Learner Achievement and Attitudes under Different Paces of Transitioning to Independent Problem Solving

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ABSTRACT

This study examined the effect of the pace of transitioning from worked examples to independent problem solving for students with three different levels of prior knowledge. Three paces of transitioning were examined: immediate transitioning, fast fading, and slow fading. The study was conducted with engineering college freshmen in the engineering knowledge domain of introductory electrical circuit analysis and found a significant interaction between the particpants' prior knowledge and the pace of transitioning to independent problem solving on retention posttest performance. The high prior knowledge participants achieved significantly higher retention scores under the fast and immediate transitioning than under the slow transitioning, whereas the low prior knowledge participants achieved significantly higher retention scores under the slow transitioning. The interaction result for retention indicates that by selectively employing slow fading for low prior knowledge learners and fast fading or immediate transitioning for high prior knowledge learners, significant improvements in learning may be achieved.

Keywords: fading, prior knowledge, worked example

I. INTRODUCTION

Instruction in introductory engineering courses typically employs worked examples and practice problems. A worked example is a fully solved example problem that allows the student to consequently examine the full sequence of the individual steps leading to the solution of a problem [1, 2, 3]. A practice problem, on the other hand, provides the student with the problem statement and the student is responsible for solving the individual solution steps. A fundamental question is how to most effectively transition the learner from studying worked examples to independently solving practice problems? This study focused on this key pedagogical aspect of introductory engineering instruction, namely the transitioning from worked examples to practice problems. In particular, this study examined the effectiveness of *different static paces of transitioning to independent problem solving* for teaching introductory electrical circuit analysis. To the best of the authors' knowledge this important pedagogical technique has not been previously examined in detail; neither in the general educational psychology literature, nor in the engineering education literature.

A number of popular contemporary models for cognitive skill acquisition, such as the Adaptive Control of Thought-Rational (ACT-R) framework [4, 5] and the cognitive load theory [6, 7, 8], suggest a transitioning from studying worked examples at the initial stage of skill acquisition to independently solving practice problems at the more advanced stages of skill acquisition. The recently proposed fading instructional design provides for a smooth transition from studying worked examples to independent problem solving [9]. In the fading approach, the learner is initially presented with a fully worked example. In the following example all but one of the problem steps are worked out and the learner is required to independently solve the missing problem step. In the subsequent example all but two problem steps are worked out and the learner is required to provide the solutions to the two missing problem steps, and so on, until the learner is required to solve all problem steps, which corresponds to independent problem solving. This fading design is implemented in two distinct ways: forward-fading, where the solution steps are omitted starting with the first problem steps, and backward-fading, where the last solution step is omitted first, then the last two, and so on. Recent studies suggest that fading, especially backward-fading, has a positive effect on learning [9, 10].

While the existing studies provide evidence of the benefits of instructional designs that transition from worked examples to independent problem solving, they do not address the question as to how *fast* this transition should occur. In the existing studies on fading, for instance, the number of worked solution steps was always reduced by one with each new example that the learner encountered [9–13]. However, the number of worked example steps can be reduced at a faster or slower pace. A thorough understanding of the impact of the pace of transitioning from studying worked examples to solving practice problems on learner achievement and attitudes is vital to reap the most benefits from instructional designs with fading worked solution steps.

As a first step towards examining the impact of the pace of transitioning to independent problem solving, the study [14] considered an adaptive fading design, where the number of worked solution steps was reduced by one if the learner's preceding solution attempt was successful, otherwise the number of worked solution steps was not reduced. A learner who solved all steps correctly experienced essentially conventional backward fading with one less worked solution step with each new problem, whereas the pace of transitioning was effectively slowed down for learner who had difficulty in solving the problem steps. Thus, the fading was adapted for each individual learner according to the learner's successes and failures in solving problem steps. It was found that adaptive fading significantly improves near- and far-transfer post-test performance compared to backward fading at a static pace, while not requiring more learning time or learning materials. A drawback of adaptive fading is that it requires individualized instruction through computer-based modules or a personal instructor/ tutor.

The present study seeks to examine whether benefits of varying the pace of transitioning can also be achieved in a group instruction setting. Consider an educational setting where the students in a class are split up into groups according to their level of prior knowledge, as assessed with a pre-test. The groups are then taught with different static paces of transitioning to independent problem solving, whereby the higher the prior knowledge level in a group, the faster pace of transitioning. While examining this instructional technique, this study included three treatment conditions corresponding to *different static paces* of transitioning to independent problem solving, namely an immediate transitioning condition, a fast fading condition, and a slow fading condition. In the immediate transitioning condition, after the initial presentation of instructional examples, the learners directly proceeded to practice. The fast fading condition corresponded to conventional backward fading. Slow fading was similar to backward fading but the pace at which the worked solution steps were faded was reduced to one solution step for every two problems. These three conditions were investigated under three levels of prior knowledge.

The primary research questions for the study were:

1. What is the effect of the pace of transitioning from worked examples to independent problem solving on learner post-test achievement?
2. Is there an interaction between the pace of transitioning from worked examples to independent problem solving and the level of prior knowledge of the learners?
3. How does the transition pace affect learner attitudes?

Time on task and performance on in-program practice items under the treatment conditions were also analyzed.

A. Related Work

Research on engineering instruction involving fading, or more generally worked examples, has received relatively little interest to date. Leland et al. [15, 16] have recently examined how self-explanations of worked examples encourage the active processing of the learning material and foster the problem solving skills of engineering students. The electrical circuit tutorial materials by McDermott and Shaffer [17] are similarly designed to encourage active processing. The present research relates to these existing works in that it explores a different worked example based approach for fostering active processing, namely through asking the learners to solve increasingly larger parts of the problems.

