Training and Transfer of Complex Cognitive Skills: Effects of Worked Examples and Conventional Problem-Solving

Abbas Darabi
David W. Nelson
Florida State University

Abstract

Thirty six senior students in chemical engineering were randomly assigned to three treatment groups in an experimental study that examined the impact of different instructional strategies for troubleshooting malfunctions in a computer-based simulation of a chemical processing plant. In two groups, different types of worked examples, process-oriented and product-oriented, were given to participants as instructional strategies for troubleshooting four plant malfunctions. The third group was given a conventional problem solving strategy for the same four problems. The results of participants' performance on solving a set of eight near-transfer problems indicated no significant transfer differences among the treatments. Neither did a far transfer task result in any significant differences. The findings of the current study supported the notion of the "expertise reversal effect" (Kalyuga, Ayres, Chandler, & Sweller, 2003), which argues that presenting new information to learners with pre-existing schemata in a given domain does not improve transfer and may induce extraneous cognitive load. Given the prior knowledge of the participants, these findings were also consistent with Sweller's (2004) thesis on the "central executive function" and his description of the "redundancy effect."

In his analogy between evolution by natural selection and human cognitive architecture, Sweller (2004) lists the assumptions of cognitive load theory. The theory assumes that the purpose of instruction is to build knowledge by making small incremental changes in long-term memory. He argued that, similar to the way a potentially injurious drastic alteration in the human genome is usually prevented by the process of natural selection in species, a sweeping change in an individual's long-term memory is prevented by the severe limitation of working memory when assimilating unfamiliar information. Such assimilation when no schema exists for organizing new information is performed by searching and testing the fit of random combinations of elements in the new material against premises derived from established assumptions retrieved from long-term memory. The demand on working memory is raised exponentially as the number of unfamiliar interacting elements of information is increased. The random search is essential to the human cognitive architecture when learners face completely unfamiliar information and a central executive is absent. However, when facing *familiar* information as opposed to *unfamiliar* information, a highly effective central executive function becomes available. As opposed to the human genome, this function is not a general biological structure, but a specific learned structure retrieved from long-term memory. In other words, cognitive processes conditioned by domain-specific knowledge act as the central executive when sufficient elements of instructional material are familiar. On the other hand, when the learner lacks a central executive because the information is unfamiliar, the use of worked examples in the design of instructional material can provide a surrogate central executive that constrains the problem space and the number of interacting elements to be randomly searched.

Based on Sweller's (2004) argument, when instruction is properly designed, effective changes to long-term memory structures are orderly and occur in small increments. Cognitive load theory provides guidelines for designing instruction. Investigating and expanding upon these guidelines, researchers have identified instructional strategies that can facilitate incremental changes in long-term memory. The use of worked examples is one of those instructional strategies that promotes efficient and effective learning by reducing extraneous cognitive load through the introduction of schemata and by acting as the "instructional central executive" (p. 21) and accommodating the limited capacity of the working memory of novices.

When teaching complex cognitive skills to novices, the instructional strategy of presenting a set of worked examples for learners to study has been repeatedly found more effective than the conventional problem solving strategy in which they are provided problems to solve immediately after presentation of information in the domain (e.g., Cooper & Sweller, 1987; Paas, 1992; Paas & van Merriënboer, 1994a; Sweller & Cooper, 1985; for a review, see Atkinson, Derry, Renkl, & Wortham, 2000). Two types of worked examples, process-oriented and product-oriented, have been distinguished with regard to the cognitive load those worked example strategies impose on learners and the instructional efficiency of those types (Van Gog, Paas, & Van Merriënboer, 2004). Specifically, Van Gog, et al. proposed that in the initial instruction of novices, the process-oriented worked example strategy, which explains not only *how* to solve a given problem but *why* the operations are employed, would result in greater problem solving performance and transfer. In contrast, the product-oriented worked examples strategy that just describes the procedures involved in solving a problem would be more effective only after a learner has constructed relevant schemata.

