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Field dependence–independence and instructional-design effects on learners' performance with a computer-modeling tool

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ABSTRACT

The study investigated the extent to which two types of instructional materials and learner field dependence–independence affected learners' cognitive load, time spent on task, and problem-solving performance in a complex system with a computer-modeling tool. 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. Implications of the effects of reduced extraneous cognitive load on students' problem-solving performance are also discussed.

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1. Introduction

Complex systems are systems composed of interconnected parts that as a whole exhibit or behave in a particular way, which is not obvious from the properties of the individual parts (Rocha, 1999). The development of skills for understanding complex systems is essential for knowing about and managing a wide range of environmental and social phenomena that greatly affect our everyday lives. Jacobson and Wilensky (2006) argued that the infusion of complex-systems concepts into the curricular content of school subjects is important and can potentially form the basis of a new type of scientific literacy, with important implications for developing curricula in the physical and social sciences from the elementary to the college level.

Despite this, exploration of the cognitive and learning issues associated with complex systems is still in its infancy (Hmelo-Silver & Azevedo, 2006). One major problem with understanding complex systems is that the approaches that are normally used do not allow the study of complex systems as interconnected com-

ponents, and thus lead to compartmentalization and fragmentation (Merrill, 2002; van Merriënboer & Kirschner, 2007; van Merriënboer, 2007; van Merriënboer & Kirschner, 2001). The use of computer-modeling tools is proposed as an instructional strategy to cope with the problems of compartmentalization and fragmentation, because they allow the study of complex systems as interconnected components, whose behavior emerges from the interconnectedness of their components, and thus counteract fragmentation (Metcalf, Krajcik, & Soloway, 2000; Penner, 2000/2001; Richmond, 2001; Sabelli, 2006; Stratford, Krajcik, & Soloway, 1998; van Merriënboer & Kirschner, 2007; White, 1993).

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; Moreno & Mayer, 1999; Thompson, 2007). 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

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materials can be designed, so that learners with different cognitive styles, or abilities, can equally benefit from computer-modeling tools. Undoubtedly, research in this area would be especially useful in guiding the integration of computer-modeling tools in teaching and learning for the benefit of all students.

For example, 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 authors of the present study examined the effects of supporting students' performance in a complex system with a computer-modeling tool, using textual explanations for one group of students, and textual and visual explanations for another group (Angeli & Valanides, 2004). In the textual and visual explanations group, the model was decomposed into four smaller diagrams of the same form, which were presented gradually along with their corresponding descriptions in alternate form (i.e., diagram, text, diagram, text, etc.). In the textual explanations group, the model was described only in narrative (i.e., textual) form. 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, and that there was a significant interaction effect between field dependence–independence and type of instructional materials. Essentially, field-independent learners 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 learners in the textual explanations only group and field dependent as well as field-mixed learners in both groups. It is however necessary to remember that, in the split-format condition, the diagram was decomposed into smaller diagrams, which were then gradually presented along with their corresponding texts in alternate form.

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; van Merriënboer, Kirschner, & Kester, 2003). 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. Effective management of student cognitive load is achieved with efforts that are systematically directed toward reducing the extraneous cognitive load, so that the total cognitive load, including the intrinsic load and the required germane load, does not exceed the limitations of working memory.

Based on the above rationale, the authors of this paper expand on their previous work by considering (1) the extent to which the type of instructional materials affects learners' self-reported cognitive load, time spent on task, and problem-solving performance in a complex system with a computer-modeling tool and (2) whether these variables depend upon learners' field dependence–independence. To this end, the present study attempted to examine how text and diagrams in integrated format and text and diagrams in split format combined with learners' field dependence–independence affected learners' cognitive load, time spent on task, and problem-solving performance, and whether there was any signifi-

cant interaction effect between the type of instructional materials and learners' field dependence–independence in terms of any of the three dependent variables.

1.1. Field dependence–independence and cognitive load theory

Field dependence–independence (FD/I) represents differences about how learners perceive, organize, and process information (Morgan, 1997; Slavin, 2000; Sternberg & Williams, 2002). These differences are often ascribed to the effects of the instructional context or of the prevailing field that is related to the complexity of the problem-solving task and the instructional materials supplementing teaching (Morgan; Morgan, 1997; Reiff, 1996; Witkin, Moore, Goodenough, & Cox, 1977). FD/I describes learners along a continuum, such that learners who fall in the two extremes of the continuum are characterized as field dependent (FD) and field independent (FI), and learners in the middle are characterized as field mixed (FM) (Liu & Reed, 1994).

