Journal of Research on Technology in Education, 2007, 40(1), 39–48

Learner Involvement in Instruction on a Complex Cognitive Task: Application of a Composite Measure of Performance and Mental Effort

A. Aubteen Darabi and David W. Nelson
Florida State University

Fred Paas
Open University of the Netherlands

Abstract

This study presents an application of a measure of learner involvement developed by Paas, Tuovinen, van Merrienboer, and Darabi (2005). These authors combined learners' performance scores with their perceived mental effort invested in instruction and used it to assess learner involvement in instructional conditions. The present study examines the differentiating attributes of the Paas et al. learner involvement measure by using data collected in an experiment that investigated the effectiveness of three computer-based instructional strategies: (a) conventional problem solving, (b) product-oriented worked examples, and (c) process-oriented worked examples. As hypothesized, learners using worked example strategies showed higher involvement scores than those in conventional problem solving. However, no differences in learner involvement were found between the two worked-example strategies. The implications of these findings for designing instructional strategies and suggestions for further research are discussed. (Keywords: involvement, engagement, motivation, instructional strategies, worked examples.)

INTRODUCTION

Theories of motivation have variously described the sources of motivation in the traditions of behavioral, humanistic, and cognitive psychology. Behavioral psychology attributes motivation to learner's prior experiences with the environment in response to present stimuli. The humanistic explanation considers motivation as individuals' fulfillment of their potentials and focuses on emotional, interpersonal, and intellectual self-actualization as the need for that fulfillment. Cognitive theories of motivation focus on peoples' beliefs and expectations, and examine variables such as expectancy for success, value placed on success, goals and goal orientation, attribution about reasons for success, needs for competence, control, and relatedness (Eggen & Kauchak, 2001). All three traditions specify that the learner's active involvement in instruction is necessary for successful learning outcomes. But the question remains: How is the necessary ingredient of involvement elicited and measured?

By explaining underlying factors of learners' behavioral, emotional, interpersonal, and cognitive involvement in learning tasks, these theories have guided research on learners' motivation and quality of the learning experience. In this line of research, the concept of "engagement" has emerged as the learner characteristic attributed to sustained, effortful, and enthusiastic participation in learning tasks. Even though the literature treats the concepts of learner *involvement* and *engagement* separately, they essentially describe the same emotional, cognitive, and behavioral characteristics.

According to Skinner and Belmont (1993), when learners engage in learning tasks they demonstrate continued behavioral involvement accompanied by positive attitude. Engaged learners select tasks that challenge their competency level, and they invest intense effort to accomplish those tasks. Furthermore, as Reeve, Jang, Carrell, Jeon, and Barch (2004) suggest, these learners are characteristically focused, directed, goal oriented, and relentless during their interaction with social and environmental learning conditions. They further propose that learners who engage in dynamic, interactive instruction are "organically" involved in their instructional experience. Thus we can argue that learning environments that employ stimulating and intriguing learning strategies are more likely to engage learners than passive instructional strategies.

On the opposite end of the engagement spectrum are the disaffected learners who, as Furrer and Skinner (2003) describe, are estranged, indifferent, defiant, or burned out, and therefore deprived of motivation for learning. Understanding the learners' lack of motivation due to frustrations, negative expectations, disappointments, and discouragements is essential in identifying the steps in the learning process and the conditions under which loss of motivation occurs (Miceli & Castelfranchi, 2000).

The other concept to which motivation research frequently refers is learners' "involvement." For instance, in their discussion of learners' engagement, Skinner and Belmont (1993) refer to *behavioral involvement* as an indicator of the learners' engagement. They described learners' engagement as "intensity and emotional quality of children's involvement in initiating and carrying out learning activities" (p. 572). The involvement concept is further characterized by Turner et al. (1998) as "complex interaction of student cognition, motivation and affect" (p. 730). Reed and Schallert (1993) also report that *involved* learners describe their learning experience as focused concentration, attention, and deep comprehension, to which Csikszentmihlyi, Rathunde, and Whalen (1993) add positive affect, goal clarity, and intrinsic motivation.

