

# WIP: Effectiveness of Worked Examples and Fading in Introductory Electrical Circuit Analysis for Learners of Different Ability Levels

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**Abstract**—This paper reports on work in progress to examine and improve the effectiveness of instructional sequences containing worked examples and fading solution steps in the domain of introductory electrical circuit analysis. We pay close attention to the ability levels of the learners, which have not been considered in detail in previous studies on fading. Our preliminary results indicate that different static paces of fading or adaptive fading can make instructional sequences with fading more effective for learners with a range of ability levels.

**Index Terms**—Adaptive fading, backward fading, example-problem, instructional sequence, interactive fading, problem-example, worked examples.

## I. INTRODUCTION

Worked examples, which consist of the problem statement, the individual solution steps leading to the final solution, and the statement of the final solution, have been demonstrated to be effective in instruction designed for initial cognitive skill acquisition, see e.g., [1]. In general for the worked examples to be effective, especially as the learners advance in their skill acquisition, the learners need to actively process the worked examples, which is commonly achieved by self-explanation of the worked solution steps [2]. To foster active processing, the learners should be provided with opportunities for practice, which in turn will advance their skill acquisition. Ultimately, the skill acquisition should advance to a point where the learners can independently solve the problems.

Recently, *fading* has been introduced as an instructional sequence that is conducive to making a smooth transition from studying worked examples to independent problem solving [3]. With the so-called backward fading sequence, the learner is initially presented with a fully worked example. Next, the learner is presented with an example where all but the last solution step are worked out. The learner is expected to attempt to solve this last step. Next, the learner is presented with a problem which has all but the last two solution steps worked out; whereby these last two steps require solution attempts by the learner. This process of reducing (fading) the worked solution steps by one with every new problem continues until all the worked solution steps are faded away and the learner has to attempt to independently solve the entire problem.

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Whenever the learner has to attempt to solve a solution step, s/he is provided with instructional feedback on the correctness of his/her solution attempt and in case of an incorrect solution it is demonstrated how to solve the step correctly [4].

The research on fading so far has focused (*i*) on investigations with social science student subjects in the domain of elementary probability theory, and (*ii*) on fading designs with one fixed pace of fading, where the number of worked solution steps is reduced by one for each new encountered example. Our work in progress advances the existing research on fading by (*a*) examining its effectiveness with engineering students in the domain of electrical circuit analysis, and (*b*) introducing and evaluating different paces of fading and adaptive fading.

## II. EXAMPLE-PROBLEM, PROB.-EX., & STATIC FADING

In an initial study (see [5], [6] for details) in this line of ongoing research we examined in the domain of series and parallel electrical circuit analysis the effectiveness of the three main types of example-based instructional sequences in relation to the learners' levels of prior knowledge. In particular, we compared: example-problem pairs, in which the learner is first presented with a worked example, followed by a practice problem; problem-example pairs, in which the learner is first presented with a practice problem, followed by a worked example; and fading sequence, in which the learner is presented with backward faded solution steps that are faded at the static pace of one solution step per problem as outlined above.

We found an interesting ability by instructional sequence interaction: low-prior knowledge learners provided with the example-problem pair instructional sequence outperformed their high-prior knowledge counterparts, whereas the high-prior knowledge participants presented with the problem-example pair sequence or the backward fading sequence outperformed their low-prior knowledge peers. One explanation for these results is that the low-prior knowledge learners were able to effectively learn from the worked examples, whereas the high-prior knowledge learners were "bored" by the worked examples, which appeared as redundant information for them in line with the recently examined expertise reversal effect [7], and benefited more from actively solving problems.

Overall, this initial study suggests that it is important to consider the learners' levels of prior knowledge when designing learning environments that rely on example-based instruction. This study also indicates that the results from studies with social science students for non-engineering domains, where

fading was found to be generally more effective than the example-problem and problem-example designs, see e.g., [3], may not directly carry over to the electrical engineering domain and that there is a need to examine instructional techniques in the electrical engineering domain with engineering students.

### III. DIFFERENT PACES OF (STATIC) FADING

Our initial study outlined in the preceding section suggests that the pace at which the instructional sequence transitions from studying worked examples to independent problem solving should be tailored to the level of ability and prior knowledge of the individual learners. To validate this conjecture we are in the process of conducting a follow-up experiment in the domain of electrical circuit analysis in which we compare (i) immediate transitioning to independent problem solving, where the learner is immediately presented with practice problems; (ii) conventional fading with a pace of one less solution step with each new example; and (iii) slow fading, where one solution step is faded for every second example.

Analysis of initial data from this ongoing experiment indicates that the learners with a higher level of prior knowledge indeed benefit from the faster transitioning to independent problem solving with the conventional fading and immediate transitioning, whereas the lower-prior knowledge learners benefit from the slow fading instructional design.

Overall these initial results indicate that tailoring the pace of transitioning to independent problem solving to the levels of prior knowledge and ability of the learners increases the effectiveness of the instructional design.

### IV. ADAPTIVE FADING

While selecting a pace of fading that suits the individual learner's level of ability and prior knowledge appears to more effectively foster learning, the fading designs studied so far are still relatively rigid in that they fade away worked solution steps at a fixed prescribed pace that does not take the correctness of the solution attempts of the learner into consideration. This has prompted us to develop an *adaptive fading* instructional design that fades away the solution steps according to the correctness of the learner responses. For illustration consider the adaptive fading design for problems with three solution steps: The first problem is fully worked out. In the second problem, the first two steps are solved (worked-out) and the learner has to attempt to solve the third step. The number of worked/to-be-solved solution steps in the next (third) problem and all the following problems depends on whether or not the solution attempts of the learner are correct. Specifically, if the solution attempt of the third step in the second problem is correct, the learner is next presented with a problem where the first solution step is worked out and the last two solution steps are to be solved by the learner. If the solution attempt is incorrect, the learner is next presented with a problem where all three solution steps are worked out.

More generally, the learner is only allowed to advance to a problem with  $n + 1$ ,  $n = 1, 2, \dots$ , missing worked solution

steps after s/he has correctly solved all the  $n$  missing solution steps in the current problem. Whenever the learner incorrectly solves a particular solution step  $k$ ,  $k = 1, 2, 3, \dots$ , then the learner is next presented with a problem where the solution steps up to and including step  $k$  are worked out and the remaining steps  $k+1$ ,  $k+2, \dots$ , require a solution attempt from the learner. In other words, the learning environment "probes" whether the learner is able to correctly solve a solution step  $k$ . If so, the learner is permitted to advance to attempting to solve one additional solution step him/herself. Otherwise s/he is demonstrated the correct solution of step  $k$  once more with a worked out solution of step  $k$ .

Our initial evaluation results for the comparison of adaptive fading with slow (static) fading indicate that higher ability learners perform equally well when exposed to either form of fading. On the other hand, lower ability learners benefit significantly from the adaptive fading.

### V. CONCLUSION AND OUTLOOK: INTERACTIVE FADING

Our work in progress has demonstrated so far that the level of prior knowledge and ability of the learners needs to be taken into consideration in order to design effective worked example based instructional sequences. We have outlined promising novel fading designs that are being thoroughly examined in our ongoing work. One interesting instructional sequence to examine in future work is *interactive fading* where the learner is not automatically shown worked solution steps and required to attempt to solve solution steps as in adaptive fading, but rather is interactively asked whether s/he wants to see a particular step worked out or prefers to attempt to solve the step after an incorrect solution attempt.

### ACKNOWLEDGEMENT

This work was supported in part by the National Science Foundation through grant Career ANI-0133252.

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