According to Jonassen and Grabowski (1993), the prevailing context differentially influences FD, FM, and FI learners, and thus fundamental differences exist amongst them. FI learners, that is, those learners who can disentangle a field into its component parts, are not influenced by the existing structure of a field, and thus can make choices independent of the perceptual field, are more successful in isolating important information from a complex whole, perform better on visual search tasks, and are more successful in analyzing ideas into their constituent parts and reorganizing them into new configurations (Davis, 1991; Goodenough & Karp, 1961; Snowman & Biehler, 2003). FD learners, who are less analytical and less attentive to detail, process information more globally, tend to see the perceptual field as a whole, and do not perform very well in a problem-solving space requiring the extraction of relevant information from a complex whole (Lambert, 1981; Tannenbaum, 1982).

Some researchers explain these differences as differences in cognitive style (e.g., Morgan, 1997), and others as differences in cognitive ability (e.g., Jonassen & Grabowski, 1993). For example, Rittschof (in press), Riding (1997), and Sternberg and Williams (2002) support the view that characterizing FD/I as a cognitive style is incorrect, because the two tests that are widely used for measuring FD/I, namely, the Group Embedded Figures Test (Witkin, Oltman, Raskin, & Karp, 1971) and the Hidden Figures Test (French, Ekstrom, & Price, 1963), measure FD/I as a cognitive ability and a value-directional construct (i.e., FI is superior to FD). A cognitive style, conversely, means that the approaches are different, but not necessarily that one is superior to the other (Jonassen & Grabowski, 1993).

Other research findings (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Miyake, Witzki, & Emerson, 2001) also converge to the view that FD/I represents differences in cognitive abilities and provide evidence indicating that these abilities are directly related to components in Baddeley's (1999) working memory model, such as, the visuospatial sketchpad subsystem and the central executive system. Indicatively, the ability to see embedded shapes is a visuospatial function, and the ability to recognize which simpler figure is hidden in a more complex one involves the use of central executive functions, such as monitoring. According to Rittschof (in press), cognitive load theory's emphasis on working-memory capacity represents a potential connection between the theory and FD/I studies, particularly those involving visuospatial materials. Another potential connection between cognitive load theory and FD/I studies is the very fact that they are both related with instructional materials; that is, cognitive load theory is directly related with the presentation of instructional materials (Sweller, van Merriënboer, & Paas, 1998), whereas FD/I studies are related with the ways learners abstract and process information from instruc-

tional materials (Angeli & Valanides, 2004; Reiff, 1996; Snowman & Biehler, 2003).

Cognitive theorists unanimously agree that the capacity of working memory is severely limited in the amount of information that can be processed. This means that the amount of information presented to learners (i.e., the number of elements in a task), the difficulty of the material (i.e., the interactivity of the elements), and the format in which the material is presented (i.e., the instruction) are factors that may inhibit or assist learners in cognitively processing the information presented (Baddeley, 1986, 1999; Chandler & Sweller, 1991; Mayer, 2001). Cognitive load is a term that refers to the load imposed on working memory during instruction aimed at teaching learners problem-solving skills, or thinking and reasoning skills (Sweller, 1994). "Cognitive load theory has been designed to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance" (Sweller et al., 1998, p. 251). Succinctly, there are three types of cognitive load that together add up to the total cognitive load, namely, intrinsic, extraneous, and germane (Kirschner, 2002; Paas, Renkl, & Sweller, 2003; Paas, Renkl, & Sweller, 2004; Sweller et al., 1998). Intrinsic cognitive load is associated with task difficulty, which is defined as the number of elements and the element interactivity in the task (Kirschner, 2002). Extraneous cognitive load is the working memory load experienced by learners as they interact with instructional materials that does not directly lead to successful intellectual performance (e.g., searching for relevant information, weak-method problem solving, integrating different sources of information) (Chandler & Sweller, 1991). Germane cognitive load is required for the construction, automation, and storage of schemata in long term memory (van Merriënboer & Sweller, 2005). If the total amount of cognitive load exceeds a learner's mental resources, then intellectual performance will be impeded (Chandler & Sweller, 1991).

When the intrinsic cognitive load imposed by a task is high, then efforts should be directed toward instructional design manipulations that lower the extraneous cognitive load so that the total cognitive load, including the necessary germane load, falls to a level within the bounds of learners' mental resources. Well-designed instruction should minimize, to the extent that is possible, extraneous cognitive load and free cognitive resources for the necessary germane cognitive load so that the total cognitive load does not exceed the limits of the total working-memory capacity.

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). "Instructional split attention occurs when learners are required to split their attention between, and mentally integrate, several sources of physically or temporally disparate information, where each source of information is essential for understanding the material" (Ayres & Sweller, 2005, p. 135). As a consequence, instructional split-attention leads to an increase in extraneous cognitive load which will negatively affect task performance (Ayres & Sweller, 2005). Examples of divided sources of information that can cause split attention are text and text (e.g., a keyword on one page and a glossary in the back of a book), text and mathematical equations (e.g., equation in one place and explanation of the equation somewhere else), and words and pictures or diagrams (e.g., a flow chart or system diagram in one place and a description of the process or system in another) (Ayres & Sweller, 2005; Mayer, 2001).