Using the concepts of involvement and engagement interchangeably, Turner et al. (1998), address the issue of measuring these concepts in the literature. They observe that studies of learners' cognition, motivation, and affect have focused on cognitive engagement and involvement, even though the empirical examination of these constructs has differed in focus. Researchers have measured engagement or involvement either through ratings of active involvement, such as effort and positive emotion, or through observations of learners' initiatives in trying to take responsibility for their behavior (Reeve et al., 2004).

Paas, Tuovinen, van Merriënboer, and Darabi (2005) described another method of measuring learners' involvement in the context of Cognitive Load Theory (CLT; see reviews by Paas, Renkl, & Sweller, 2004; Sweller, van Merriënboer, & Paas, 1998). The measure focused on the relative involvement of learners in two or more instructional conditions. It combined the learners' mental effort invested in the learning task and the cognitive load imposed by the performance of that task.

The present study used Pass et al.'s (2005) methodology to examine learners' involvement in three instructional strategies using an existing data set. The strategies included two types of worked examples (process- and product-oriented worked examples) and conventional problem solving. The purpose of the study was to compare the relative involvement attributes of these strategies. The learning task was troubleshooting a computer-simulated chemical processing plant. We hypothesized that learners using both of the worked example strategies would have higher involvement scores than learners using conventional problem solving because they would be encouraged to try the new-found strategies illustrated by the worked examples rather than their own familiar strategies. We also hypothesized that the process-oriented worked example group would show greater involvement than the product-oriented worked example group because the explanation of reasons for diagnoses in the process-oriented worked examples would stimulate individual reasoning about problem-solving strategies.

METHOD

Participants and Experimental Setting

Thirty-six senior engineering students enrolled in a chemical engineering design course participated in the study as part of a required class assignment. All participants had taken courses that instructed concepts, rules, and principles of distillation. The engineering professor required his students to complete the practice to understand how a chemical plant operates as part of their course, but the activity was not graded. The professor did not specify any penalty if they did not complete the activity, but all students completed the activity.

The experiment was conducted in a research laboratory specifically designed for research on the acquisition and transfer of complex cognitive skills using a computer-based simulation. The simulation provided an authentic learning environment in which the participants played the role of the chemical processing plant operator (see Figure 1). As long as all sub-systems of the plant functioned normally, the operator's role involved merely observing the automated operation of the plant. However, the gradual deterioration of the plant's components caused specific malfunctions that the operator diagnosed and repaired as quickly and as efficiently as possible. The learning environment thus afforded students numerous opportunities to handle several mission-critical emergencies which, in the actual operation of a plant, would be rare but potentially costly.

Design and Procedure

Participants were randomly assigned to three groups of 12. All 36 individually received computer-based instruction on how to troubleshoot simulated malfunctions. This introduction consisted of self-paced, computer-based text and graphics to teach participants about the components, features, and troubleshooting processes required to run the simulation. The time they spent in the self-paced instruction ranged from 21 to 56 minutes.

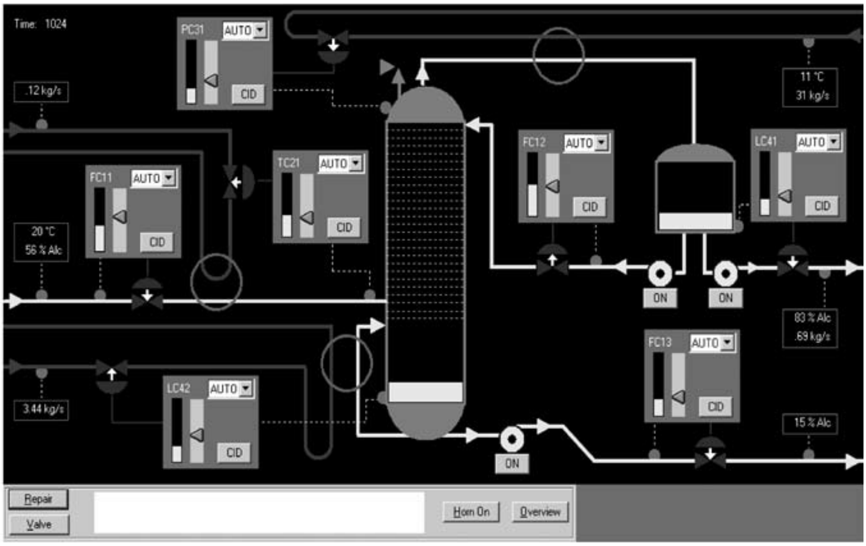

Figure 1: Main interface of the simulation of the chemical processing plant control panel.