Based on Van Gog, et al.'s (2004) contentions, process-oriented worked examp les should be more effective when used with novices who have established relevant schemata prior to instruction. They would therefore benefit from the knowledge provided by *why* problem solving principles. To our knowledge, no empirical studies have been conducted to examine both of these strategies at once for their impact on the instructional outcomes. The current study investigated the effects of these two types of worked examples with a control condition that employed conventional problem solving. It reports measured effects on performance of acquired skills in troubleshooting.

Method

Participants

Thirty-six senior engineering students enrolled in a Chemical Engineering Design course offered by the Florida A&M University – Florida State University College of Engineering participated in the study as part of a required class assignment. They engaged in this activity as a required assignment in their final semester of the bachelor's degree program. Twenty-one of the participants were male and 15 were female. All except one were Chemical Engineering majors and had taken courses that introduced concepts of distillation.

Procedure

The participants engaged in instruction about a water-alcohol distillation plant as a simulation specifically designed (De Croock & Betlem, 1999) for experiments in the area of complex cognitive skills (see Figure 1). The initial instruction on how to operate the simulation was the same for each participant. In the following treatment, three instructional strategies were employed: (1) process-oriented worked examples, (2) product-oriented worked examples, and (3) conventional problem solving. Each of the three treatment groups encountered the same four faults in the plant. For even distribution of participants with varying degrees of prior knowledge in distillation, the subjects were divided into two categories of high and low according to their scores in a recent course that taught them distillation. Equal numbers of participants in high and low categories were then randomly assigned to the three treatment groups and were given, process-oriented worked examples (PC), product-oriented worked examples (PD), and conventional problem solving (PB).

Following the instruction, as a near-transfer task, all 36 participants diagnosed eight malfunctions they had not previously encountered, for which they were limited to 12 minutes for each malfunction. Participants were told to "make as few incorrect diagnoses as possible and diagnose the malfunction as quickly as possible." A far transfer task designed in CHEMCAD measured the number of trials for participants to solve a problem conceptually related to the near transfer task. CHEMCAD is a computer simulation program used by chemical engineers.

Performance Measures

Three measures of performance were used to assess learners' performance. Those three measures were (1) the total number of correct diagnoses within the 12 minute limit, (2) the number of incorrect diagnoses participants reported, and (3) the time required to diagnose a malfunction correctly.

Mental Effort

The 9-point Mental Effort Scale (Paas & van Merrriënboer, 1994b) measured the subjects' perceived mental effort invested in performing the tasks. At the high end of the scale, 9 was associated with the response "very, very high mental effort" and at the low end of the scale, 1 was associated with the response "very, very low mental effort." The scale was administered immediately following each correct diagnosis and repair to provide a subjective rating of the variable "cognitive load."

Results

With alpha set at .05, an ANOVA revealed no significant differences among the treatment conditions on any of the dependent measures of performance. Table 1 displays the mean performance scores and standard deviations for treatment groups, summed across the eight problems, along with reports of perceived mental effort. The far transfer performance measured in number of trials to solve the problem are also reported in Table 1.

Table 1 *Means and standard deviations of dependent measures summed across eight problems*

	Process-oriented worked examples (PC)		***Product-oriented worked examples (PD)***		***Conventional problem solving (PB)***	
	M	***SD***	***M***	***SD***	***M***	***SD***
Correct diagnoses	6.91	1.00	6.75	0.97	7.17	0.83
Incorrect diagnoses	27.33	13.09	32.33	12.35	25.75	7.88
Time to correct diagnoses (in seconds)	1086	402	1097	320	1034	357
Perceived mental effort	44.33	11.22	46.83	8.86	40.41	6.88
Far transfer performance	14.08	5.87	15.92	7.25	17.58	12.85

Further analysis of the data revealed an unexpected difference between male and female participants on two of the performance measures. Females had a significantly ($p = 0.02$) higher number of incorrect diagnoses ($M = 33.60$, $SD = 11.35$) than males ($M = 24.81$, $SD = 10.12$). They also took less time, calculated in seconds ($M = 870.93$, $SD = 227.52$), than their male counterparts ($M = 1215.62$, $SD = 332.95$) to correctly diagnose the malfunctions ($p = 0.002$).