The presentation and format of the feedback in fading with a pace of one less worked example step with each new problem was examined in [12]. It was found that novice learners, especially those with lower academic ability, achieved better near-transfer post-test performances when the feedback was in textual form and automatically presented by the learning system. Fading with a pace of one less worked example step with each new problem was compared with abruptly switching from worked examples to practice problems in "Encountering the Expertise Reversal Effect with a Computer-based Learning Environment on Electrical Circuit Analysis" [13]. It was found that fading resulted in significantly lower near-transfer post-test performance for higher prior knowledge learners compared to problem-example pairing.

II. Method

A. Participants

The participants in this study were 235 engineering college freshmen representative of the freshman class at a large metropolitan university in the Southwest U.S. The experimental sample consisted of 186 males (79 percent) and 49 females (21 percent). The average age of the participants was 20.07 years ($SD = 2.89$) and the range was from 17 to 39 years old. The average grade point average (GPA) of the participants was 3.09 ($SD = 0.52$).

B. Materials

A computer-based learning environment served as a platform for the rigorously controlled assessment of the effectiveness of the different paces of transitioning to independent problem solving. The program had two main sections, (1) an Introductory Overview, and (2) Practice. The introductory overview contained basic instruction on the fundamental concepts of electrical circuits and presented the participants with steps for calculating the electrical current, voltage, and resistance in parallel electrical circuits. The information contained in this material was concise and was presented on six screens. The overview introduced the participants to (a) the physical meaning and units of electrical current, voltage, and resistance, (b) electrical circuit elements, such as light bulbs and batteries and the way circuit elements are connected with wires in parallel electrical circuits, (c) the physical meaning and units of resistance as well as Ohm's Law, and (d) the calculation of the total resistance in a parallel circuit. The program explained how to calculate the total resistance for the parallel circuits from basic principles, namely Ohm's Law and the properties of resistance and voltage in the electrical circuits.

After the Introductory Overview section, the participants proceeded to practice the steps in solving parallel electrical circuit analysis. The computer-based instructional environment presented a set of instructional examples/problems with three distinct solution steps each on computing the total resistance in parallel circuits. Each step was clearly labeled and visually distinguished from the other steps. The participants navigated linearly through the individual examples/problems by clicking the "Continue" button while revealing one step at a time. The program allowed the participants to proceed through the module by clicking on the "Next Problem" buttons after all three steps in a problem had been displayed. The participants were not allowed to return to previous steps and problems once they had finalized their answers.

Only a single attempt at solving each missing step was allowed. Feedback followed each participant's solution attempt. If the solution of the missing solution step was correct, the feedback confirmed that the solution attempt was correct. In the case of an incorrect attempt, explanatory feedback provided the correct answer.

Instructional Sequence of Examples/Problems

Transitioning Pace		Problem Number							
		1I	2I	3I	4I				
Immediate (I)	Step	?	?	?	?				
	Step	?	?	?	?				
	Step	?	?	?	?				
		Problem Number							
		1F	2F	3F	4F	5F	6F		
Fast (F)	Step	1	1	1	?	?	?		
	Step	2	2	?	?	?	?		
	Step	3	?	?	?	?	?		
		Problem Number							
		1S	2S	3S	4S	5S	6S	7S	8S
Slow (S)	Step	1	1	1	1	1	1	?	?
	Step	2	2	2	2	?	?	?	?
	Step	3	3	?	?	?	?	?	?

Note: "?" indicates steps that the learner has to solve independently

Figure 1. Sequencing of problem steps under immediate, fast, and slow fading.

The feedback was automatically presented by the module in textual format, which has recently been found to be beneficial for novice learners [12]. The solved step(s) remained visible on the screen after the final answer was presented, allowing time for the participants to study the entire solution.

The module had been programmed to operate in one of three modes that corresponded to the three different paces of transitioning to independent problem solving. The individually worked solution steps were faded at three different paces, specifically immediately after the initial knowledge acquisition, fast faded, or slowly faded. The principles of immediate, fast, and slow fading are illustrated in Figure 1.

The instructional sequence of the examples/problems and steps requiring independent problem solving from the participants varied according to the experimental condition. Even though the number of examples/problems were different in the treatment conditions (eight in the slow fading, six in the fast fading, and four in the immediate transition), the actual number of steps that the participants solved independently was held constant at 12 across the three different transitioning conditions. The equivalent number of 12 solution steps to be solved independently by the participants is represented by "?" in Figure 1.

1) Immediate Transitioning Condition: The learner was only presented with instructional examples in the introductory overview section of the program. In the practice section, all problem steps required the learner to engage in independent problem solving. Thus, no fading of worked solution steps was implemented. Rather, after the initial presentation of examples, the learner immediately practiced the newly gained skills by working through a set of four practice problems (denoted by I1, I2, I3, and I4 in Figure 1), with each problem having three solution steps.

2) Fast Fading Condition: This condition corresponded to the conventional backward fading approach. For example, problem 1F, was fully solved (worked out) and the learners viewed the three solved problem steps. In the second problem (2F), as illustrated in Figure 1, the first two steps were solved and the learners had to solve the third step. In the third problem (3F), only the first solution step was worked out and the learners had to solve the second and third solution step. In the fourth problem, the learners had to solve all three solution steps independently. After this fast transition from studying examples to independent problem solving, the learners further practiced their newly acquired skills by attempting to solve two more problems. This brought the total number of problem steps attempted independently to 12.