Research by Sweller and colleagues (Chandler & Sweller, 1991; Sweller, Chandler, Tierney, & Cooper, 1990; Tarmizi & Sweller, 1988; Ward & Sweller, 1990) showed that in different content domains (i.e., algebra, biology, physics, computer training) disparate sources of information which must be mentally integrated in order to be comprehensible need to be physically and temporally integrated in order to reduce extraneous cognitive load. In a study by Chandler and Sweller (1996) though, the results showed that the split-attention principle applied only to high element-interactivity material. According to Ayres and Sweller (2005), element interactivity refers to the number of elements that must be simultaneously processed in working memory in order to be comprehended. Materials that are low in element interactivity are easily learned whereas materials high in element interactivity are more complex and place more load on working memory. "Element interactivity affects intrinsic cognitive load, whereas the split-attention effect is considered extraneous cognitive load, because it is created by the format of the instructional materials" (Ayres & Sweller, 2005, p. 142).

In more practical terms, a simple diagram and related text that have few interacting elements do not need to be presented in an integrated format (i.e., integrating the text into the diagram) because they can be easily learned even when presented in a non-integrated, spatially split format. Recent research studies have also demonstrated significant interactions between levels of learner expertise and the split-attention effect (Kalyuga, Ayres, Chandler, & Sweller, 2003; Kalyuga, Chandler, & Sweller, 1998). Kalyuga, Ayres, Chandler, and Sweller found that novice learners were not able to comprehend diagrams only, and benefited from textual explanations integrated into the diagrams. More experienced learners however performed significantly better with the diagram-only format. They concluded that materials in an integrated format were superior for novices, but inferior for more knowledgeable learners. They concluded that experienced learners "are able to bypass working-memory capacity limitations by having many of their schemas highly automated due to extensive practice" (p. 24) and that an increased level of expertise contributes to reduced working memory load.

Along this line of reasoning, the authors in this study sought to investigate (1) the effects of the two well-researched instructional formats, namely text and diagrams in integrated format and text and diagrams in split format on novice learners' cognitive load, time spent on task, and problem-solving performance in a complex system with a computer-modeling tool, (2) whether the dependent variables were different among FD, FM, and FI learners, and (3) whether there were any significant interaction effects between type of materials and FD/I in terms of any of the three dependent variables.

1.2. Research hypotheses

The research hypotheses of the study were:

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.

2. Methodology

2.1. Participants

Participants were recruited from a teacher education department during the spring semester of 2008. In total, 195 students volunteered to participate in the study. Of the 195 students, 18 (9.23%) were freshmen, 108 (55.38%) were sophomores, 24 (12.31%) were juniors, and 45 (23.08%) were seniors. In an effort to keep the sample of the study as homogeneous as possible, only the 108 sophomores were invited to participate in the study (96 female (88.9%), 12 male (11.1%); mean age = 19.22 years, $SD = .63$ years). All students had previously taken a class to develop basic computing skills. The researchers explicitly asked all students to specify whether they had any other prior knowledge related to complex-systems concepts and dynamic systems modeling software. None reported any familiarity.

2.2. Research design and procedures

First, the researchers administered the Hidden Figures Test (HFT; French et al., 1963) during three different sessions scheduled at times convenient for all students. Scores on the HFT ranged from 1 to 28 (max = 32 points). Students' average performance on the HFT was 13.89 ($SD = 6.52$). The cut-off scores were decided taking into consideration how other researchers determined the cut-off scores in their own research (Angeli & Valanides, 2004; Chen & Macredie, 2004; Daniels & Moore, 2000; Khine, 1996), so that meaningful comparisons of results across studies could be made. There are however small deviations in the cut-off scores adopted by the different researchers working in this area.

For the present study, 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. Based on this classification scheme, 40 students were determined to be FD learners, 38 to be FM learners, and the remaining 30 students to be FI learners. Students from each FD/I category were randomly assigned to one of two experimental conditions, namely the separated text and diagram condition (i.e., split-format condition) and the integrated text and diagram condition (i.e., integrated-format condition). While initially students were randomly and equally assigned into the two groups, some of them, due to unforeseen scheduling problems, were unable to attend their pre-assigned session. For this reason, the split-format group consisted of 15 FD, 19 FM, and 15 FI learners, while the integrated-format group consisted of 20 FD, 17 FM, and 15 FI learners. Five FD students from the split-format group and two FM students from the integrated-format group did not attend their pre-assigned session, and thus there were 49 students in the split-format group and 52 students in the integrated-format group.

