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Integration of VHDL Simulations and Written Reflections to Improve Student Understanding of Sequential Logic Circuits

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1. Introduction

Reflection is known to be a valuable tool that can enhance student learning. Although the benefits of self-reflection are well-known, it is under-utilized in engineering education. Thus, there is a growing body of research on how to promote and deploy reflective activities in the engineering classroom (Benson).

One recent development is the integration of computer-aided simulation tools and written reflections (Dickerson). Computer-aided simulation tools provide students with the ability to predict the behaviors of complex systems without having to concern themselves with every single detail of the problem at hand. Thus, in problem-solving scenarios where complex math and extended analyses are often required, students can rapidly explore alternative designs and evaluate the results of parameter changes with minimal effort. This tool can lower the barrier for reflection, as students can be encouraged to reflect on easily generated simulation results. This technique was initially developed in the context of a sophomore-level electrical engineering course on microelectronics and shown to be an effective technique to drive metacognitive thinking.

While simulation-guided reflections were originally developed for improving student understanding of nonlinear, analog circuit devices (e.g. transistors), it was later extended to the domain of digital logic circuits. Digital logic circuits can be modeled using Hardware Description Languages and logic simulators. Therefore, a similar feedback loop involving problem solving, simulation, reflection, re-analysis, can be deployed in digital circuits courses.

In this work, simulation-guided written reflections are used to enhance student understanding of sequential logic circuits. Sequential logic circuits are challenging for students to understand as they not only require knowledge circuit operation, but also how the state history of these circuits evolve over time. In this study, students are given an examination and then asked to critically evaluate their responses using just a logic simulator, without knowledge of their actual performance on the exam. Students are then asked to write reflections on the experience and their responses are assessed according to previous methods shown to be effective for assessing reflections (Dickerson).

2. Background and Context

This intervention was deployed and assessed in an undergraduate digital circuits course during the fall 2021 semester. The audience for the course is sophomore electrical and computer engineering students. The population in this study included 37 students with varying levels of achievement. The course is typical for classes of this sort – two lectures per week with an accompanying lab session. In Digital Circuits courses, students learn the basics of Boolean algebra, combinational logic circuits, circuit optimization and then finally sequential logic circuits. In this work, we emphasize student learning of sequential logic circuits since it is a topic that embodies all of the preceding topics in the course. During the laboratory sessions, students learn how to use programmable logic devices (i.e. FPGA) and write Hardware Description Language code to model the circuits that they learn about in the lecture.

Figure 1 shows an example assessment from the class. In this problem, the students were given a circuit with several flip-flop circuits, an example input waveform and were asked to predict what the output waveform would be. This sample problem, and student response, shows why sequential logic circuit are so difficult for students to analyze. Not only do they have to recall how each device operates, that have to visualize how the behavior of the circuit evolves over time (i.e. the circuits have state)