3) Slow Fading Condition: In this condition the first problem (1S) was fully solved (worked out) and the learners viewed the three solved problem steps. Unlike the fast fading condition, all three solution steps in the second problem (2S) were also worked out, as illustrated in Figure 1. In the third and fourth problems, the first two solution steps were worked out and the learners had to solve the third solution step. In the fifth and sixth problems, only the first solution step was worked out and the learners had to solve the second and third solution step. In the seventh and eighth problems, the learners had to solve all three solution steps independently.

C. Procedures

One week before the experimental treatment, the participants were administered a pre-test, which is described in the Section II.D. Based on the results of the pre-test, the participants were blocked by prior knowledge and randomly assigned into one of the nine different treatment groups as defined by 3 (prior knowledge: high, medium, or low) $\times$ 3 (pace of transitioning to independent problem solving: slow, fast, or immediate) factorial design.

The following week the treatment (computer learning phase) took place. Each participant was seated in front of a Windows-based desktop computer. The participants were instructed to work independently of their peers. The participants studied the initial training materials within the computer-based learning environment. Following the introductory self-study of the basic principles of electrical circuit analysis, the participants studied worked-out examples (in the slow and fast fading conditions) and engaged in independent problem solving (in all conditions) in the computer module. During this phase the experimental variation took place. After finishing the activities in the computer-based learning environment, the participants were administered a paper-based attitude survey. The post-test was handed out last and required answering six multiple-choice questions and independent problem solving of eight problems.

D. Criteria Measures

The study used a post-test and an attitude survey to evaluate the impact of the two independent variables and their interaction. A pre-test was used as a measure of prior knowledge. Following [18], the construct validity of all criterion measure instruments was assessed with the judgment of subject matter experts on electrical engineering instruction in conjunction with a pilot with a sample of the target audience.

1) Pre-test: The pre-test was composed of two parts, with each part consisting of six questions. The first part contained six multiple-choice items relating to the basic physical meaning of electrical current, voltage, resistance, and elementary properties of electrical circuits. These questions measured conceptual understanding of basic properties of electrical circuits. The second part of the pre-test included six items that required the participants to solve problems by applying Ohm's Law and the basic principles of current and voltage in the domain of basic electrical circuits. In particular, the participants had to provide an open-ended response, e.g., engage in independent solving of relatively straightforward problems. Each solution involved one arithmetic operation. The complete pre-test consisting of 12 items had a reliability of Cronbach $\alpha = 0.79$, whereby an α value between 0.72 and 0.88 generally indicates acceptable to high reliability.

2) Post-test: A fourteen-item paper-based post-test consisting of conceptual understanding, retention, and transfer problems was created to assess the participants' ability to retain and to transfer the knowledge obtained from the instructional environment to novel problems. The conceptual understanding items were identical to the pre-test and had a reliability of Cronbach $\alpha = 0.45$. In interpreting this relatively low level of the Cronbach α coefficient, it is important to note the relatively small number of six items on this section of the post-test. In addition, while the mean scores for the different conceptual items were relatively consistent (lying within a range from 0.74–0.94), the range of the between-subjects standard deviations was relatively wide (0.26–0.48), which may reflect diverse levels of understanding of the different conceptual aspects among the learners. The retention and transfer problems required the participants to independently solve electrical circuit analysis problems. The participants had to work out three solution steps in each problem, whereby each step involved reasoning about the behaviors of the currents, voltages, and resistance values in the circuit and carrying out the appropriate calculations.

Four post-test items were similar to the problems the participants encountered within the computer-based learning environment, meaning that they had the same underlying structure but different surface features, such as parameter values and cover stories. These post-test items measured retention of participants' knowledge. Their solution required the participants to engage in the same problem-solving tasks as in the learning (computer) phase. The problem statements provided the participants with the battery voltage and the individual resistance values of two to three circuit elements and required the participants to compute the total resistance of the given electrical parallel circuits. The retention items had a reliability of Cronbach $\alpha = 0.80$.

Four problems measuring transfer performance were also included in the post-test. Transfer problems had different underlying structure and different surface features than the practice problems within the computer-based learning environment. The transfer parallel circuit problems contained only the individual resistance values and the current flowing through one of the resistors. The participants were required to calculate the current provided by the battery. In order to solve the transfer problems the participants had to apply the same basic principles (Ohm's law and basic properties of voltages and currents in parallel circuits) as in the practice problems, but the sequence in which these principles were deployed and the circuit element to which Ohm's Law was applied varied from the practice problems and from the solution steps presented in the introductory overview. The transfer items had a reliability of Cronbach $\alpha = 0.89$.

3) Enroute Measures-Practice Performance and Time in Program: Enroute measures included the practice performance which is a count of correct solution attempts of each learner when solving the missing solution steps. The practice performance was included to assess the impact of the two independent variables on the learning process. The program also measured the time learners spent on the introductory overview of electrical circuit analysis, and the time spent on the independent problem solving of missing solution steps (which added up to the total instruction time spent during the learning phase). The timing measurements were included to assess whether any differences in learner achievement or attitudes were due to differences in the learning time.

4) Attitude Survey: A fourteen-item Likert-type five-choice (4 = strongly agree, 0 = strongly disagree) attitude survey was included for the comprehensive formative assessment of the examined different paces of transitioning to independent problem solving. The survey was designed to assess participants' (a) perceptions toward the overall instructional effectiveness of the module (4 items), (b) continuing motivation, i.e., willingness to continue to study the electrical engineering area (3 items), (c) perceptions about the effectiveness of the instructional strategies (3 items), and (d) attitudes regarding the usefulness and instructional value of different paces of transitioning to independent problem solving (4 items). The survey also included three three-choice items to assess perceptions about the number of in-program examples and problems (too little, about right, too many), and the pace of transitioning (too slow, about right, too fast).