Each group was then involved in two 90-min phases of research procedures. During the first phase, there was a 30-min lecture about complex-systems concepts presented by the researcher (first author of this paper), followed by a 60-min practice session using Model-It®, a computer-modeling tool. During the 30-min lecture, the researcher explained the development of a model, namely, that first the entities of the model need to be identified, then the char-

acteristics of the entities or variables need to be determined, and, finally, the qualitative or quantitative relationships among the variables need to be also defined. The researcher stressed the value of computer models as tools for controlling variables and testing hypotheses. Finally, it was shown that variables are always defined prior to running a model, and that they can be classified as dependent or independent variables, while there was also a discussion about the two types of variables and their relation.

In the following 60 min, students collaborated with the researcher and developed conceptual models for two phenomena, namely growth of plants and economic growth of a family. Indicatively, in the case of the growth of plants, the researcher explained that plant growth is the dependent variable, while sunlight, soil make-up, water, and carbon dioxide are the main independent variables. Subsequently, the researcher demonstrated Model-It®, and the students created and ran the model of plant growth in Model-It®. A similar strategy was also followed for creating and running a model for family economic growth. Different problem-solving scenarios regarding the two models were also given to the students to solve. Students tested different hypotheses for each model by controlling variables, using the software, and observing how manipulations of the inputs (i.e., independent variables) of the model affected the outputs (i.e., dependent variables).

During the second 90-min phase, students were instructed to use Model-It® together with a set of instructional materials to solve a problem about immigration policy. Two different sets of instructional materials were distributed to the two groups of students. In the split-format condition, students received the separated text and diagram set of instructional materials. In the integrated-format condition, students received the integrated text and diagram set. Both groups of students could only use the materials and the computer model in Model-It® to individually think about and solve the problem. There was no scaffolding provided by a human tutor. Every 15 min, a computer pop-up dialogue box prompted the participants to subjectively rate the cognitive load that they were experiencing.

According to Paas, van Merriënboer, 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. Thus, the following question was specifically asked: "How much mental effort are you putting into solving the task?" In cognitive load research, 7-point Likert scales are frequently used to measure the invested mental effort (Corbalan, Kester, & van Merriënboer, 2006; Marcus, Cooper, & Sweller, 1996; Tindall-Ford, Chandler, & Sweller, 1997) or the difficulty of the materials (Cuevas, Fiore, & Oser, 2002; Kalyuga, Chandler, & Sweller, 1999). In compliance with this, 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).

2.3. 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. Because of the potential danger that this might bring to the American economy in the long run, the chief immigration officer of the United States asked his research staff to prepare a conceptual model of the problem so as to better conceptualize and understand the complicated situation. A research-staff team prepared the model shown in Fig. 1 and presented it to the chief immigration officer. Succinctly, the model in Fig. 1 shows how an increase in Mexican population would cause an increase in the Mexican labor force and subsequently an increase in the Mexican unemployment rate. As a result, an increase in the Mexican unemployment rate would cause an increase in the movement of Mexicans to the United States, and,

