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# Instructional design effects and computer modeling software: cognitive style and the split-attention effect

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## Abstract

One hundred and one primary student teachers were initially categorized into field-dependent, field-mixed, and field-independent learners based on their performance on the Hidden Figures Test, and were then randomly assigned to two experimental conditions. One group received a static diagram and a textual description in a split format, and the second group received the same static diagram and textual description in an integrated format. MANOVA revealed that the split-format materials contributed to higher cognitive load, higher time spent on task, and lower problem-solving performance than the integrated-format materials. There was also an interaction effect, only in terms of students' problem-solving performance, between field dependence-independence and instructional materials, indicating that the facilitating effect of the integrated-format materials was restricted to the field-independent learners. Conclusions are drawn in terms of how the well-documented split-attention effect manifests itself irrespective of students' field dependence-independence.

**Keywords:** cognitive load, field dependence-independence, modeling software, split-attention effect

## Introduction

Computer modeling tools are powerful tools for building systems with interactive and interdependent components (Jonassen, 2004). They have been quite popular in teaching for a number of years, but there is not yet a great deal of empirical research examining how to design effective instructional materials to support learners' performance in a complex system with these tools (Ayersman, 1995). In addition, the use of computer modeling tools as instructional tools and their relationship to research on cognitive styles is largely unexplored, although it appears to be an area holding great promise (Dillon & Gabbard, 1998; Penner, 2000/2001; Sabelli, 2006). Ideally, this effort should involve research investigations of how instructional materials can be designed, so that learners with different cognitive styles, or abilities, can equally benefit from computer modeling tools.

Students with different cognitive styles, or abilities, may either profit, or be impeded, by the nature of the computer tool used (Ayersman, 1995; Messick, 1976; Salomon, 1994). In related previous research, the results indicated that learners receiving the combination of textual and visual explanations outperformed those who received textual explanations only, that performance was significantly related to field dependence–independence (FD/I), and that there was a significant interaction effect between FD/I and type of instructional materials. Essentially, field-independent learners (FI) receiving the combined textual and visual explanations, although in a split-format presentation, exhibited better problem-solving performance with a computer modeling tool than field-independent (FI) learners in the textual explanations only group and field-dependent (FD) as well as field-mixed learners (FM) in both groups.

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Researchers (e.g., Feltovich, Coulson, & Spiro, 2001; Narayanan & Hegarty, 1998) have also shown that learning about complex systems imposes high load on learners' cognitive resources, because of the highly interconnected nature of the elements, which collectively constitute the system and define its functions. In other words, the intrinsic cognitive load imposed by the combination of the number of elements in complex systems and the interactivity of those elements is so high, so that the instruction chosen must optimize germane load and minimize extraneous load (Sweller, 1994; Sweller, van Merriënboer & Paas, 1998). Thus, it is imperative that researchers conduct sound research into the pedagogy of instruction on complex systems, with special regard for the role and limitations of working memory, so as to appropriately determine the design of their instructional materials, and encourage effective student engagement with the learning activities, and effective management of student cognitive load. A useful starting point for investigating the relationship between cognitive load theory and FD/I, within the context of complex problem-solving with a computer modeling tool is to consider ways of how to deal 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 is the phenomenon that hampers intellectual performance when learners must integrate information sources separated in time (i.e., temporal split attention) or space (i.e., spatial split attention). As a consequence, instructional split-attention leads to an increase in extraneous cognitive load which will negatively affect task performance (Ayres & Sweller, 2005).

Along this line of reasoning, the authors in this study sought to examine the following research hypotheses.

1. Diagram and text in split format will lead to higher cognitive load, more time spent on the problem-solving task, and lower problem-solving performance than an integrated text and diagram condition.
2. 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.
3. FI learners' problem-solving performance will be significantly better than that of FD and FM learners, and FM learners' problem-solving performance will be significantly better than that of FD learners, because of their different disembedding abilities.
4. There will be no interaction between type of instructional materials and FD/I in terms of cognitive load and time spent on task.
5. There will be a significant interaction effect between type of instructional materials and FD/I in support of a significantly higher performance for learners with better disembedding abilities in the integrated text and diagram condition.

## Methodology

### *Participants*

In total, 101 sophomores participated in the study (mean age = 19.22 years, *SD* = .63 years). None of the participants reported any familiarity with complex systems and computer modeling tools.

