T-V) multivariate analysis of variance was conducted to detect differences in time spent to study the materials, to work with Model-It, and total time on task. No significant differences were identified between the T-O and T-V groups or between the FD, FM, and FI groups. Thus, no differences in student problem-solving performance could be attributed to differences in how much time was spent on task.

A 3 (FD, FM, FI) x 2 (T-O, T-V) ANOVA was performed to identify any differences related to the instructional materials or the classifying variable, and their possible interaction effect. The results indicated that students in the T-V group outperformed those in the T-O group, F (1, 59) = 5.253, p =. 025; that performance was significantly related to FD/I, F (2, 59) = 5.658, p =. 006; and that there was also a significant interaction effect between the instructional materials groups and FD/I, F (2, 59) = 3.938, p =. 025. In essence, all significant differences can be attributed to the significant interaction effect between materials and FD/I.

The magnitude of the superior performance of FI learners in the T-V group in comparison with FI learners in the T-O group was estimated using the effect size, which was found to be +1.8. This indicates that the average FI learner in the T-V group was at 1.8 standard deviations above the mean of FI learners in the T-O group. Similarly, FI learners in the T-V group had a statistically significant higher performance than FD learners in the same group. The advantage for FI learners in the T-V group over the mean performance of FD learners in the same group was associated with a large effect size of +1.38.

Discussion. The results strongly suggest that the effectiveness of the instructional materials depended on learners' FD/I. The results do not provide support to theoretical positions regarding the potential of visual information (i.e., easier to retrieve and remember) in promoting learning, such as Dual Coding Theory (Paivio, 1986). What caused the problem for the FD learners? Was it too much cognitive load for them? Was the instructional design of materials problematic for FD learners? Did FD participants need more time with Model-It before the experiment?

Experiment 2

Based on the results of Experiment 1, in Experiment 2 we sought to improve the instructional design of the materials in order to manage this way the cognitive load that FD learners might have potentially experienced with the materials in Experiment 1. Specifically, we dealt with split attention, because the process of problem solving with a computer modeling tool requires that learners mentally integrate several sources of information from visuospatial materials, so as to understand the entire model. Split attention occurs when learners must integrate information sources separated in time (i.e., temporal split attention) or space (i.e., spatial split attention) (Ayres & Sweller, 2005) and all sources are important to be considered. As a consequence, instructional split-attention leads to an increase in extraneous cognitive load, which negatively affects task performance (Ayres & Sweller, 2005).

Participants. One hundred and one sophomores from a teacher education department participated in the study. Based on their HFT scores participants were classified into 35 FD, 36 FM, 30 FI learners. Participants from each group of FD, FM, and FI learners were randomly assigned into two groups, namely, Split-format condition (49 participants), and Integrated-format condition (52 participants).

Instructional materials. Two sets of materials were used, namely the split-format and integrated format materials. In the split-format condition, the model was first presented as a static diagram followed by its textual description below in a spatially-split format. Thus, the sources of information (i.e., diagram and text) were physically, but not temporally separated. The textual description identified all independent and dependent variables in the model and explained all cause-and-effect relationships between them. In the integrated-format condition, the model was presented in an integrated format with its textual description. In essence, in these materials, all textual explanations were physically embedded into the diagram. Participants in the Split-format condition received the split-format materials, and participants in the Integrated-format condition received the integrated-format materials.

Research procedure. Each student participated in two 90-minute research sessions. In the first research session there was a 30-minute presentation from the researcher about complex-systems concepts (entities, variables, relationships, dependent and independent variables, controlling variables, testing hypotheses), and a 60-min practice with Model-It (participants created their own models about the growth of plants and economic growth, they controlled variables and tested several hypotheses).

During the second research session participants worked with Model-It and a set of instructional materials to solve a problem about immigration policy. Every 15 minutes a pop-up dialogue box prompted the participants to subjectively rate the cognitive load that they were experiencing. According to Paas, van Merrienboer, and Adam (1994), cognitive load is measured in terms of the mental effort a learner perceives at an instance in time, as he/she is still learning. The following question was specifically asked: ‘‘How much mental effort are you putting into solving the task?” The participants were asked to record their responses on a 7-point Likert scale ranging from very-very low effort (1) to very-very high effort (7).

Research hypotheses. The research hypotheses for Experiment 2 were formulated as follows:

- Split-format materials will lead to higher cognitive load, more time spent on the problem-solving task, and lower problem-solving performance than integrated-format materials.

- There will be no difference in cognitive load and time spent on task among FD, FM, and FI learners because all students in this study were novices in the subject matter of complex-systems concepts and dynamic systems modeling software.

- FI learners' problem-solving performance will be significantly better than that of FD and FM learners.

- There will be no interaction between type of instructional materials and FD/I in terms of cognitive load and time spent on task.

- There will be a significant interaction effect between type of instructional materials and FD/I in support of a significantly higher performance for FI learners in the integrated text and diagram condition.

Results. The results indicate that students in the split-format condition reported a significantly higher mean cognitive load, $\underline{F}(1, 95) = 5.66$, $\underline{p} = .02$, partial $\eta^2 = .12$, and that they also spent more time on the problem-solving task, $\underline{F}(1, 95) = 17.20$, $\underline{p} = .00$, partial $\eta^2 = .15$, than students assigned to the integrated-format condition.

In contrast, students assigned to the split-format condition had significantly lower problem-solving performance, $\underline{F}(1, 95) = 5.66$, $\underline{p} = .00$, partial $\eta^2 = .06$, than students in the integrated-format condition.

There was a significant interaction effect between type of materials and FD/I in terms of problem-solving performance. Post hoc comparisons using the Scheffé method (Marascuilo & Levin, 1970) indicated that FI learners in the integrated-condition outperformed both FD and FM learners, but there was no significant difference in problem-solving performance between FD and FM learners.

Effect size statistics using Cohen's *d* indicated that the average problem-solving performance of FI learners in the integrated-format condition was 2.49 *SD* above the mean problem-solving performance of FI learners in the split-format condition. Similarly, the magnitude of the superior problem-solving performance of FI learners in the integrated-format condition, as compared with FD learners in the same condition was also very high (Cohen's *d* = 2.69). The advantage of FI learners' performance in the integrated-format condition over the mean performance of FM learners in the same condition was computed with an effect size of 2.42.

Discussion

These results clearly confirm all hypotheses and indicate that the design of the instructional materials can either lessen or increase cognitive load and time spent on task. Thus, not only can we speak of instructionally effective integrated materials, but also of instructionally more efficient materials (Paas & van Merriënboer, 1993). In essence, the results corroborate the large body of research on the split-attention effect. The contribution of this study to the existing body of research on split attention lies in the significant interaction between FD/I and experimental condition in terms of students' problem-solving performance. In other words, well-designed instructional materials do not always lead to effective instruction and successful performance for all learners.

General Discussion and Concluding Remarks

Both experiments indicate that the FD/I theory is not value-free because FI learners are consistently associated with better problem-solving performance. Accommodating learners' cognitive style in instruction though may not only have cognitive benefits but also cognitive costs because no matter how you try to make an instructional treatment better for someone, you will make it worse for someone else, but also because "no matter how you try to make an instructional treatment better in regard to one outcome, you will make it worse for some other outcomes" (Messick, 1976, p. 266).

Ideally students should be taught in ways that are sensitive to individual differences but this is difficult in a classroom with a large body of students and a sole educator. Technology with the affordance for adaptation of instruction may be a solution. Future work on the design of adaptive learning systems with shared instructional control to satisfy the needs of all learners may be worthy of systematic pursue.

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