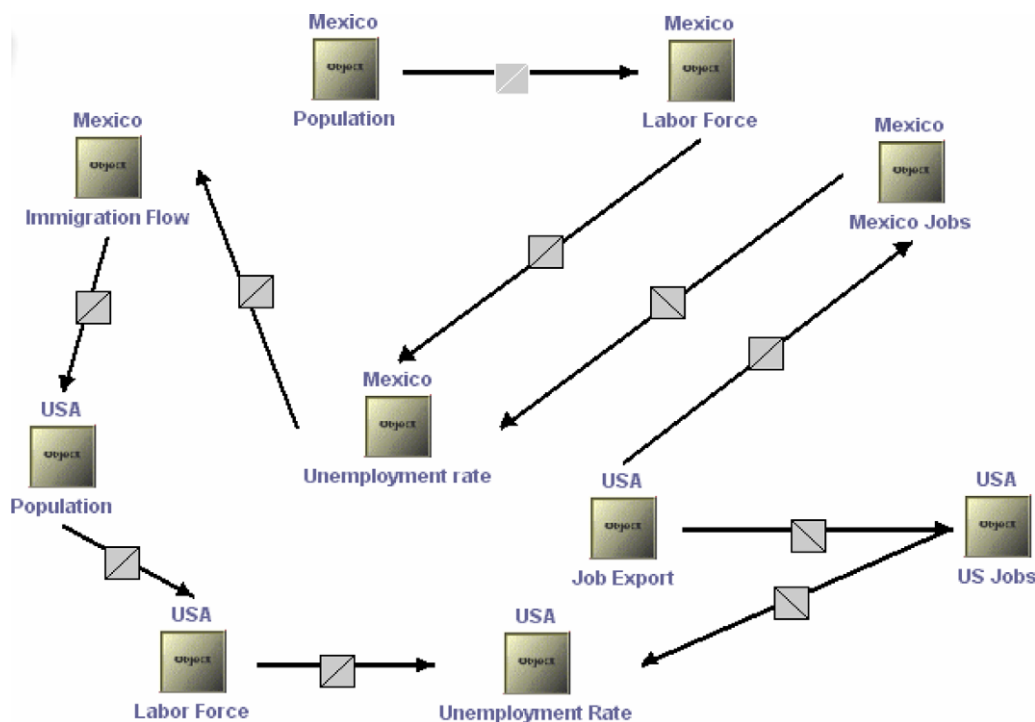


Fig. 1. The model depicting the USA–Mexico immigration problem.

eventually, an increase in the U.S. population, labor force, and unemployment rate. Consecutively, an increase in the number of jobs available in the United States would cause a decrease in the U.S. unemployment rate, but an increase in job exports from the United States to Mexico would cause an increase in the U.S. unemployment rate. Finally, an increase in the movement of U.S. businesses to Mexico would cause a decrease in the Mexican unemployment rate.

In addition to the model in Fig. 1, the chief immigration officer also received information regarding four possible immigration policies, namely (a) Open Border, (b) Closed Border, (c) Job Export, and (d) Immigration. The open border policy encouraged the immigration of Mexicans into the United States and allowed the free relocation of businesses from the United States to Mexico. The closed border policy discouraged the immigration of Mexicans into the United States and the movement of businesses from the United States to Mexico. The job export policy created disincentives for American businesses to relocate to Mexico, such as, higher taxes for goods produced in Mexico, which are intended for sale in the United States. Lastly, the immigration policy prohibited the immigration of Mexicans to the United States, but took no action regarding the movement of businesses from the United States to Mexico. Both sets of materials instructed the students to assume the role of chief immigration officer and decide which immigration policy should be adopted to successfully deal with the situation. Students in both conditions were instructed to read the materials, examine the model in Model-It[®], form and test hypotheses based on the four policies, evaluate the simulated outcomes of the computer model, and, finally, write a policy statement defending the policy of their choice for regulating the situation at the Mexico–United States border in the most effective way. Both sets of materials also included instructions for opening the file with the model in Model-It[®].

In the split-format condition, the model in Fig. 1 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 in Fig. 1 was presented in an integrated format with its textual description. In essence, in these materials, all textual explanations were physically embedded into the diagram. Both sets of instructional materials were informationally equivalent because the textual or visual representations in both sets allowed for the extraction of exactly the same information required for solving the specific task (Schnotz, 2002).

2.4. Description of Model-It[®]

Model-It[®], a computer-modeling tool that has been successfully used with middle school, high school, and college students (Metcalf et al., 2000; Stratford et al., 1998), was used to create and test the model of immigration dynamics shown in Fig. 1. The user first creates the entities of the model in Model-It[®] (i.e., Mexico and United States) for the model used in this study. For each entity, several variables such as population, labor force, immigration rate, and jobs are associated. These variables are designated as independent or dependent, depending upon the direction of the relationship between them. For example, in Fig. 1, Mexican labor force is the dependent variable and Mexican population is the independent variable because any increase in the Mexican population will cause an increase in the Mexican labor force. As shown in Fig. 2, 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 (see Fig. 3), 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

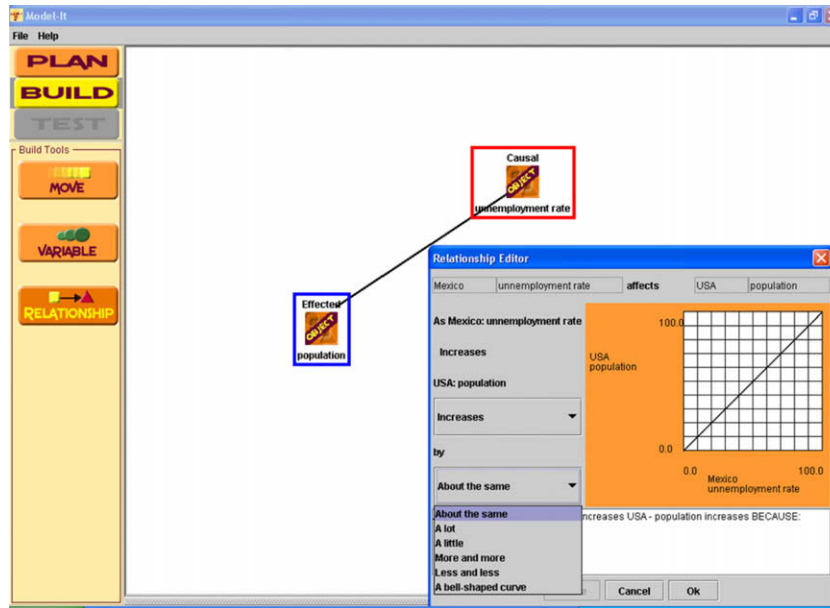


Fig. 2. Creating relationships between variables.

