HOW DO FIELD-DEPENDENT AND FIELD-INDEPENDENT LEARNERS' INTERACT WITH A COMPUTER MODELING TOOL TO SOLVE A PROBLEM? IMPLICATIONS FOR THE DESIGN OF JOINT COGNITIVE SYSTEMS

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Abstract

Research accounts on examining only the performance of a system are not sufficient, because they cannot establish principles about how technology affordances work with learners, and how one should go about improving the performance of the system. Therefore, in the current study, a mixed-method research methodology was undertaken in order to understand how 119 learners with different cognitive styles interacted with a computer-modeling tool to solve a problem. Implications for the design of effective joint cognitive systems are also discussed.

Introduction

Learners and tools can form joint cognitive systems, if certain conditions are met (Dalal & Kasper, 1994; Brezillon & Pomerol, 1997). Learner cognitive style is one factor that needs to be taken into consideration, because it can interfere with the desirable effects expected from problem solving with computers (Dalal & Kasper, 1994; Dragon, 2009; Burnett, 2010). Thus, investigations regarding the role of cognitive style on learners' performance during problem solving with computer tools become important, because they can inform the design of effective joint cognitive systems, and can provide valuable guidance about how to integrate computer tools in teaching and learning in advantageous ways for the benefit of all learners.

Accordingly, the present study discusses the results of an experiment that was undertaken in order to investigate the effects of cognitive style on learners' performance and interaction during complex problem solving with a computer-modelling tool.

Literature Review

The concept of joint cognitive systems stresses the fact that neither the system nor the user is able to solve the problem at hand alone (Hollnagel & Woods, 2005). A critical contributor to the efficacy of the joint cognitive system is the relationship between the cognitive characteristics of the user and the corresponding cognitive characteristics of the system. The term cognitive coupling has been used to describe this relationship (Fitter & Sime, 1980; Dalal, 1990; Dalal & Kasper, 1994). Poor cognitive coupling may lower the performance of the joint cognitive system no matter how intelligent the individual partners. Hollnagel (1986) suggests that important cognitive characteristics of users are goals, problem-solving strategies, knowledge, and cognitive style. Cognitive style represents the characteristic mode of functioning shown by individuals in their perceptual and thinking behavior during the decision-making process (Schwering, 1987; Messick, 1976; Morgan, 1997). The most popular cognitive style, especially for instructional technology research, is field dependence-independence (FD-I) (Dragon, 2009).

FD-I is based on the individual's reliance on the context to extract specific meaning. 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; Graf, 2000). The key difference between FD and FI learners is visual perceptiveness (Goodenough & Karp, 1961). FD learners, who are asked to identify a simple geometric figure that is embedded in a complex figure, will take longer to identify the simple figure than FI learners, or FD learners may not be able to do it at all. FI learners are impersonal, individualistic, interested in abstract subject matter, intrinsically motivated, perceive analytically, have self-defined goals and reinforcements, can self-structure situations, and use hypothesis-testing to attain concepts. FD learners are socially oriented, more in need of structure, more dependent on others for reinforcement, more in need of externally defined objectives, perceive globally, use the spectator approach for concept attainment, and have difficulty in abstracting relevant information from visual (or even textual) instructional materials.

Much of the research on FD-I has concentrated on examining the effects of FD-I on learners' computer performance (Burnett, 2010; Dragon, 2009). However, research accounts on examining only the performance of a system are not sufficient, because they cannot establish principles about how technology affordances could work with learners, and how one should go about improving the performance of the system. Therefore, in the current study, the authors assumed a mixed-method research approach in order to understand how learners of different field type interacted with Model-It® to solve a complex problem. The study discusses both quantitative results regarding learners' performance and interaction with the computer tool, and qualitative findings about how FD, FM, and FI learners actually used the affordances of Model-It® in order to solve the problem. Based on the results of previous work (Burnett, 2010; Dragon, 2009), it is hypothesized that FI learners will outperform FD learners in this study as well in terms of problem-solving performance. Regarding learners' interaction with Model-It® it is hypothesized that FI learners will interact with Model-It® in a very goal-directed way for the purpose of testing hypotheses, whereas FD learners will probably be confused and unsure about how to use the software to collect data for the purpose of proposing a solution to the problem at hand.