E. Scoring and Blocking Procedures

The pre-test contained a total of twelve items. Each correctly answered question received one point, resulting in a total pre-test score in the range from 0–12 points for each participant. The overall average pre-test score was 7.00 ($SD = 2.96$). Based on the pre-test, the participants were blocked into three distinct groups that reflected the various levels of prior content-specific knowledge. The cutoff points for assigning participants into the three prior knowledge groups were selected as $\pm 1SD$ from the mean, thus resulting in two cut points of 4 and 10, respectively. The low prior knowledge group had a pre-test score of 4 or less ($M = 3.50$, $SD = 0.78$) and a total of 58 participants. The medium prior knowledge group had a pre-test score in the 5 to 9 range ($M = 6.41$, $SD = 1.09$) and 111 participants. The high prior knowledge participants scored 10 or above on the pre-test ($M = 11.08$, $SD = 0.77$) and had 66 participants.

The conceptual understanding items were identical on the pre-test and post-test and were scored in the same manner on both tests. For the scoring of the retention and transfer post-test items, each correctly solved arithmetic operation that the participants had to carry out while solving the post-test problems was assigned a score of 1. The maximum total score was 19 for the retention post-test items and 13 for the transfer post-test items.

III. Results

A. Achievement

Participant achievement on three types (conceptual understanding, retention, and transfer) of post-test problems is reported in Table 1. The table shows the mean scores (*M*) and standard deviations (*SD*) for each treatment condition and level of prior knowledge. The mean scores were 5.30 (88 percent) on conceptual understanding, 16.93 (89 percent) on retention, and 7.82 (60 percent) on transfer.

A 3 (prior knowledge: high, medium, and low) $\times$ 3 (pace of transitioning to independent problem solving: slow, fast, immediate) $\times$ 3 (post-test problem types: conceptual understanding, retention, and transfer) multivariate analysis of variance (MANOVA) conducted on the post-test scores, i.e., the total scores for conceptual understanding, retention, and transfer, yielded a significant overall difference for the prior knowledge factor, Wilks' $\Lambda = 0.78$, $F(6,448) = 9.83$, $p < 0.001$. The totals rows in Table 1 reveal that high prior knowledge participants outperformed their medium prior knowledge counterparts on all three types of post-test problems and that the medium prior knowledge subjects outscored the low prior knowledge participants on all three types of problems.

The MANOVA did not yield a significant overall difference for the pace of transitioning to independent problem solving factor, Wilks' $\Lambda = 0.99$, $F(6,448) = 0.43$, $p = 0.86$. However, the interaction of treatment and prior knowledge was significant, Wilks' $\Lambda = 0.90$, $F(12, 593) = 1.97$, $p = 0.02$. As a follow-up to the significant MANOVA findings, 3 (prior knowledge) $\times$ 3 (pace of transitioning) univariate analyses of variance (ANOVAs) tests were performed for each of the three post-test problem types.

1) Conceptual Understanding: The 3 $\times$ 3 ANOVA conducted on the post-test conceptual understanding questions revealed a significant main effect for the prior knowledge factor, $F(2,226) = 8.99$, $MSE = 0.92$, $p < 0.001$, $\eta^2 = .074$. Follow-up pairwise comparisons using the Fisher's LSD post hoc tests uncovered that both high ($M = 5.58$) and medium ($M = 5.36$) prior knowledge participants scored significantly higher ($p < 0.001$ and $p = 0.002$ respectively) than their low ($M = 4.86$) prior knowledge counterparts. There was no significant interaction between the treatment and prior knowledge.

2) Retention: The follow-up 3 $\times$ 3 ANOVA uncovered significant differences between the different prior knowledge groups on retention post-test performance, $F(2,226) = 18.48$, $MSE = 9.99$, $p < 0.001$, $\eta^2 = 0.141$. A Fisher's LSD post hoc test on prior knowledge revealed that the high prior knowledge participants ($M = 18.11$) scored significantly higher ($p < 0.001$) than their low prior knowledge counterparts ($M = 14.81$). Similarly, the medium prior knowledge participants ($M = 17.33$) also scored significantly higher ($p < 0.001$) than their low prior knowledge counterparts ($M = 14.81$). The difference in performance between the high and medium prior knowledge participants was not significant.

The ANOVA for retention scores also revealed a significant prior knowledge by pace of transitioning interaction on the post-test retention items, $F(4, 226) = 4.74$, $MSE = 9.99$, $p = 0.001$. This interaction is shown in Figure 2. The interaction reflects a different pattern of scores for the three prior knowledge levels across the three treatment conditions. The high prior knowledge participants scored higher under the fast fading and immediate transitioning conditions than under the slow fading condition. The medium prior knowledge participants performed at a similar level under all three treatments. In contrast to the high prior knowledge participants, the low prior knowledge subjects had higher retention scores under the slow fading condition than under the fast fading and immediate transitioning conditions.

The prior knowledge by pace of transitioning interaction effect was analyzed using a simple main effect analysis. The analysis revealed that the retention scores of the high prior knowledge participants varied significantly by the pace of transitioning, $F(2,63) = 3.89$, $MSE = 6.53$, $p = 0.03$. Fisher's LSD post hoc tests revealed that the retention scores of high prior knowledge participants were significantly higher under both the fast fading ($M = 18.86$) and immediate transitioning ($M = 18.64$) conditions than under the slow fading condition ($M = 16.91$), $p = 0.01$ and $p = 0.03$, respectively. For the low prior knowledge participants, the mean retention scores also varied significantly by pace of transitioning, $F(2,55) = 3.97$, $MSE = 17.08$, $p = 0.03$. Follow-up pair-wise comparisons for these participants revealed that they had a significantly higher score ($M = 17.00$) under the slow pace of transitioning than under the fast fading ($M = 13.80$) and the immediate transitioning ($M = 13.68$) conditions, $p = 0.02$ for both comparisons. There were no significant differences between the mean retention scores of the medium prior knowledge participants under the three different paces of transitioning.