### *Research design and procedures*

Based on the Hidden Figures Test (French, Ekstrom & Price, 1963) students who scored 10 or lower were classified as FD, those who scored from 11 to 17 were classified as FM, and those who scored from 18 to 28 as FI. Students from each FD/I category were randomly assigned to either the separated text and diagram condition (i.e., split-format condition) or the integrated text and diagram condition (i.e., integrated-format condition).

Each group was involved in two 90-minute phases of research procedures. During the first phase, there was a 30-minute lecture about complex-systems concepts followed by a 60-minute practice session using Model-It®, a computer-modeling tool. During the second phase, students were instructed to use Model-It® together with a set of instructional materials to solve a problem about immigration policy. Every 15 minutes, a computer pop-up dialogue box prompted the participants to subjectively rate the cognitive load that they were experiencing. 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).

### *Instructional materials*

Two different sets of materials were used. Both sets began by describing a problematic situation at the Mexico-United States border regarding the illegal immigration of Mexicans to the United States caused by high unemployment in Mexico. In addition to the model, learners also received information regarding four possible immigration policies, namely: (a) Open Border, (b) Closed Border, (c) Job Export, and (d) Immigration. Both sets of materials instructed the students to test each immigration policy and decide which one should be adopted to successfully deal with the situation.

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. In the integrated-format condition all textual explanations were physically embedded into the diagram.

### *Description of Model-It®*

In Model-It® (Metcalf, Krajcik & Soloway, 2000) the user first creates the entities of the model (i.e., Mexico and United States). For each entity, several variables such as population, labor force, immigration rate, and jobs are associated. 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). During run time, the value of an independent variable can be manipulated to show how it affects the value of a dependent variable.

## Instruments

### *Hidden Figures Test*

The Hidden Figures Test was used to determine learner FD/I (French, Ekstrom & Price, 1963). It consists of 32 questions and for each question the test presents five simple figures and requires learners to identify which of these simple figures is embedded in a complex visual configuration. FI learners are more successful in identifying the simple figure in the more complex one than FD and FM learners.

### *Problem-solving performance*

A problem-solving scoring rubric was developed inductively using the constant comparative analysis method developed by Glaser and Strauss (1967). The rubric had three mutually exclusive levels with scores ranging from 1 (low performance) to 3 (high performance). The researcher and a rater independently evaluated students' problem-solving performance and Pearson's correlation between the two raters was satisfactory ($r$ = .84). All observed disagreements were easily resolved after discussion.

## Results

Table 1 shows descriptive statistics. The results of a 3 (FD/I) X 2 (materials) MANOVA indicated that the interaction effects between materials and students' FD/I in terms of students' cognitive load and time spent on task were not significant, but the interaction effect between materials and FD/I in terms of students' problem-solving performance was significant, $F(2, 95) = 8.73$, $p = .00$, partial $\eta^2 = .16$ (see Figure 1).

**Table 1. Descriptive statistics of learners' perceived cognitive load, time spent on task, and problem-solving performance for the two conditions and FD/I**

| | FD/I | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FD | | | FM | | | FI | | | Total | | |
| Condition | *M* | *sd* | *n* | *m* | *sd* | *n* | *m* | *sd* | *n* | *m* | *sd* | *n* |
| | **Perceived cognitive load** | | | | | | | | | | | |
| **Separated** | 4.84 | .86 | 15 | 4.50 | .76 | 19 | 4.63 | .69 | 15 | 4.64 | .77 | 49 |
| **Integrated** | 4.06 | .51 | 20 | 4.24 | .88 | 17 | 3.93 | 1.12 | 15 | 4.08 | .84 | 52 |
| **Total** | 4.40 | .78 | 35 | 4.38 | .82 | 36 | 4.28 | .98 | 30 | 4.36 | .85 | 101 |
| | **Time on task** | | | | | | | | | | | |
| **Separated** | 59.00 | 21.56 | 15 | 58.42 | 19.93 | 19 | 63.00 | 16.23 | 15 | 60.00 | 19.12 | 49 |
| **Integrated** | 48.75 | 10.75 | 20 | 47.65 | 5.89 | 17 | 47.00 | 7.75 | 15 | 47.88 | 8.42 | 52 |
| **Total** | 53.14 | 16.81 | 35 | 53.33 | 15.81 | 36 | 55.00 | 14.91 | 30 | 53.76 | 15.77 | 101 |
| | **Problem-solving performance** | | | | | | | | | | | |
| **Separated** | 1.60 | .51 | 15 | 1.79 | .54 | 19 | 2.00 | .38 | 15 | 1.80 | .50 | 49 |
| **Integrated** | 1.55 | .60 | 20 | 1.71 | .59 | 17 | 2.87 | .35 | 15 | 1.98 | .78 | 52 |
| **Total** | 1.57 | .56 | 35 | 1.75 | .55 | 36 | 2.43 | .57 | 30 | 1.89 | .66 | 101 |