Methodology

Participants

One hundred and nineteen sophomores volunteered to participate in the study. The average age of the participants was 19.56 years (*SD* = .45). All participants had basic computing skills, but no prior knowledge related to computer modeling tools. The Hidden Figures Test (French, Ekstrom, & Price, 1963) was used to classify participants into a field type. Participants were classified into 41 FD, 41 FM, and 37 FI learners.

Model-It®

Model-It® (Metcalf, Krajcik, & Soloway, 2000), was used to create a 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 relationships between variables, the user may run the model.

River Past Screen Recorder®

River Past Screen Recorder® ran in the background of each computer, while students were using Model-It® to solve the problem, in order to capture all screen mouse movements into video files. These video files were later analyzed to understand how learners interacted with Model-It® to solve the problem.

Instructional Task

Participants had to individually explore a computer model using Model-It® in order to propose a solution to a problematic situation at the USA-Mexico border. Succinctly, the model showed how an increase in the unemployment rate of Mexico caused an increase in the movement of Mexicans to the United States, and, eventually, an increase in the U.S. population, labour force, and unemployment rate. In addition, participants were given four possible immigration policies to explore using the model in Model-It®, namely (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 the model in Model-It®. Then, they were asked to propose, in writing, which one of the four possible policies should be adopted in order to regulate as optimally as possible the situation at the USA-Mexico border. Learners' written responses were later evaluated using a problem-solving performance assessment rubric.

Instructional Materials

All participants received the same set of instructional materials. In the materials, the model was presented in an integrated format with its textual description. In essence, all textual explanations were physically embedded into the diagram. The integrated-format materials were chosen to be used in this study, because based on the outcomes of previous research (Ayers & Sweller, 2005), they are efficient materials that do not promote instructional split-attention, which eventually leads to an increase in extraneous cognitive load (Ayres & Sweller, 2005; Chandler & Sweller, 1991; Chandler & Sweller, 1996).

Instruments

The Hidden Figures Test (HFT) was used to determine learner FD-I (French, Ekstrom, & Price, 1963). It consists of 32 questions divided equally into two parts. Twelve minutes are allowed for each part. The test presents five simple figures and asks learners to identify which one of these simple figures is embedded in a more complex figure.

Research Procedure

First, the researcher administered the HFT and scores on the HFT ranged from 1 to 31 (max = 32 points). Students' average performance on the HFT was 13.56 (*SD* = 7.35). The cut-off scores were decided taking into consideration how other researchers determined the cut-off scores in their own research (Chen & Macredie, 2004; Daniels & Moore, 2000; Khine, 1996), so that meaningful comparisons of results across studies could be made. 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 31 as FI. Based on this classification scheme, 41 students were determined to be FD learners, 41 to be FM learners, and the remaining 37 students to be FI learners.

Students participated in three 90-min phases of research procedures. During the first phase, there was a 30-min lecture about systems, followed by a 60-min lab session where students learned how to use Model-It®. During the second 90-min research session, students collaborated with the researcher and developed computer models for two phenomena, namely growth of plants and economic growth of a family. 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 third 90-min phase, students were instructed to use Model-It® together with the instructional materials to solve a problem about immigration policy.

Results

A Rubric for Assessing Learners' Problem-Solving Performance

The rubric that was used to assess learners' problem-solving performance was constructed inductively using the constant comparative analysis method (Glaser & Strauss, 1967; Strauss & Corbin, 1990). The rubric had three mutually exclusive levels with scores ranging from 1 (low performance) to 3 (high performance). The criteria that were used for evaluating learners' problem-solving performance was 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, (c) identified pros and cons for each policy, and (d) considered possible long-term effects of the full impact of each policy. The researcher and a trained rater independently evaluated students' problem-solving performance, and Pearson's correlation between the two raters was found to be satisfactory ($r = .88$). The researcher and the rater easily resolved the observed disagreements, after discussion.