Condition	Prior Knowledge		Conceptual (max. 6)	Retention (max. 19)	Transfer (max. 13)
Slow Fading	High	*M*	5.48	16.91	8.22
	(*N=23*)	*SD*	0.95	4.16	4.76
	Medium	*M*	5.28	17.26	8.62
	(*N=39*)	*SD*	1.12	2.99	4.96
	Low	*M*	4.89	17.00	5.42
	(*N*=19)	*SD*	1.29	1.67	3.82
Fast Fading	High	*M*	5.71	18.86	11.14
	(*N=21*)	*SD*	0.72	0.65	2.83
	Medium	*M*	5.51	17.81	7.95
	(*N*=37)	*SD*	0.84	2.12	5.18
	Low	*M*	4.75	13.80	4.25
	(*N=20*)	*SD*	0.64	2.46	3.46
Immediate Transitioning	High	*M*	5.55	18.64	10.32
	(*N=22*)	*SD*	0.67	1.05	3.62
	Medium	*M*	5.29	16.91	7.89
	(N=35)	*SD*	1.02	3.46	4.95
	Low	*M*	4.95	13.68	4.89
	(*N=19*)	*SD*	1.13	6.56	5.37
Totals	High	*M*	5.58	18.11	9.85
	(*N=66*)	*SD*	0.79	2.67	3.99
	Medium	*M*	5.36	17.33	8.16
	(N=111)	*SD*	1.00	2.90	5.00
	Low	*M*	4.86	14.81	4.84
	(*N=58*)	*SD*	1.03	4.34	4.24

Table 1. Post-test performance on conceptual understanding, retention, and transfer items by treatment group and prior knowledge.

3) Transfer: As a follow-up to the significant MANOVA finding for the prior knowledge factor, a univariate test was conducted on the transfer dependent measure. The 3 × 3 ANOVA revealed significant differences in transfer scores among the three levels of participant prior knowledge, $F(2,226) = 19.45$, $MSE = 20.69$, $p < 0.001$, $\eta^2 = 0.147$. Pairwise differences across the prior knowledge factor were identified using Fisher's LSD post hoc tests. The comparisons revealed that high prior knowledge participants ($M = 9.85$) scored significantly higher than both their medium prior knowledge ($M = 8.16$) and low prior knowledge ($M = 4.84$) counterparts, $p = 0.02$ and $p < 0.001$ respectively. The difference in transfer performance between the medium ($M = 8.16$) and the low ($M = 4.84$) prior knowledge participants was also significant ($p < 0.001$). The interaction between prior knowledge and pace of transitioning was not significant on the transfer measure, $F(4,226) = 1.52$, $MSE = 20.69$, $p = 0.20$.

B. Program Practice Performance

The maximum obtainable score was 12. The overall average score that the participants achieved was 7.42 (62 percent). The mean scores were 7.76 (65 percent) for the high prior knowledge participants, 7.55 (63 percent) for the medium group, and 6.79 (57 percent) for the low prior knowledge group. Performance on the en route practice problems was analyzed using a 3 (prior knowledge) × 3 (pace of transitioning) analysis of variance (ANOVA). The ANOVA revealed that there were no significant differences in practice problem mean scores for either prior knowledge or pace of transitioning. The interaction between prior knowledge and pace of transitioning was also non-significant.

C. Time in Program

The means and standard deviations for the introductory information, the in-program practice, and the total in-program times are