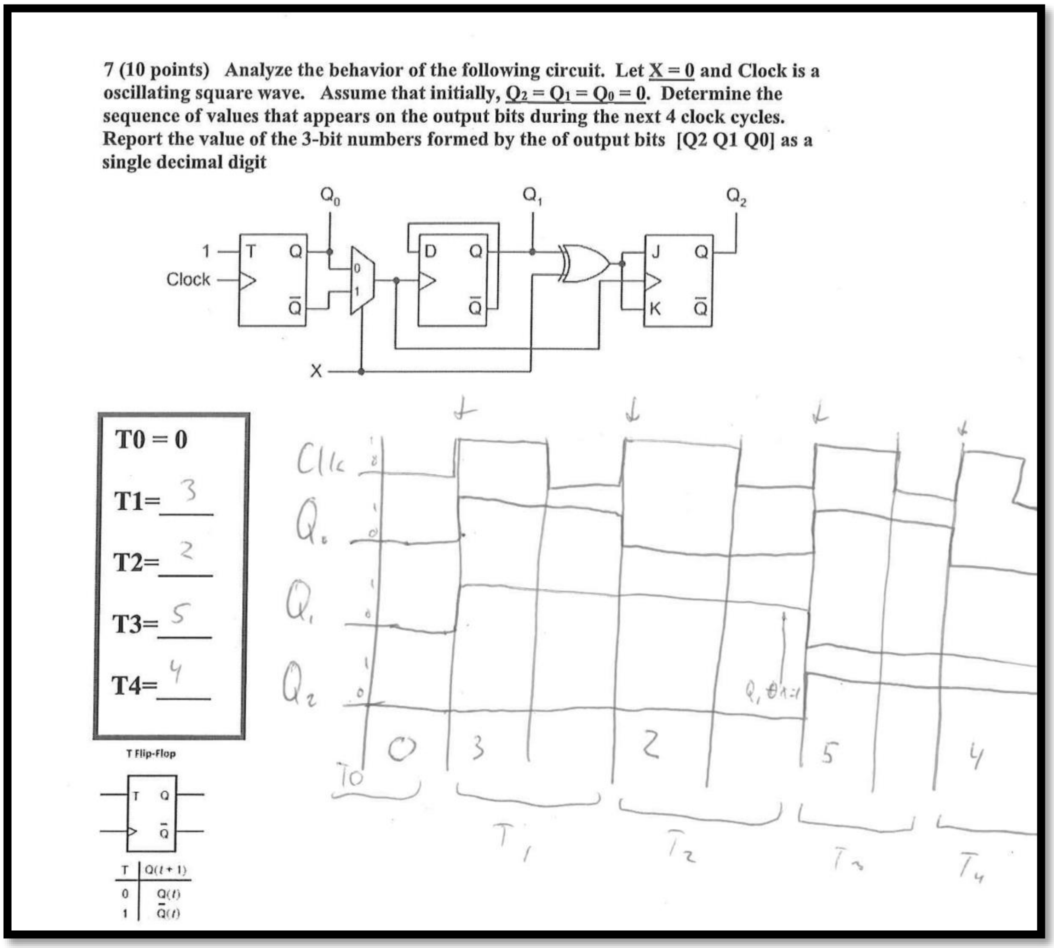


Figure 1. Example examination question on analysis of sequential logic circuits

Computer-aided simulation of circuits is what is used as the focal point of our reflection techniques. Figure 2 shows an example assessment and corresponding simulation result. For this particular reflection exercise, students were asked to analyze their response to the “counter” circuit shown in figure 1.

Post-exam, for the reflection process, students were provided a VHDL file that accurately modeled the counter circuit. For the reflection process, students simulated the counter and checked to see if the output they predicted matches up with the simulation. The leads to one of two outcomes for the student: Either they see the same answer, reaffirming their understanding of the topic, or a discrepancy. In the case of a discrepancy, students can rapidly explore alternative solutions, hopefully causing them to re-examine their work and see where they went wrong. Figure 2 shows the post-exam reflection exercise as given to the students to complete after finish the problem of figure 1.

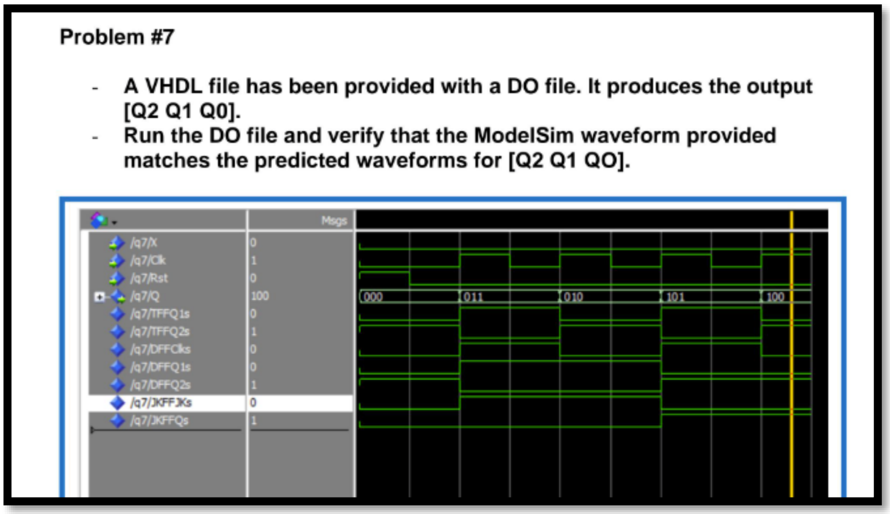


Figure 2. Example VHDL simulation of a sequential logic circuit. Figure shows a student revaluation of an examination response.