Worked examples and conventional problem solving were the contrasted instructional strategies. The three strategies included process-oriented worked examples, product-oriented worked examples (Van Gog, Paas, & van Merriënboer, 2004), and conventional problem solving and were assigned to treatment groups Process, Product, and Problem, respectively. These three instructional strategies were implemented as they are described below:

Process-oriented worked examples. The participants in the Process group were presented with text and graphics describing a procedure for analyzing four simulated plant malfunctions. The instruction not only described the troubleshooting process but also explicated principled reasoning about *why* steps were taken and *how* the most likely cause of the malfunction could be diagnosed.

Product-oriented worked examples. The participants in the Product group were given four worked-out examples with the same malfunctions that were presented to the Process group. The participant's task was to study each of the worked examples in a procedural step-by-step format. However, in contrast to the Process treatment, these worked examples stated only *how* the problems were solved, but not the reasons *why* each step in the procedure was taken. The procedure included five steps for solving each problem: (a) identify the affected regulating loop, (b) inspect preceding and following loops, (c) identify the components of the affected regulating loop, (d) examine each component in the loop—which involved three sub-steps that concluded with identifying the contradictory component as the cause of the malfunction—and (e) report the diagnosis.

Conventional problem solving. Rather than studying how to solve the problem, participants in this strategy, the Problem group, started troubleshooting malfunctions with the fully functional simulation as their practice of skill. They were asked to troubleshoot the same problems as the worked example groups without any description or explanation of the problems.

Following completion of their assigned strategy, which ranged in duration from 8 to 46 minutes, all participants diagnosed the same set of eight novel malfunctions. Participants were instructed to diagnose malfunctions making as few incorrect diagnoses as possible. Twelve minutes were allowed for each malfunction. If a malfunction was not diagnosed correctly within the allotted time, the simulation would end the episode and direct the participant to the next malfunction. The simulation software collected participants' performance and mental effort data after each malfunction episode using the measures described below.

MEASURES AND INSTRUMENTS

Performance measure. For each malfunction following the instructional strategy, the software recorded whether the participants correctly diagnosed the fault on the first try. In the operation of an actual chemical plant, there is little room for operator error. The first-try-correct measure was selected as the performance indicator because of the operational task criticality in the actual chemical distillation environment. The performance score represented the number of first-try-correct responses out of a total of eight.

Mental Effort Scale. The 9-point, single-item Mental Effort Scale (Paas & van Merriënboer, 1994a) measured the perceived mental effort subjects invested in performing the tasks. The question prompted participants to indicate the amount of mental effort they invested in the task they had just completed. At the high end of the scale, "9" was associated with the learner's investment of "very, very high mental effort," and at the low end, "1" was associated with "very, very low mental effort." The scale was administered immediately following each malfunction, whether the malfunction was repaired or not, to provide a subjective rating of the participant's "cognitive load." Paas (1992), Paas and van Merriënboer (1994b), and De Crook, van Merriënboer, and Paas (1998) report Cronbach's coefficient alpha of 0.90, 0.82, and 0.98 respectively. De Crook and van Merrienboer (2007) reported a coefficient of 0.88.