The results indicated that students in the split-format condition reported a significantly higher mean cognitive load, $F(1, 95) = 5.66$, $p = .02$, partial $\eta^2 = .12$, and that they also spent more time on the problem-solving task, $F(1, 95) = 17.20$, $p = .00$, 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, $F(1, 95) = 5.66$, $p = .00$, partial $\eta^2 = .06$, than students in the integrated-format condition. The main effect related to type of materials in terms of perceived cognitive load and time spent on task was significant, while the corresponding interaction effects between type of materials and FD/I were not. In essence, all students in the split-format condition experienced significantly higher cognitive load and spent significantly more time on task than students in the integrated-format condition.

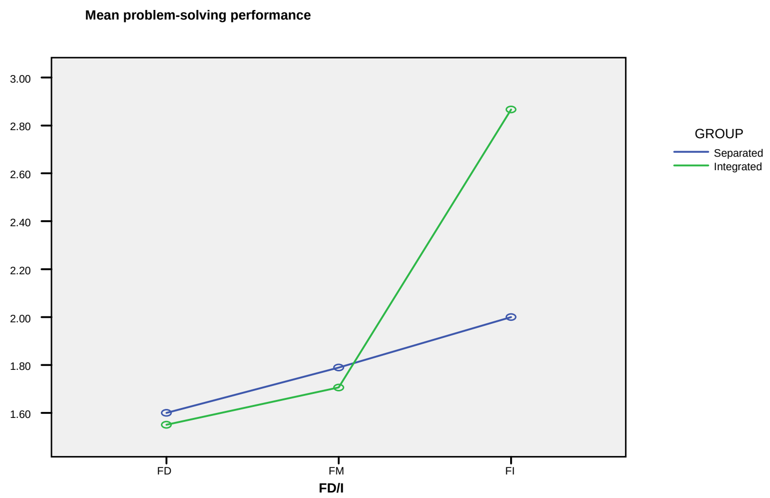


**Figure 1. Interaction effect between condition and FD/I**

The main effect related to FD/I in terms of problem-solving performance was also significant, but, in addition, 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 outperformed both FD and FM learners, but there was no significant difference in problem-solving performance between FD and FM learners. These results coupled with the significant interaction effect between type of materials and FD/I in terms of problem-solving performance clearly indicate that the existing differences between FI learners and the other two groups of learners are attributable to the nature of the significant interaction effect presented in Figure 1. As demonstrated there, the interaction between type of instructional material and FD/I relates to the significantly higher performance of FI learners in the integrated-format condition as compared to both FD and FM learners in the same condition, or as compared to the performance of all learners including the FI learners in the split-format condition.

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

The results showed a statistically significant interaction effect between type of instructional materials and FD/I in terms of students' problem-solving performance, while the interaction effects between type of instructional materials (i.e., split format and integrated format) and students' FD/I in terms of students' cognitive load and time spent on task were not. There was also a significant main effect related to the type of materials used for each of the three dependent variables. The main effect related to FD/I in terms of problem-solving performance was also significant, but this effect should be cautiously examined taking into consideration the significant interaction effect between type of materials (i.e., their split or integrated format) and FD/I in terms of problem-solving performance. More specifically, FI learners outperformed both FD and FM learners, but there was no significant difference in problem-solving performance between FD and FM learners. These results coupled with the significant interaction effect between type of materials and FD/I in terms of problem-solving performance clearly indicate that the existing differences between FI learners and the other two groups of learners relate to the significantly higher performance of FI learners in the integrated-format condition, as compared to both FD and FM learners in the same condition, or as compared to the performance of all learners, including the FI learners, in the split-format condition.