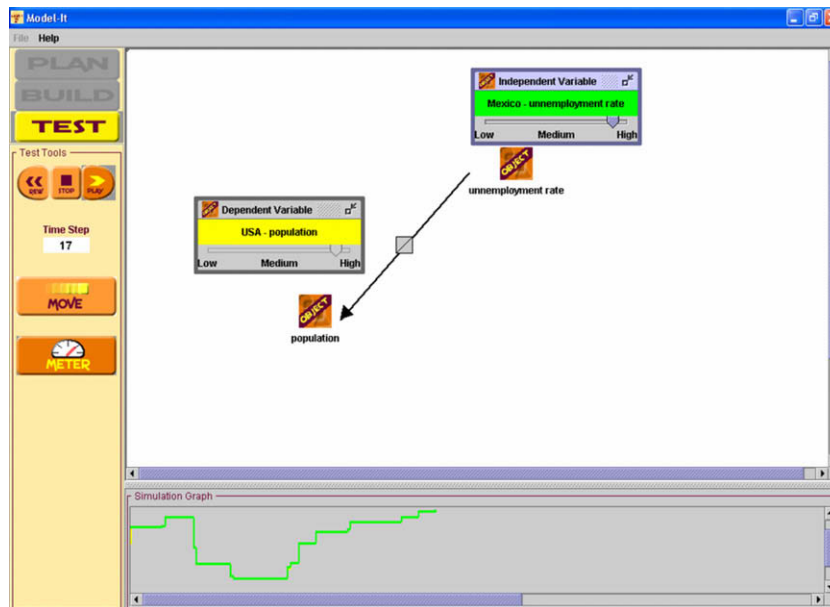


Fig. 3. Running a model in Model-It®.

variable can be manipulated during run time to show how it can affect the value of a dependent variable.

2.5. Instruments

2.5.1. Hidden Figures Test

The Hidden Figures Test (HFT) is one of the 72 tests in the kit of factor referenced cognitive tests and is used to determine learner FD/I (French et al., 1963). It consists of 32 questions and can be administered either in a group or individually. The 32 questions are divided into two parts. The test administrator allows 12 min for answering all questions in each part. The test presents five simple figures and requires learners to identify which of these simple figures is embedded in a complex visual configuration, and then trace the outline of the simple figure in the more complex one.

The test activity involved in the HFT has been described as perceptual disembedding, and is the most reliable and widely used test for determining FD/I (Rittschof, in press). “Using perceptual disembedding tests some studies have treated FD/I as a continuous variable, while others have specified cutoff scores for two (field dependent and field independent) or occasionally three levels of FD/I.” (Rittschof, in press, p. 3). The middle level is usually referred to as “field neutral” or “field mixed” (Graf, 2000). It was also found that the HFT is highly correlated ($r = .67-.88$) with the Group Embedded Figures Test (Witkin et al., 1971).

2.5.2. Problem-solving performance

Students’ 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)

and Strauss and Corbin (1990). The constant comparative method was carried out in three phases, namely comparison (a) within a single viewpoint/solution, (b) among viewpoints/solutions within the same condition (split format or integrated format), and (c) of viewpoints/solutions from the two conditions. The analysis led to three criteria for discriminating between the different levels of the rubric. The criteria evaluated the extent to which a participant (a) reached a decision by correctly interpreting the simulated outcomes of the model, (b) examined the consequences of all policies, and identified pros and cons of each policy, and (c) considered possible long-term effects of the full impact of each policy and recognized that consequences may take a long time before they are felt.

Consequently, 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 was satisfactory ($r = .84$). The rater and the researcher discussed the observed disagreements and easily resolved the differences after discussion.

3. Results

Table 2 shows descriptive statistics (i.e., means and standard deviations) of students' perceived cognitive load, time spent on task, and problem-solving performance, for the two conditions (split-format and integrated-format materials) and the three categories of FD/I. Cognitive load was calculated as the average value of all ratings of mental effort as reported by each learner during problem solving.

A 3 (FD/I) \times 2 (materials) multivariate analysis of variance was performed with FD/I and materials as the independent variables, and cognitive load, time spent on task, and problem-solving performance as the dependent variables. Between-subjects effects of this analysis are presented in Table 3.

The results in Table 3 indicate that the interaction effects between type of learning 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 significant, but the interaction effect between type of learning 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 Fig. 4).