Measure of learners' involvement. The following technique was used to compute and depict learners' involvement of instructional conditions according to Paas et al. (2005). Following their methodology, we converted the mental effort and performance scores into z scores to compute the involvement (I) measure according to the following equation:

$$I = \frac{R + P}{\sqrt{2}}$$

The standardized scores for mental effort (R) and performance (P) were represented on a Cartesian graph with mental effort on the x-axis and performance on the y-axis (see Figure 2). A particular point in this coordinate system refers to a z score for mental effort and its respective z score for performance of a given instructional condition. This graph applies the above equation based on the computation of the perpendicular distance of a point (defined by the stan-

Table 1: Descriptive Statistics for Performance, Mental Effort, and Involvement in Eight Performance Tasks by Treatment Group

						95% Confidence Interval for Mean		*Range*	
Variable	*Treatment Group*	*n*	*M*	*SD*	*Std. Error*	*Lower Bound*	*Upper Bound*	*Min.*	*Max.*
Performance	Problem	12	1.08	1.00	0.29	0.45	1.72	0	3
	Process	12	1.50	1.31	0.38	0.67	2.34	0	4
	Product	12	2.25	1.36	0.39	1.39	3.11	1	5
	Total	36	1.61	1.29	0.22	1.17	2.05	0	5
Mental effort	Problem	12	5.05	0.86	0.25	4.51	5.60	3.63	6.25
	Process	12	5.54	1.40	0.40	4.65	6.43	2.75	7.00
	Product	12	5.85	1.11	0.32	5.15	6.56	4.38	8.00
	Total	36	5.48	1.16	0.19	5.09	5.88	2.75	8.00
Involvement	Problem	12	3.28	0.80	0.23	2.77	3.79	2.12	4.47
	Process	12	3.86	0.82	0.24	3.34	4.38	2.51	5.36
	Product	12	4.49	1.00	0.29	3.86	5.12	2.94	6.01
	Total	36	3.88	1.00	0.16	3.54	4.21	2.12	6.01

dardized means of mental effort and performance for each instructional condition) to a zero involvement line, which is graphically presented as $R + P = 0$. This graph provides a visual display of the composite measure as an indication of learners' involvement, which, according to Paas et al. (2005), represents the motivational attributes of an instructional condition. A shift to the upper right of the coordinate system indicates an increase in those attributes, and a shift to the lower left indicates a decrease.

RESULTS

The data collected for the experiment described in this study were analyzed for the purpose of examining learners' involvement in three instructional strategies based on Paas et al.'s (2005) technique. The descriptive statistics about the variables in this analysis are presented in Table 1.

The degree of learner involvement was calculated by the aforementioned equation using the standardized scores of first-try-correct performance and of mental effort. Analysis of variance was used to examine the learners' involve-

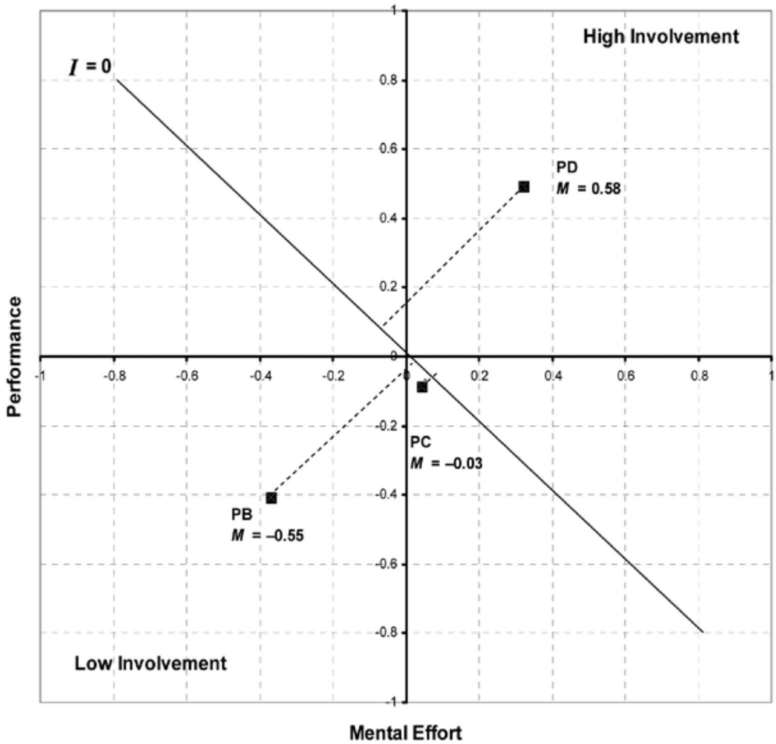

Figure 2: Relative involvement properties for instructional conditions: process-oriented worked examples (PC), product-oriented worked examples (PD), and conventional problem solving (PB). The diagonal line represents the central composite measure of involvement.