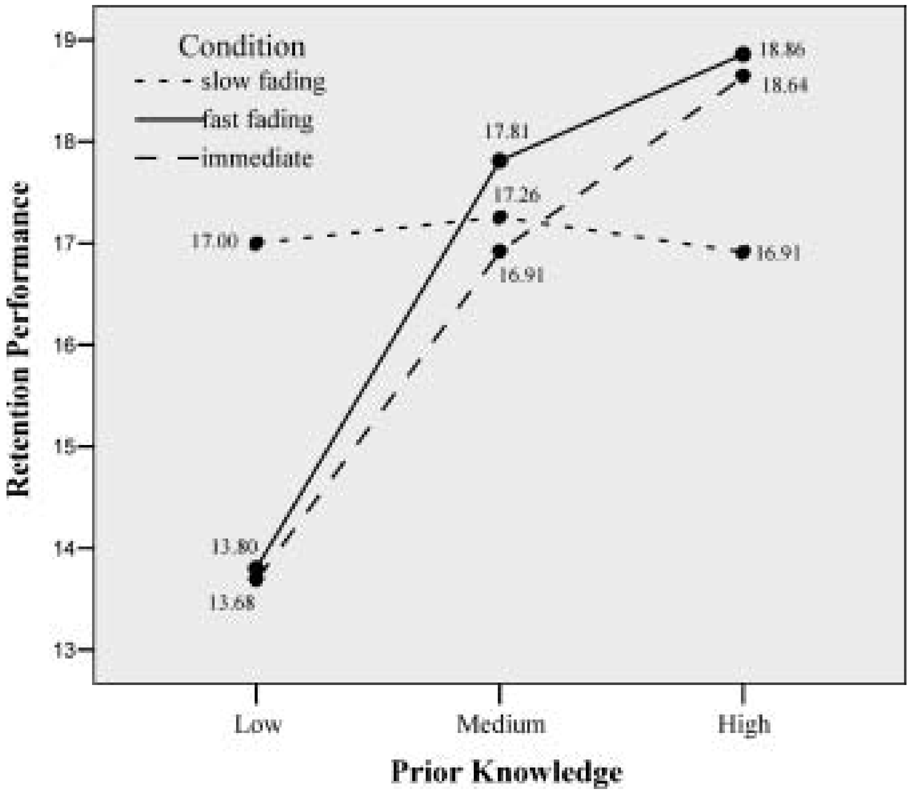

Figure 2. Illustration of pace of transitioning to independent problem solving by prior knowledge interaction: Low prior knowledge students learn better with slow fading, whereas high prior knowledge students learn better with fast fading or immediate transitioning.

Condition		Introductory Info Time (minutes)	Practice Time (minutes)	Total Time (minutes)
Slow Fading (N = 81)	M	6.85	8.10	14.94
	SD	3.78	1.87	4.67
Fast Fading (N = 78)	M	7.13	8.50	15.63
	SD	3.91	2.56	5.21
ImmediateTransitioning (N =76)	M	6.80	8.12	14.93
	SD	3.54	1.57	4.08

Table 2. Time spent on introductory information, in-program practice, and total time in program by treatment group.

reported by treatment in Table 2. The overall average total time participants spent interacting with the computer-based program was 15.17 minutes (SD = 4.67). Participants spent an average of 6.93 minutes (SD = 3.73) on the introductory information. An ANOVA yielded a main effect on the prior knowledge factor, $F(2,226) = 5.77$, MSE = 13.30, $p = 0.004$, $\eta^2 = .049$. Follow-up post hoc tests revealed that the high prior knowledge participants ($M = 5.69$) spent significantly less time on the introductory information than their medium prior knowledge ($M = 7.19$) and low prior knowledge counterparts ($M = 7.83$), $p = 0.01$ and $p = 0.001$ respectively. There were no significant differences in introductory information time for the pace of transitioning factor. The interaction of prior knowledge and pace of transitioning was also non-significant. The average time spent on the in-program practice problems was 8.24 minutes (SD = 2.05). Mean times on practice problems were 8.00 minutes for high prior knowledge participants, 8.29 minutes for the medium group, and 8.41 minutes for the low prior knowledge participants. The 3 $\times$ 3 ANOVA for time spent on practice problems yielded no significant main effect differences and no significant interaction. Overall, the time results indicate that the advantage of the different paces of transitioning for the different levels of prior knowledge can not be attributed to the amount of instructional time.

D. Participant Attitudes

The attitude items were scored on a five-point scale, ranging from 4 indicating strong agreement with the positive statements to 0 corresponding to strong disagreement. The overall mean scores in descending order for the individual attitudinal categories were 3.22 for pace of transitioning, 3.19 for instructional strategies, 3.07 for instructional effectiveness, and 2.51 for continuing motivation. The Cronbach α across all the survey items was $\alpha = 0.91$, indicating high reliability of the survey.

The overall mean score across all the 14 attitude items on the survey for all the participants was 3.02 ($SD = 0.64$), a favorable rating indicating that the participants generally agreed with the positive statements about the computer-based learning program and its components. The mean scores across all the 14 attitude items were 3.12 ($SD = 0.59$) for the low prior knowledge participants, 3.06 ($SD = 0.56$) for the medium, and 2.87 ($SD = 0.78$) for the high prior knowledge participants. Participants assigned to the immediate transitioning to independent problem solving treatments had a mean score of 3.10 on the attitude survey, participants in the fast fading condition had a mean score of 2.99, and those in the slow fading condition had a mean of 2.97.

A 3 (prior knowledge) $\times$ 3 (pace of transitioning) $\times$ 4 (attitudinal category) multivariate analysis of variance (MANOVA) was conducted to test for significant differences by prior knowledge and pace of transitioning. Because of the large number of comparisons on the attitude items, α was set at 0.01 for all statistical tests on these items. The $3 \times 3 \times 4$ MANOVA revealed significant differences on the main attitudinal categories for the prior knowledge factor, Wilks' $\Lambda = 0.86$, $F(8,446) = 4.22$, $p < 0.001$, but not for pace of transitioning or the interaction of prior knowledge and pace of transitioning. Follow-up univariate ANOVAs for prior knowledge on each of the four main attitudinal categories revealed significant differences for this factor on the instructional strategies category, $F(2,226) = 9.23$, $MSE = 0.57$, $p < 0.001$, $\eta^2 = 0.076$. Fisher's LSD post hoc tests on the instructional strategies category revealed that low prior knowledge participants ($M = 3.38$) and medium prior knowledge participants ($M = 3.30$) had significantly more positive attitudes toward the usefulness of the individual instructional strategies than their high prior knowledge counterparts ($M = 2.86$), $p < 0.001$ for both comparisons. Individual items in this category on which the low and medium prior knowledge subjects had significantly more positive attitudes than the high prior knowledge participants related to the instructional effectiveness of examples and problems but not to the role of instructional feedback. There were no significant differences between the overall means on the attitudinal categories related to pace of transitioning, instructional effectiveness, and continuing motivation.

