Computers & Education 62 (2013) 221–230

Contents lists available at SciVerse ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Examining the effects of field dependence–independence on learners' problem-solving performance and interaction with a computer modeling tool: Implications for the design of joint cognitive systems

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ARTICLE INFO

Article history:
Received 2 December 2011
Received in revised form
31 October 2012
Accepted 1 November 2012

Keywords:
Cognitive style
Computer modeling tools
Problem solving
Complex problem

ABSTRACT

An investigation was carried out to examine the effects of cognitive style on learners' performance and interaction during complex problem solving with a computer modeling tool. One hundred and nineteen undergraduates volunteered to participate in the study. Participants were first administered a test, and based on their test scores they were classified into three groups, namely field-dependent, field-mixed, and field-independent learners. Participants then received the same set of integrated-format materials and were asked to use a computer modeling tool to solve a complex problem about immigration policy. A multivariate analysis of variance was performed with field type as the independent variable, and cognitive load, problem-solving performance, and learner interaction with the computer tool as the dependent variables. The results indicated that there was no significant difference in terms of the amount of cognitive load reported. However, there was a significant difference in terms of learner problem-solving performance. Specifically, field-independent learners outperformed field-dependent learners, and field-mixed learners outperformed field-dependent learners. The results also indicated significant differences in computer interaction between field-independent and field-dependent learners, and between field-mixed and field-dependent learners. The qualitative findings of the study showed that students who interacted poorly with the software were unsure about how to systematically use the affordances of the computer tool to solve the problem, did not have a goal-directed plan or strategy in mind about how to investigate the issue at hand, and had difficulty with testing the immigration policies by appropriately controlling variables in order to collect data to inform decision making. Implications are discussed in terms of designing computer systems that scaffold learners' complex problem solving by considering the cognitive demands of the task.

1. Introduction

Learners and tools can work together as effective joint cognitive systems if a relationship exists between the cognitive characteristics of the learners and the corresponding characteristics of the system (Brezillon & Pomerol, 1997; Dalal & Kasper, 1994). Learners have goals, problem-solving strategies, knowledge, and cognitive style (Hollnagel, 1986). In the same way, systems have goals, problem-solving strategies, knowledge, and cognitive style, developed using the system's image of the learners' goals, strategy, knowledge, and style. In other words, the learner's cognitive characteristics are mirrored by the system's characteristics (Dalal & Kasper, 1994).

Cognitive style is thus an important cognitive characteristic of the learner that has been known to influence complex problem solving and decision-making with computer tools (Burnett, 2010; Dragon, 2009; Schwering, 1987). According to Frensch and Funke (1995), complex problem solving is viewed as the interaction between a problem solver and a complex task in the context of a specific environment. The variables related to the problem solver are distinguished between domain-general and domain-specific knowledge, information processing (cognitive style, strategies, monitoring, and evaluation), and non-cognitive variables (motivation and personality). The task itself is depicted in terms of the barriers that exist between a given state and a goal state. The transition from the given state to the goal state is constrained by the problem solver's knowledge and information processing capabilities, and by the tools that are available to the problem solver. Despite

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http://dx.doi.org/10.1016/j.compedu.2012.11.002

being an important variable, research results on cognitive style are mixed and conflicting. Therefore, ongoing investigations regarding the role of cognitive style on learners' performance during complex problem solving with computer tools are important. Clearly, research efforts that address which components within the problem solver and task affect complex problem solving, and in what way, will be useful in terms of advancing the theory of complex problem solving.

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 during complex problem solving with a computer modeling tool, namely Model-It®. Computer-modeling tools are powerful tools for building systems with interactive and interdependent components (Jonassen, 2004). Model-It® allows the creation of entities, variables, and relationships among variables. The learner can run the model to see how changes in the independent variables affect the dependent variables. Accordingly, the study reports quantitative results regarding learners' performance with Model-It®, and qualitative results about how learners interacted with Model-It® to solve a complex problem. The contribution of the current study to the existing body of research on learning with computer modeling tools and cognitive style lies in the qualitative examination of how learners with different cognitive styles interacted with a computer modeling tool during complex problem solving. The qualitative examination revealed a relationship between cognitive style and complex problem solving – a research focus that was missing from the current body of literature. Implications about the design of joint cognitive systems are discussed.