A rubric for assessing learners' interaction with the computer-modelling tool

Students' interaction with Model-It® was captured in video files with River Past Screen Recorder®. For each video file, a transcript was created. Each transcript contained a table with three columns, namely, STUDENT ID, TIME, and ACTION. STUDENT ID was student's identification number, TIME represented the beginning and ending time of an action, and ACTION was a description of what the student was doing on the computer screen during that time. Each transcript was then assessed on the basis of an inductively constructed rubric using the constant comparative analysis method as well (Glaser & Strauss, 1967; Strauss & Corbin, 1990). The rubric had three mutually exclusive levels, and participants' scores ranged from 1 (low interaction) to 3 (high interaction). Learners' interaction with Model-It® was evaluated based on five criteria regarding the extent to which students (a) opened all meters first before running the model, b) ran the model, c) evaluated all four immigration policies, d) controlled variables correctly, and (e) made confident and goal-directed mouse movements. An independent rater was trained and assessed 30 transcripts from each group of FD and FM learners and 28 transcripts from the FI group, as the researcher randomly selected them. A Pearson r between the rating of the independent rater and that of the researcher was calculated and found to be 0.86. This reliability value was regarded very satisfactory considering the complexity of the data. The rater and the researcher also discussed the observed disagreements and easily resolved after discussion the existing differences.

Learners' Problem-Solving Performance, and Interaction with Model-It®

Table 1 shows descriptive statistics (i.e., means and standard deviations) of students' problem-solving performance, and interaction with Model-It® for each classification of FD-I. A multivariate analysis of variance was performed with FD-I as the independent variable, and problem-solving performance and learner interaction as the dependent variables. The results indicated that there was a statistically significant difference in terms of learners' problem-solving performance, $F(2, 116) = 10.65$, $p = .00$, $n^2 = .16$. Post hoc comparisons using the Tukey HSD method indicated that FI learners outperformed FD learners, and that FM learners also outperformed FD learners. There was also a statistically significant difference in terms of learners' interaction with Model-It®, $F(2, 116) = 14.61$, $p = .00$, $n^2 = .20$. In essence, students who interacted poorly with the software were unsure about how to systematically use the affordances of the software to solve the problem. Also, the qualitative data showed that learners who performed poorly with Model-It® did not have a systematic plan in mind of how to investigate and decide about the issue at hand, and had difficulty with testing the immigration policies by appropriately controlling variables in order to collect data. Post hoc comparisons using the Tukey HSD method revealed significant differences in computer interaction between FI and FD learners, and between FM and FD learners.

Table 1

Descriptive Statistics of Learners' Problem-Solving Performance and Interaction With the Computer Tool for Each Classification of FD-I

Field Dependence-Independence											
FD			FM			FI			Total		
M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Problem-Solving Performance											
1.39	.59	41	1.95	.71	41	2.05	.78	37	1.79	.75	119
Computer Interaction											
1.71	.51	41	2.15	.65	41	2.38	.49	37	2.07	.62	119

Based on the qualitative findings, most FD learners did not even realize that they had to run the model by first opening all meters in order to test hypotheses by controlling variables. Those FD learners who ran the model did so by opening only a subset of the meters, an inappropriate tactic for testing a model since all meters needed to be open to observe how a change in one variable affected all other variables in the system. Obviously, the complexity of the system was overwhelming for the FD learners to manage effectively. FM learners, unlike FD learners, were in a much better position in terms of using the affordances of Model-It® to collect data and solve the problem. It was nonetheless obvious that the complexity of the system was also uncomfortable for FM learners, because some of them attempted to study the system by examining a part of it at a time. This of course is not an acceptable strategy, because the system as a whole must be examined in order to observe how one variable affects all others. Another major difference between FD and FM learners was the very fact that FM learners, even though not all of them, made confident and quick mouse movements indicating that the mouse movements of FM learners were directed toward a goal. Lastly, FI learners, even though not all of them according to the descriptive statistics in Table 1, appeared to be very systematic in terms of testing one immigration policy at a time by controlling the correct independent variable/s. Their mouse movements were always quick and confident, and clearly showed that FI learners had a plan in mind and a strategy of how to collect data in order to solve the problem. Of course, solving the problem successfully required two other cognitive skills, namely data organization and data evaluation. While no qualitative data regarding learners' actions away from the computer were collected, based on the quantitative data on learners' problem-solving performance, it is fair to conclude that FI and FM learners were better able to organize and evaluate the computer data collected than FD learners.