The results in Table 3 also indicate that there was a significant main effect related to the type of materials used for each of the three dependent variables. Specifically, the results in Tables 2 and 3 indicate 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 stu-

dents 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. These results should be cautiously interpreted taking the interaction effects into consideration.

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. These results taken together clearly indicate that both perceived cognitive load and time spent on task were significantly higher for students assigned to the split-format condition, and also that both perceived cognitive load and time spent on task were not dependent on FD/I. In essence, all students (i.e., FD, FM, and FI learners) in the split-format condition experienced significantly higher cognitive load and spent significantly more time on task than students in the integrated-format condition. These results not only replicate the results of previous well-known research studies by Sweller and colleagues (Sweller, 1994; Sweller et al., 1998) on the split-attention effect, but they also provide additional evidence supporting the notion that this well-documented effect is not affected by students' FD/I, since the effect manifested itself across all students irrespective of their performance on the HFT or their FD/I categorization (i.e., FD, FM, or FI learners).

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 Fig. 4. 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. It seems that FI learners' perceptual disembedding ability was facilitated by the materials in the integrated-format condition, or that it was inhibited by the materials in the split-format condition due to the higher cognitive load and time spent on task caused by the split-attention effect.

The magnitude of the superior problem-solving performance of FI learners in the integrated-format condition as compared with FI

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

Table 2
Descriptive statistics of learners' perceived cognitive load, time spent on task, and problem-solving performance for the two conditions and FD/I.

Condition	FD/I									Total		
	FD			FM			FI			m	SD	n
	m	SD	n	m	SD	n	m	SD	n			
<i>Perceived cognitive load</i>												
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	10
<i>Time on task</i>												
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
<i>Problem-solving performance</i>												
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

Table 3
Between-subjects effects of the 3 (FD/I) × 2 (materials) MANOVA with cognitive load, time spent on task, and problem-solving performance as the dependent variables (N = 101).

Source	SS	df	MS	F	Sig.	η^2
<i>Type of materials (A)</i>						
Cognitive load	1.49	1	1.49	5.66	.02	.12
Time spent on task	3792.38	1	3792.38	17.20	.00	.15
Problem-solving performance	4.59	1	4.59	5.66	.00	.06
<i>FD/I (B)</i>						
Cognitive load	.50	2	.25	.38	.69	
Time spent on task	63.22	2	31.61	.14	.87	
Problem-solving performance	12.98	2	6.49	24.70	.00	.34
<i>Interaction (A × B)</i>						
Cognitive load	1.38	2	.69	1.05	.35	
Time spent on task	159.10	2	79.55	.36	.70	
Problem-solving performance	4.59	2	2.29	8.73	.00	.16
<i>Error</i>						
Cognitive load	62.29	95	.66			
Time spent on task	20942.26	95	220.45			
Problem-solving performance	24.97	95	.26			
<i>Total</i>						
Cognitive load	1988.18	101				
Time spent on task	316800.00	101				
Problem-solving performance	405.00	101				
<i>Corrected total</i>						
Cognitive load	72.05	100				
Time spent on task	24870.30	100				
Problem-solving performance	43.80	100				

learners' performance in the split-format condition (i.e., effect size) was determined using Cohen's *d*, which is the degree of mean difference between the first group (integrated-format condition) and second group (split-format condition) of students divided by the pooled standard deviation (Cohen, 1988). The effect size (Cohen's $d = 2.49$) was very high indicating 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. When the sample sizes are small (Feingold, 1992; Wilcox, 1995), as it was the case in the present study, effect-size statistics should be interpreted cautiously taking into consideration possible departures from normality. Despite the small sample size in the present study, the magnitude of the effect sizes are so high that they strongly indicate

real differences between the respective groups, irrespective of possible departures from normality.

4. Discussion

In the present study, 101 primary student teachers were initially categorized as FI, FM, and FD learners based on their performance on the HFT. An equal number of students from each subgroup (i.e., FI, FM, and FD) was randomly assigned to either one of two experimental conditions, namely the split-format condition in which the text and diagram were separated in space and the integrated-format condition where the text and diagram were integrated. Both groups of students were initially instructed about complex-systems concepts and about the development and usefulness of a model. Then, they collaborated with the researcher and developed conceptual models using Model-It®, and subsequently created and ran the models and tested several hypotheses for each model by using the software. Lastly, they were instructed to use Model-It® together with their respective set of instructional materials to solve a problem about immigration policy, while their