These results clearly confirm hypotheses 1, 2, and 4, and indicate that the design of the instructional materials can either lessen or increase cognitive load and the time spent on task, and, consequently, affect the cognitive resources available for activities conducive to problem solving. Specifically, the results showed that both cognitive load and time spent on task were significantly higher for the spatially split condition, while problem–solving performance was significantly better for the integrated condition. In other words, not only can we speak of instructionally effective integrated materials, but also of instructionally more efficient materials.

Particularly relevant here is the split-attention effect. For example, in both conditions, the two sources of information in the instructional materials (i.e., split-format and integrated-format) needed to be processed simultaneously in order to derive meaning from the materials. These two sources of information were spatially integrated in one condition and spatially separated in the other. Thus, in the latter condition there was a need to mentally integrate the separate sources of information that were unintelligible in isolation, while, in the former, mental integration was not needed. In the integrated condition, the two separate sources of information were spatially integrated obviating the need to search for relations between them. It seems that the significantly higher total cognitive load and the significantly higher time spent on task associated with the split-format condition were attributed to this split–attention affect which imposed an unnecessary extraneous cognitive load that interfered with problem solving.

The results of the study also indicate that there were no significant differences among the three subgroups of students (i.e. FI, FM, FD), and no significant interaction effects between the type of materials and students' FD/I in terms of cognitive load and time spent on task. Thus, the main effect related to FD/I was not significant for cognitive load or time spent on task signifying the consistent difficulty of the task across all learners. In other words, there was no evidence of the expertise reversal effect which was not to be expected since all students in this study were novices in the subject matter of complex-systems concepts and dynamic systems modeling software. The three subgroups of students were different only in terms of FD/I, but none of them had any familiarity, or prior knowledge, relating to complex-systems concepts and dynamic modeling software. Learning about complex systems using dynamic modeling software imposes high cognitive load because of the large number of elements in the complex systems and their high interactivity. The higher cognitive load is usually accompanied by higher time spent on task, and reduced mental resources for schema construction or automation of schemata. The results obtained here indicate that the high cognitive load imposed by a complex system with a computer modeling tool transcended any differences in terms of FD/I. Thus, there were no significant differences between the three subgroups of learners (i.e., FI, FM, and FD), and no interaction effects between the type of materials and FD/I in terms of cognitive load and time spent on task.

The main effect related to FD/I for learners' problem-solving performance was significant and there was also a significant interaction effect between FD/I and experimental condition (i.e., type of instructional materials). Further analyses indicated that these differences were directly related to the superior performance of FI learners in the integrated condition who outperformed all other learners from both experimental conditions. In fact, FI learners from both conditions exhibited better problem-solving performance than FD and FM learners, while there was no significant difference in problem-solving performance between FD and FM learners. In both conditions, FI learners tended to perform better than the other two types of learners, and FM learners tended to perform better than FD learners. Thus, hypotheses 3 and 5 were only partially supported, indicating that FD/I can have a facilitating effect in problem-solving performance in favor of FI learners (and/or FM in comparison to only FD learners) under instructional conditions that do not impose high extraneous cognitive load, restricting the available cognitive resources for processing the necessary information needed for the construction of knowledge schemata.

In essence, the results obtained in the research reported on in this article 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. The interaction clearly indicated that the facilitating effect of the integrated condition was restricted to FI learners despite the fact that no significant differences in cognitive load and time spent on task were found among FD, FM, and FI learners. In other words, well-designed instructional materials do not always lead to effective instruction and successful performance. As the results of this study showed, FD, FM, and FI learners were all presented with well-designed instructional materials (i.e., the integrated text and diagram materials), but the cognitive characteristics of FD and FM learners, i.e., their individual information-processing and or limited disembedding capabilities, did not enable them to successfully learn with these materials during problem solving with the computer modeling tool. Thus, based on the results of this study, any instructional design that results in lowering the total cognitive load, due to the effective design of the instructional materials, may be further improved by tailoring or adapting them to the specific cognitive characteristics of the learners.

Finally, the interaction effect between FD/I and instructional materials conveys some kind of cognitive coupling between learner characteristics and materials (Fitter & Sime, 1980). Proper cognitive coupling occurs when the interaction between learners and instructional environments result in successful problem-solving performance (Moffat, Hampson & Hatzipantelis, 1998). Thus, the field of instructional design should consider the learner and the instructional environment as a joint cognitive system and should aim at maximizing the overall performance of this system as a whole (Dalal & Kasper, 1994).

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