Discussion

The results showed that the main effects related to FD-I for learners' problem-solving performance and interaction with Model-It® were both significant. FI learners exhibited better problem-solving performance than FD learners, and FM learners exhibited better problem-solving performance than FD learners. Also, there was a significant difference in computer interaction between FI and FD learners, and between FM and FD learners.

The findings showed that FD learners, once more, were not able to benefit from the integrated-format materials, which were shown to be efficient and effective in previous studies (Sweller, 1994; Ayres & Sweller, 2005). The results of the present study show that no matter how efficient the instructional design of the materials, if learners' cognitive style is incongruent with the nature of the computer task, learners' problem-solving performance will not be the best possible.

The qualitative findings of the study, regarding learners' actual interactions with the affordances of Model-It® to solve the problem, are important, because they enable us to better understand the partnership between tools and humans, and inform research efforts in terms of finding ways to make this partnership as optimal as possible. According to Moffat, Hampson, and Hatzipantelis (1998), proper cognitive coupling occurs when the interaction between the learner and the instructional environment results in successful problem-solving performance. The qualitative findings of the study indicated that no cognitive coupling occurred between the computer tool and FD learners since most of them did not even run the model in order to collect data and solve the problem. In fact, the qualitative results showed that FD learners were not able to manage the complexity of the computer task at all, and most of the time they made slow and unsure mouse clicks indicating how lost FD learners were in the problem-solving space. Based on the qualitative findings of this study, a number of implications can be drawn regarding the design of joint cognitive systems.

Implications for the Design of Joint Cognitive Systems

Despite the fact that the quantitative and qualitative results of this study showed that the cognitive style of field dependence/independence significantly affected learners' problem-solving performance and interaction with Model-It®, accommodating learners' cognitive style in the design of computer systems will have cognitive benefits for some learners, but also it will have cognitive costs for some others, because no matter how you try to design a system to better meet the needs of one particular type of learners, you will make it worse for some other type of learners. Moreover, it is possible that a similar coupling will prove to be counterproductive, because the computer system may reinforce the user’s cognitive biases, and thus decrease the system’s overall performance (DeWaele, 1978; Huber, 1983; Dalal & Kasper, 1994).

For all these reasons and based on how the participants in the present study interacted with Model-It® to solve the problem, the authors herein support the point of view that the design of effective joint cognitive systems should be based upon considering factors that are directly related to the nature of the problem-solving task, and the support that learners would need in order to complete the task successfully. For example, solving a complex problem with a computer modeling tool requires that learners possess certain cognitive skills such as (a) the skill to devise a goal-directed plan of what they need to do to solve the problem, (b) the skill to employ an appropriate strategy for systematically collecting data, (c) the skill to organize data, and (d) the skill to evaluate data to inform decision making. Learners of different field type may or may not have these skills, but nonetheless these skills are important for solving the specific task at hand. Therefore, to enable a joint cognitive system to perform at optimal levels, the computer partner should be able to provide the means for the human partner to develop these skills during real problem-solving task time, so that the human partner can have a successful learning experience with the computer partner. This can be achieved by designing a system that (a) provides all tools necessary for solving a specific type of task, (b) is adaptive in terms of the cognitive support that learners of different cognitive styles would need to use, (c) provides the means for data organization and evaluation through the mechanisms of external memory systems (i.e., through different computer representations and visualizations) to complement learners’ actual memory systems, and (d) provides the means for self-evaluation of performance through ongoing diagnosis of the problem-solving strategy and calibrated support and personalization of the learning experience.

In conclusion, nobody would disagree with the notion that students should be taught in ways that are sensitive to their individual differences, but this is difficult to be achieved in a real classroom with a large body of students and a sole educator, or by designing systems that are tailored to the specific needs of a particular group of students. Instead, a research area worthy of serious consideration from those interested in designing optimal joint cognitive systems can be the design of computer systems that will provide personalized problem-solving experiences, directly related to the cognitive demands of the specific task at hand, to all types of learners.

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