Discussion

In the context of Sweller's (2004) analogy of human cognitive architecture to evolution by natural selection, worked examples can provide an instructional central executive when none exists in the domain represented by the learning tasks. Worked examples are found to be effective (Cooper & Sweller, 1987; Paas, 1992; Paas & van Merriënboer, 1994a; Sweller & Cooper, 1985) because they cause incremental changes in long-term memory through acquisition of the new information they present, thus building new schemata. However, if a learner's long-term memory contains pre-existing schemata for solving problems in the domain, the instruction would not be effective and could even impose extraneous cognitive load.

In this context, the process-oriented worked examples were expected to contribute to the participants' performance more than the other strategies by providing the elements for building new schemata. We argue that the ineffectiveness of the worked examples demonstrated by the results of this study was due to high level of the participants' prior knowledge and the existence of schemata for solving these types of problems. It seems likely that the participants, who were already familiar with the principles of distillation, gained little from the principled reasoning presented in the worked examples. Indeed, they might have experienced the "expertise-reversal effect" (Kalyuga, Ayers, Chandler, & Sweller, 2003; Kalyuga, Chandler, Tuovinen, & Sweller, 2001), in which instruction designed to facilitate construction of schemata conflicts with learners' existing schemata and thus inhibits their understanding.

According to the data presented in Table 1, all three treatment groups correctly solved an average of seven of the eight problems presented to them. We attribute this rather high performance to the participants' prior knowledge which rendered the strategies practically ineffective for these participants. Further support for this argument is apparent in the participants' perceived mental effort also presented in Table 1. According to this information, the mean mental effort for the three groups across the eight problems they solved was near the midpoint of the mental effort scale. They reported an average mental effort of 40, 44, and 47 out of a possible score of 72 across the eight tasks. These are relatively low mental effort scores for solving complex problems and indicate that participants had little difficulty. This argument is further substantiated by participants' performance on the far transfer task. All of the participants correctly solved the CHEMCAD problem with an average number of trials (M = 15.86) much lower than expected.

We speculate that novice participants, given the same instructional treatments and experimental conditions, would respond differently to the different types of worked examples. Using process-oriented worked examples, novices would be expected to perform better than those using the other strategies. However, they would be expected to invest much higher mental effort in the problem solving process. In summary, the conventional problem solving exercises were probably more suitable for these participants and the use of worked examples made little difference in their performance. These findings further substantiate our argument that the participants' prior knowledge accounted for the worked examples not being significantly different from the conventional problem solving strategy in their contribution to the participants' performance.

Further analysis of the performance measures revealed two unexpected results among the participants. Females made more incorrect diagnoses than males and took less time to diagnose malfunctions. We attribute this difference to the instruction given at the beginning of the performance phase of the experiment. We told the participants to "diagnose the malfunction as quickly as possible" and "make as few incorrect diagnoses as possible." Apparently males and females responded differently to these instructions. Based on the results of the study, each group favored only one portion of the instructions. An explanation for the reasons for these differences between the diagnostic behaviors of males and females could be the subject of further research.

Future investigation can also focus on the effectiveness of the strategies used in this study by involving novice participants in the same experimental conditions. Worked examples – process-oriented and product-oriented – along with the conventional problem solving strategy may demonstrate a significant difference in novices' performance. The lack of a central executive in novices' long-term memory structures – or schemata – should reveal the different effects of the instructional strategies. We suggest that replicating the experiment with novice learners would provide a set of data by which one can compare the results with those of this study.

References

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

Cooper, G., & Sweller, J. (1987). The effects of schema acquisition and rule automation on mathematical problem-solving transfer. *Journal of Educational Psychology, 79*, 347-362.

De Croock, M. B. M., & Betlem, B. (1999). DISTILLER: A computer simulation of a water/alcohol distillery system for research and training for transfer of supervisory control and troubleshooting skill. In M. B. M. De Croock, Ed. *The Transfer Paradox: Training Design for Troubleshooting Skills*, pp. 59-87. Enschede, The Netherlands: Print Partners Ipskamp.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. Educational Psychologist, 38(1), 23-31.

Kalyuga, S, Chandler, P., Tuovinen, J., & Sweller, J. (2001). When problem solving is superior to studying worked examples. *Journal of Educational Psychology, 93*(3), 579-588.