ment in the three different strategies. The omnibus test showed a significant difference among the strategies, F (2, 23) = 5.95, p = .006. A planned contrast was analyzed to explore the difference between the conventional problem-solving group (Problem) and the worked example groups (Process and Product). Assuming equal variance, the planned contrast indicated that the learners' involvement in the worked example conditions were significantly different from those in the conventional problem condition (t = -2.88, df = 33, p = .007). To investigate the possibility of a difference between the two worked example groups (Process and Product), the two strategies were contrasted against one another while holding the Problem strategy constant. Again assuming equal variances, the difference between the two conditions was not significant with alpha set at the .05 level (t = -1.91, df = 33, p = .065).

To illustrate the relative involvement of the learners in these strategies we then used the involvement component variables, performance and mental effort, to plot a graph as described in the Method section. The standardized scores of first-try-correct as the performance measure and the invested mental effort for each group were plotted on the x- and y-axes, respectively (see Figure 2).

DISCUSSION

The results supported our first hypothesis that learners using worked example instructional strategies would show greater involvement than the learners using the conventional problem solving strategy. The measure of involvement was based on the Pass et al. (2005) metric, which was developed in the context of CLT, and used learners' invested mental effort and their performance scores as components of the metric. The *involving* features of worked examples found in this study complemented the positive instructional contributions of worked examples found in the literature (Atkinson, Derry, Renkl, & Wortham, 2000; Sweller, Van Merriënboer, & Paas, 1998).

Motivation literature lists attributes of involvement or engagement as (a) sustained, effortful, and enthusiastic participation, (b) positive attitude, (c) intense effort, (d) focused attention, and (e) goal directedness (Reeve et al., 2004; Skinner & Belmont, 1993). Learners who demonstrate any or all of these attributes might be motivated by either performance or learning goals. Accordingly, the composite of standardized mental effort and performance scores may be considered as a measure of learner involvement for the comparison of instructional strategies or other variables.

With regard to cognitive load theory, the underlying involvement measure used in this study relies on the supposition that investment of mental effort in learning tasks, commensurate with the appropriate level of *germane* cognitive load (cognitive demand of instruction that contributes to learning), results in better performance of learning tasks. *Extraneous* cognitive load (cognitive demand of instruction that inhibits learning), on the other hand, results in lower performance scores. Given these principles and the measure's use of both mental effort and learners' performance scores, we suggest that the higher level of involvement indicated by worked examples represents the germane, or effective, cognitive load imposed by these strategies, hence their greater instructional value from behavioral, cognitive, and emotional standpoints. The increased involvement of learners using worked examples may have derived from the focused, goal-directed approach to problem solving that the worked examples modeled.

Our second hypothesis predicted that participants using process-oriented worked examples would demonstrate higher involvement than participants using product-oriented worked examples. Contrary to our expectation, there was no significant difference between the two strategies. We suspect that the similar involving features of the two worked example strategies or the small sample size was responsible for this lack of significant differences. A valid pretest of participants' prior knowledge about troubleshooting the distillation process might have provided a covariate for examining with analysis of covariance the strategies' contributions to subjects' performance and involvement.

Overall, this study provided an example of how the composite measure of involvement recommended by Paas et al. (2005) can differentiate between learners participating in different instructional conditions. Furthermore, considering learners involvement as a motivational attribute of the instructional strategy, the findings indicate that worked examples might be more motivating than the conventional problem solving strategy. For better support of this point, we suggest that this measure of learners' involvement be contrasted with other well-established measures of instructional motivation. An example would be Keller's (1987) Instructional Materials Motivation Survey (IMMS) that analyzes learner perception of the motivational aspects of instructional materials in terms of attention, relevance, confidence, and satisfaction.