The three attitudinal items relating to the number of in-program examples and problems, and the pace of transitioning were analyzed separately because they were asked in a three-response answer form instead of the five-response form for the level of agreement items. Overall, the participants perceived the number of examples and problems in the program as about right. The pace of transitioning to independent problem solving also was generally viewed as about right. However, five participants in both the high prior knowledge group (22 percent) and the medium prior knowledge group (13 percent) noted that the pace of transitioning in the slow fading condition was too slow. On the other hand, eight participants in the low prior knowledge group (42 percent), but none in the medium or high prior knowledge groups, responded that the pace of transitioning in the immediate transitioning condition was too fast.

IV. Discussion

This study, which was conducted with engineering freshmen in the engineering knowledge domain of introductory electrical circuit analysis, examined the impact of the pace of transitioning to independent problem solving on performance and attitudes of participants with three levels of prior knowledge. The primary difference in the treatments was the pace in which the problem-solving demands on the participants were increased. Under the slow fading condition, the participants progressively moved to independent solving of practice problems after viewing worked examples. Under the fast fading condition, the problem solving demands were introduced at a faster pace. Under the immediate transitioning condition, the transition to independent problem solving was abrupt after the presentation of the introductory information.

A. Performance

Since the pace of transitioning to independent problem solving by prior knowledge interaction is the most important result of this study, this section is mostly focused on this interaction. Before discussing this interaction, we briefly note that several significant differences were obtained between prior knowledge levels on post-test performance. These findings reflect the general expectations of higher prior knowledge learners performing better than their lower prior knowledge counterparts.

1) Interaction of Pace of Transitioning with Prior Knowledge: This study uncovered a significant interaction between pace of transitioning to independent problem solving and participant prior knowledge on retention. The high prior knowledge participants achieved significantly higher retention scores under the fast and immediate transitioning than under the slow transitioning. In contrast, the low prior knowledge participants achieved significantly higher retention scores under the slow transitioning compared to the immediate and fast transitioning. These results are consistent with a range of theoretical models.

According to the Adaptive Control of Thought-Rational (ACT-R) theory [4], high prior knowledge participants are at a more advanced state in the cognitive skill acquisition process. Within the ACT-R framework, the rationale underlying the conventional fading design [19] posits that worked example study becomes less useful while the importance of problem solving practice increases when reaching the higher stages in the ACT-R skill acquisition model. Indeed, this study found that the immediate and fast transitioning, which place more problem solving responsibility on the learner, were more effective for the more advanced high prior knowledge learners.

The result that the high prior knowledge participants perform worse under the slow transitioning condition provides further empirical evidence for the existence of the expertise reversal effect [20] (only the study by Reisslein, et al. [13] has previously observed the existence of the expertise reversal effect for engineering education). According to the expertise reversal effect, the worked examples are redundant information for the learners with higher knowledge levels. This redundant information burdens the advanced learners as extraneous cognitive load and reduces their germane cognitive load, resulting in a reduced capability to further advance their understanding of the subject matter. The slow transitioning condition in this study provided the participants with 12 worked example steps compared to zero worked example steps in the immediate transitioning condition and six worked example steps in the fast transitioning condition. Thus, the high prior knowledge participants had to process more redundant information in the slow transitioning condition. This processing likely interfered with effective learning. As a result, the high prior knowledge participants probably had fewer cognitive resources available for independently solving the practice problem steps.

The better performance of the low prior knowledge participants under the slow transitioning condition compared to the immediate and fast transitioning conditions is consistent with the worked-example effect [8]. The worked examples provide the novice learners with an analogical base for solving other problems and free the learners from performance demands during the initial skill acquisition [7]. With the slow transitioning in this study, the participants were given the opportunity to study two fully worked examples before being asked to independently solve their first problem step, compared to zero fully worked examples in the immediate transitioning condition and one fully solved example in the fast transitioning condition. Overall, the slow transitioning in this study provided the participants with twice as many worked example steps as the fast fading condition. These worked example steps likely allowed the low prior knowledge participants to acquire initial knowledge more effectively without being burdened by problem solving demands before they had acquired this knowledge.

For the medium prior knowledge participants there were no significant differences in the post-test retention performance across the three treatment groups. These participants apparently had a sufficiently high level of prior knowledge to cope with the problem solving demands placed on them by the fast and immediate transitioning conditions. At the same time their level of prior knowledge was likely sufficiently low to avoid a pronounced expertise reversal effect.

The responses to the attitudinal item relating to the pace of transitioning to independent problem solving reflect the general expectation that the immediate-transitioning pace was perceived as too fast by a large portion (42 percent) of low prior knowledge participants, but not by any of the medium or high prior knowledge participants. In contrast, several of the high prior knowledge participants (22 percent), but none of the low prior knowledge subjects, perceived the pace as too slow under the slow fading condition. These attitude results are consistent with the performance results in that the high prior knowledge group, which had significantly lower retention scores with the slow transitioning compared to the immediate and fast transitioning, had a tendency to perceive the slow transitioning as too slow. Similarly, the low prior knowledge group, which achieved significantly lower retention scores with the immediate transitioning compared to the slow transitioning, had a tendency to perceive the immediate transitioning as too fast. Thus, the attitudinal results further underscore the expertise reversal effect for the high prior knowledge participants. Similarly, they further underscore the importance of the worked example effect for the low prior knowledge learners.

For the conceptual understanding and transfer measures, the analysis revealed tendencies for interactions similar to the significant interaction found for retention. However, these interaction tendencies for conceptual understanding and transfer were not strong enough to produce significant results with the size of our experimental sample. The weakness of these interaction effects may have been due to the primary focus of the practice (transitioning) phase on retention skills. Coupling the transitioning technique with additional techniques for fostering active processing, such as soliciting self-explanations [21], may strengthen the effects for conceptual understanding and transfer and appears to be an interesting direction for future research.