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

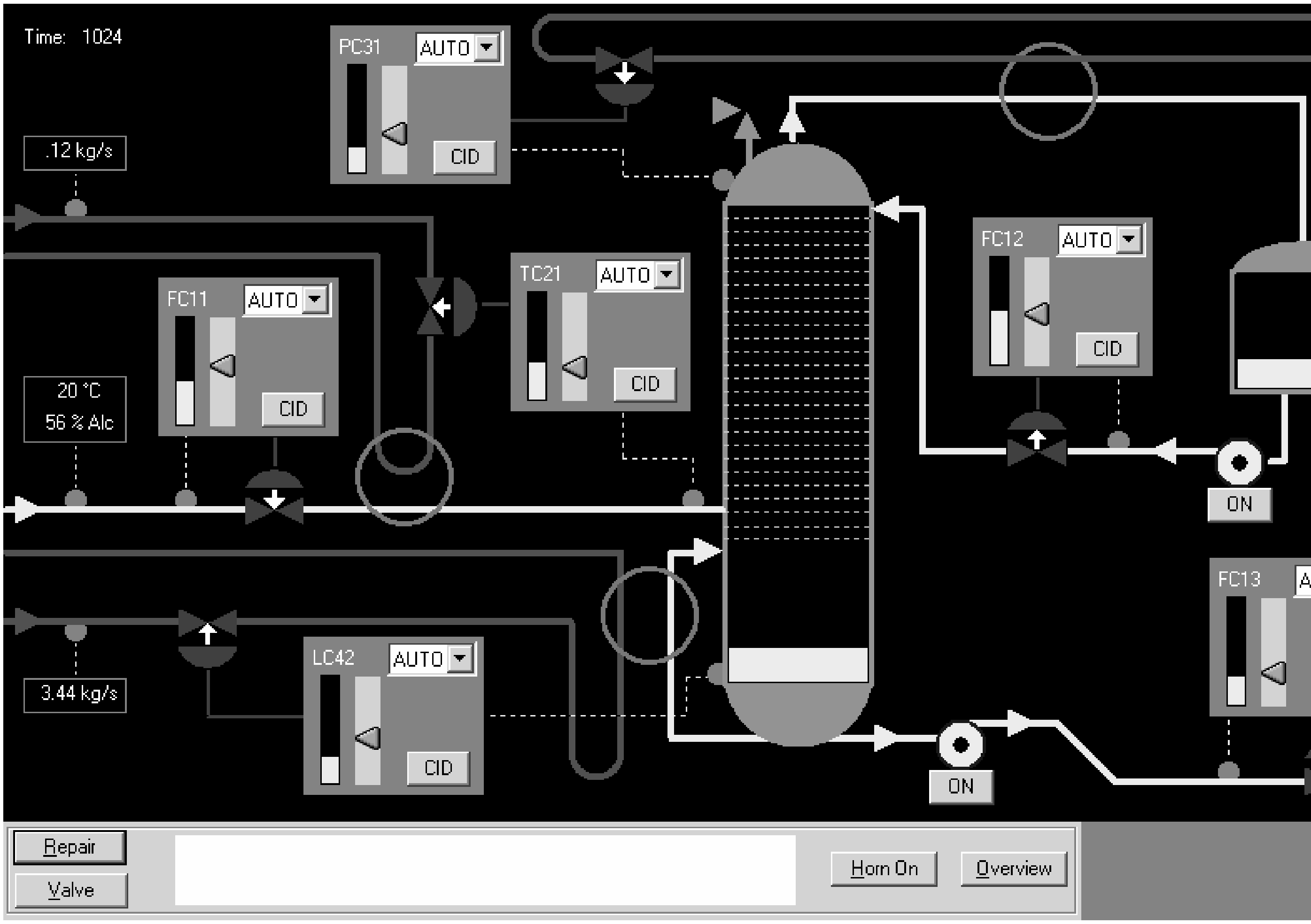
Paas, F. G. W. C., & van Merrriënboer, J. J. G. (1994a). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive load approach. *Journal of Educational Psychology, 86*, 122-133.

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

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science (32)*1-2, 9-31.

Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction, 2*, 59-89.

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



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