Pending such research, this measure is one of the useful tools for differentiating between instructional strategies or groups of learners in terms of their involvement. This measure may be helpful to instructional designers in their analysis of learner characteristics and formative evaluation of instructional materials. In pilot testing of any instructional module, one can gain considerable information about the appropriateness of the content to learner characteristics as well as the level of involvement of the learners among alternative instructional methods or materials by using this approach.

Contributors

A. Aubteen Darabi, PhD, is an associate professor with the Department of Educational Psychology and Learning Systems at Florida State University. He is also one of the Lead research Scientists at the Learning Systems Institute directing research projects funded by federal government.

David Nelson, PhD, is an instructional designer working on training and research projects at the Learning Systems Institute at Florida State University

Fred Paas, PhD is an associate professor at the Open University of the Netherlands Educational technology Expertise Center

References

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. (2000). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research, 70*(2), 181–214.

Csikszentmihlyi, M., Rathunde, K., & Whalen, S. (1993). *Talented teenagers: The roots of success and failure*. Cambridge, England: Cambridge University Press.

De Crook, M. B. M., van Merriënboer, J. J. G., & Paas, F. (1998). High versus low contextual interference in simulation based training of troubleshooting skills: Effects on transfer performance and invested mental effort. *Computers and Human Behavior, 14*, 249–267.

De Crook, M. B. M., & van Merriënboer, J. J. G. (2007). Paradoxical effects of information presentation formats and contextual interference on transfer of a complex cognitive skill. *Computers in Human Behavior, 23*, 1740–1761.

Eggen, P. D., & Kauchak, D. P. (2001). *Strategies for teachers: Teaching content and thinking skills* (4th ed.). Boston: Allyn & Bacon.

Furrer, C., & Skinner, E. (2003). Sense of relatedness as a factor in children's academic engagement and performance. *Journal of Educational Psychology, 95*, 148–162.

Keller, J. M. (1987). *IMMS: Instructional materials motivation survey*. Tallahassee, FL: Florida State University.

Miceli, M., & Castelfranchi, C. (2000). Nature and mechanisms of loss of motivation. *Review of General Psychology, 4*(3), 238–263.

Paas, F. (1992). Training strategies for attaining problem-solving skill in statistics: A cognitive load approach. *Journal of Educational Psychology*, *84*, 429–434.

Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science, 32*(1–2), 1–8.

Paas, F., Tuovinen, J., Van Merrriënboer, J. J. G., & Darabi, A. (2005). A motivational perspective on the relation between mental effort and performance: Optimizing learners' involvement in instructional conditions. *Educational Technology, Research & Development*, *53*(3), 25–34.

Paas, F., & van Merrriënboer, J. J. G. (1994a). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills, 79*(1, part 2), 419–430.

Paas, F. & van Merriënboer, J. J. G. (1994b). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive load approach. *Journal of Educational Psychology*, *86*, 122–133.

Reed, J. H., & Schallert, D. L. (1993). The nature of involvement in academic discourse tasks. *Journal of Educational Psychology, 85*, 253–266.

Reeve, J., Jang, H., Carrell, D., Jeon, S., & Barch, J. (2004). Enhancing students' engagement by increasing teachers' autonomy support. *Motivation and Emotion, 28*(2), 147–169.

Skinner, E. A., & Belmont, M. J., (1993). Motivation in the classroom: Reciprocal effects of teacher behavior and student engagement across the school year. *Journal of Educational Psychology, 85*, 571–581.

Sweller, J., Van Merriënboer, J. J. G., & Paas, F. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251–296.

Turner, J. C., Meyer, D. K., Cox, K. E., Logan, C., DiCinto, M., & Thomas, C. T. (1998). Creating contexts for involvement in mathematics. *Journal of Educational Psychology, 90*, 730–745.

Van Gog, T., Paas, F., & van Merrriënboer, J. J. G. (2004). Process-oriented worked examples: Improving transfer performance through enhanced understanding. *Instructional Science, 32*(1–2), 83–98.