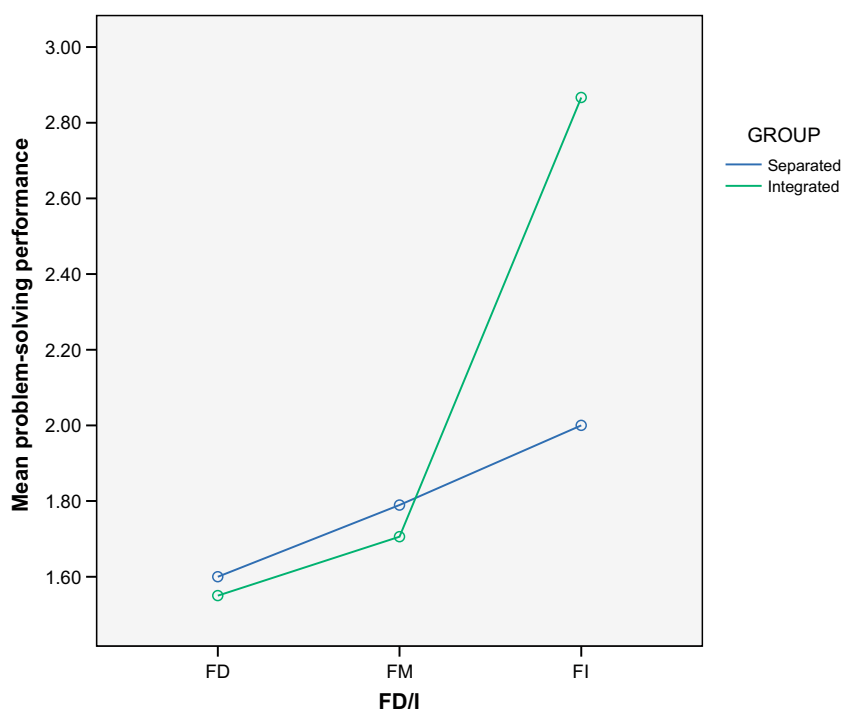


Fig. 4. Interaction effect between condition and FD/I.

performance was evaluated using three dependent variables, namely, cognitive load, time spent on task, and problem-solving performance.

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 (Paas & van Merriënboer, 1993).

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.

Although, there is no empirical evidence nor technique which allows us to discriminate between extraneous and germane cognitive load (van Merriënboer, Schuurman, de Croock, & Paas, 2002), it can be indirectly concluded that in the split-format condition, the extraneous cognitive load that is irrelevant to the construction of cognitive schemata was increased, and thus the germane cognitive load that is directly relevant to schema construction and to better problem-solving performance was necessarily lower. Thus, the extraneous cognitive load could be significantly higher for the split-format condition and students spent significantly more time on task, but had significantly lower problem-solving performance on the complex issue of immigration policy. Obviously, the increased cognitive load in the split-format condition did not contribute to better problem-solving performance, indicating that increased extraneous cognitive load was imposed on students by the instructional materials and that this interfered with their problem-solving performance. In contrast, the integrated condition imposed a lower amount of extraneous cognitive load on the learners, while it simultaneously redirected attention from extraneous to germane processes that significantly improved both instructional efficiency (i.e., lower cognitive load and time spent on task) and

instructional effectiveness (i.e., better problem-solving performance). This provides additional support to the generally accepted idea that decreasing extraneous cognitive load may free cognitive resources for germane cognitive activities and better learning outcomes. These results provide additional support to the idea that “the proper allocation of available cognitive resources is essential to learning” (Kalyuga et al., 2003, p. 24), and, that students should expend only as little as possible cognitive resources on activities that are not directly related to schemata construction and automation.

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 perfor-

mance. 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. The present conclusions converge with the conclusions of a previous study (Angeli & Valanides, 2004) where it was also found that the text-and-visual group outperformed the text-only group due to an interaction effect between FD/I and type of materials. In that study, the visual was decomposed into smaller visual components, which were presented gradually along with their corresponding texts in alternate form, and it was concluded that the “functional role of visuals depends on cognitive differences” (Angeli & Valanides, 2004), such as FD/I.

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).

Finally, the results of the present study along with those of a previous study (Angeli & Valanides, 2004) may trigger additional discussion relating to the idea that the construct of FD/I is a value-directional construct rather than a cognitive style. These results converge with other research findings (Miyake, Friedman et al., 2001; Miyake, Witzki et al., 2001) indicating that FD/I represents differences in cognitive abilities, and that FI learners always have an advantage over FD and FM learners. However, further research to resolve the issue of whether FD/I is a cognitive style or represents differences in cognitive abilities still needs to be carried out. Similarly, investigations of how students self-regulate their interaction with instructional materials are needed so as to better understand the relationship between FD/I and the split-attention effect. Indicatively, future research studies can be designed to digitally capture learners' interactions with various computer tools and materials (e.g., eye tracking, logging of mouse movement and keystrokes, etc.) in order to better understand how learners use them, so that effective instructional designs can be employed to effectively support, facilitate, and guide all students' learning irrespective of their FD/I.

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