2) Impact of Pace of Transitioning to Independent Problem Solving: A significant difference in post-test performance was not obtained between the three treatment groups, although there was a significant interaction as discussed above. Taking the learners' levels of prior knowledge into consideration is thus important when applying different paces of transitioning in educational practice. The outcomes of this study suggest that there is no advantage to simply employing one of the examined paces over the others. However, by selectively employing the slow transitioning for participants with lower levels of prior knowledge and the fast or immediate transitioning for the participants with higher levels of prior knowledge, significant improvements in learning may be achieved.

B. Program Practice Performance

No statistically significant differences were obtained on the in-program practice performance for either pace of transitioning or prior knowledge. However, the tendencies in the practice performance scores largely followed the trends of the retention performance. That is, there was a non-significant trend for participants with a higher level of prior knowledge to perform somewhat better than their lower prior knowledge counterparts on the in-program practice.

The overall absence of significant differences for prior knowledge on the practice performance may be due to the fact that the practice achievement reflects only the performance at an intermediate stage in the training process. After the participant entered a solution to a practice problem step, feedback was provided that either confirmed the correctness of the answer or provided the correct solution. Thus, even if the solution entered by the participant was incorrect, he or she could still improve his or her understanding by carefully examining the correct solution and reflecting on how to correctly solve the problem step.

C. Attitudes

The prior knowledge of the participants had a significant relationship to the attitudes toward the instructional strategies. The attitudes of the low and medium prior knowledge participants were significantly more positive toward the usefulness of instructional strategies employed in the module than those of their high prior knowledge counterparts. One explanation for this result could be that the low and medium prior knowledge participants, who may struggle more in faster-paced instruction, had a greater appreciation of the use of both worked examples and practice problems. On the other hand, the high prior knowledge participants may not have valued the worked examples. The high prior knowledge subjects may have found the introductory information outlining the theoretical basis for the subject matter sufficient for their learning.

The overall mean score of 3.02 out of 4 possible on the 14 attitude items indicates that the participants had positive attitudes toward the instructional effectiveness of the program irrespective of their level of prior knowledge or pace of transitioning. This is a positive outcome in that participants generally perceived that they learned from the program, found it to be at least as good as regular classroom instruction, and would recommend it to others.

Overall, the pace of transitioning category received the most positive ratings of the four categories included in the attitude survey. The low prior knowledge participants rated the pace of transitioning slightly more positively than their high prior knowledge counterparts. These more positive attitudes of the low prior knowledge participants were particularly notable for the slow fading ($M = 3.50$ for low and 2.78 for high prior knowledge) and fast fading conditions ($M = 3.41$ and 3.06, respectively). The low prior knowledge participants may have appreciated the opportunity to progressively build up their confidence to solve more problem steps independently.

The continuing motivation category received the least positive rating. The mean score was 2.51 (whereby 2 corresponds to "Neither agree nor disagree" and 3 corresponds to "Agree"). In interpreting this result it is important to keep in mind that the learners spent a relatively short average time of 15 minutes in the learning environment. This time may have been too short to affect motivation tendencies that may have formed over the time span of a few weeks or months that the participants had spent in the engineering program prior to participating in this study.

V. Conclusion

This study examined the effectiveness of the pedagogical technique of different paces of transitioning to independent problem solving for teaching introductory engineering content, specifically, electrical circuit analysis, to freshman engineering students. The results indicate that tailoring the pace of transitioning to independent problem solving to the levels of prior knowledge of the students can significantly increase the effectiveness of the instruction for the retention learning performance of high prior knowledge and low prior knowledge participants. In particular, this study found that slow transitioning for learners with low levels of prior knowledge and fast or immediate transitioning for learners with high levels of prior knowledge achieve significant improvements in learning.

The different paces of transitioning to independent problem solving can not only be implemented in personalized instruction through computer-based learning modules or personal tutors, but also in group instruction through work sheets, work books, or instructor presentation on a blackboard or on projected slides. For implementation through instructor presentation, for instance, the instructor presents the worked example steps on the board or on slides and asks the students to complete the missing steps. After the students have attempted the missing steps, the instructor provides and explains the correct solution, and the students correct or supplement their solution and ask clarifying questions. The worked steps and missing steps are adjusted according to the different paces of transitioning. More specifically, this research suggests the following approach. First, the students are administered a pre-test that assesses their prior knowledge of the concepts to be taught. Next, the learners are split into three groups of higher, medium, and lower prior knowledge according to two cut-off thresholds. The present study used the mean pre-test score plus/minus one standard deviation of the pre-test score as the two cut-off thresholds. Depending on the distribution of the prior knowledge levels of the learners and the difficulty level of the learning material, different cut-off points may be appropriate. A methodology for determining good cut-off points is an important direction for future work. Once the learners are divided into three groups, the high prior knowledge learners are taught with the immediate transitioning technique, the medium prior knowledge learners with the fast fading technique, and the low prior knowledge learners with the slow transitioning technique.

Further investigation on how to increase the overall mastery of the content domain may be especially beneficial for low prior knowledge learners. The overall mastery level achievement in this study was 89 percent on retention. However, the retention was only 78 percent for the low prior knowledge participants, compared to 91 percent for medium and 95 percent for high prior knowledge participants. One instructional approach that could increase the retention level of the low prior knowledge participants is the incorporation of prompts that solicit and provide feedback of self-explanations on missed items [15, 16, 21]. With self-explanations the learner explains to her/himself the missed solution steps of the worked examples. Prompting the learner to provide self-explanations and providing feedback on the provided self-explanations could deepen the active processing of the content, which could improve retention for low prior knowledge learners.

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