2. Literature review

A key concept in problem solving with computers is the ability of the human partner to cope with technological complexity, so that the joint cognitive system can perform its intended functions in a dynamic environment (Hollnagel & Woods, 2005). The design of joint cognitive systems gives an emphasis on the cognitive aspects of solving a task. This entails some very strong requirements about the design of systems such as (a) the sharing of cognitive representations, (b) the organization and evaluation of data, (c) a sharing of the interaction control, (d) a consideration of learners' cognitive characteristics, (e) an understanding of the context-specific nature of the problem to be solved, and (f) the exchange of information, knowledge and explanations between the human partner and the system, to enable the human partner to make an informed decision (Brezillon & Pomerol, 1997; Dalal & Kasper, 1994; Maturana & Varela, 1980; Winograd & Flores, 1987; Woods, 1985).

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 (Dalal, 1990; Dalal & Kasper, 1994; Fitter & Sime, 1980). Poor cognitive coupling may lower the performance of the joint cognitive system no matter how intelligent the individual partners. On the other hand, "when the coupling between user and system is effective, each compensates for the deficiencies and reinforces the strengths of the other on a dynamic basis in response to a changing environment with changing task conditions" (Dalal & Kasper, 1994, p. 678). 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 (Messick, 1976; Morgan, 1997; Schwering, 1987). In the literature, different cognitive styles are mentioned, such as for example field dependence–independence, impulsivity–reflectivity, and leveling–sharpening (Burnett, 2010). 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, and it is relatively a fixed characteristic at the onset of adolescence (Witkin, Moore, Goodenough, & Cox, 1977). FD-I describes learners along a continuum such that individuals on one end are considered to be Field Dependent (FD) and individuals on the other end Field Independent (FI). Individuals who fall in the middle of the continuum are characterized as Field Mixed (FM) (Graf, 2000; Liu & Reed, 1994). 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 identify the simple figure at all. FI learners are analytical, competitive, individualistic, task oriented, internally referent, intrinsically motivated, hypothesis testing, self-structuring, linear, detail oriented, and visually perceptive (Garger & Guild, 1984; Hall, 2000; Saracho, 1989), whereas FD learners are group-oriented, global, sensitive to social interactions and criticism, extrinsically motivated, externally referential, not visually perceptive, non-verbal, and passive learners who prefer external information structures (Garger & Guild, 1984; Hall, 2000; Saracho, 1989). Governor (1998) added that FD learners are in more need of social input and external help in interpreting clues embedded in a particular learning task, while Hu (1998) observed that FI learners are more analytic and rely less on external clues than FD learners.

FD-I has been criticized for not meeting the criteria for cognitive style at a conceptual or an empirical level, because it was found to correlate with ability (Grigorenko & Sternberg, 1995; McKenna, 1983). Nonetheless, researchers continue to refer to FD-I as a cognitive style (i.e., Miyake, Friedman, Rettinger, Shah, & Hegerty, 2001; Miyake, Witzki, & Emerson, 2001), in recognition of the fact that more systematic research is needed to resolve the issue of whether FD-I is a cognitive style or represents differences in cognitive abilities (Rittschof, 2010).

Contemporary research studies show persistently that FI learners are consistently associated with better academic or problem-solving performance (Angeli & Valanides, 2004; Angeli, Valanides, & Kirschner, 2009; Burnett, 2010; Dragon, 2009; Rittschof, 2010; Zhang & Sternberg, 2006), indicating that FD-I is not value-free. In two previous related experiments, Angeli and Valanides (2004), and Angeli et al. (2009) investigated the extent to which instructional materials and learner FD-I differentially affected learners' performance with Model-It® – a computer modeling tool. In both experiments, participants were asked to solve the same complex problem with the same computer modeling tool, participants' field type (FD, FM, or FI) was determined by administering the Hidden Figures Test (French, Ekstrom, & Price, 1963), and participants' problem-solving performance with Model-It® was evaluated with an assessment rubric that was developed inductively using the constant comparative method (Strauss & Corbin, 1990). In both experiments, participants from each type of FD, FM, and FI learners were randomly assigned into two groups. Each group received different instructional materials. In the first experiment (Angeli & Valanides, 2004), participants in one group received the text-only materials, and participants in another group received the text-and-visual materials. The sets differed in how the structure of the model was explained. In the text-only set of materials the model was described in textual form only. In the text-and-visual set of materials the model was decomposed into four smaller diagrams and each one of the diagrams was presented along with its description in narrative form. Diagrams and text appeared in alternate format. The results of the