2. Methods

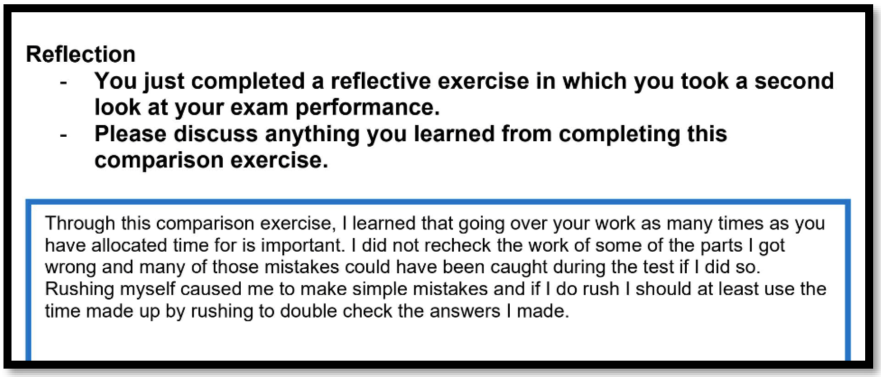
For the study presented in this work, 37 Electrical and Computer Engineering sophomores were asked to engage in this simulation-based reflection process. In this section, we present a detailed breakdown of the methods used.

2.1 Use of VHDL Simulations to initiate Written Reflections

The reflection process was structured as follows:

1. Students were given a midterm exam that primarily covered sequential logic circuits
2. Ungraded exams were returned to the students, allowing them to examine their work
3. Students were provided guidance on how to simulate each problem on the exam using VHDL code
4. Students were asked to think about the simulation results, compare them to their exam responses and write reflections about their performance.

To initiate the reflection process in step 4, student were asked to respond to the prompt: "Please discuss anything you learned from completing this comparison exercise". Figure 3 shows the prompt as given to the students and an example student response. In the example response, one can see evidence of metacognitive thinking. They note that they should've "rechecked" their work, that they “rushed” and can improve next time around by more carefully “reviewing” their work.


Reflection

- **You just completed a reflective exercise in which you took a second look at your exam performance.**
- **Please discuss anything you learned from completing this comparison exercise.**

Through this comparison exercise, I learned that going over your work as many times as you have allocated time for is important. I did not recheck the work of some of the parts I got wrong and many of those mistakes could have been caught during the test if I did so. Rushing myself caused me to make simple mistakes and if I do rush I should at least use the time made up by rushing to double check the answers I made.

Figure 3. Reflection Prompt given to students and a sample response.

2.2 Assessment of Student Reflections

The students’ written responses were analyzed using qualitative methods. An analyst well-versed in the subject matter read through each student response in detail and then categorized them according to a rubric. The rubric was designed to assess the responses according to their depth and richness. The assessment rubric contained four categories:

1. Non-reflection – student does not respond or their response lacks effort or seriousness.
2. Understanding – student’s response is confined to theory (e.g. a logic / math error was made)
3. Reflection – student’s response contains personal insights (e.g. my study habits need to improve)
4. Critical Reflection – student provides evidence of a change in perspective.

The goal of this assessment is to evaluate the extent to which the simulation exercise is eliciting metacognitive thinking (i.e. level 3 / level 4 responses).

3. Results

The analysis of the depth of the reflections yielded the results displayed in table 1. Under each rubric category is the average examination score for students assessed at a particular depth level. The exam analyzed was a follow up examination on sequential logic circuits.

Table 1: Summary of Depth Analysis

Non-reflection	Understanding	Reflection	Critical Reflection
1	8	28	0
2%	22%	76%	-

The results of table 1 reveal that the exercise was successful in eliciting metacognitive thinking in the majority of students, which is the desired outcome. Very few students did not reflect (non-reflection) or provide evidence of a change in behavior (critical reflection). However, 76% of participants reflected at a higher level.

The results show that there were not statistically significant differences in exam scores between the populations. However, this does not suggest that the intervention was not successful. The elicitation of metacognitive thinking cannot be easily mapped back to average exam scores and thus is a limitation of this work. In future studies, detailed analyses of individual examination problems that map back to specific reflection exercises will be examined in detail.

4. Conclusions

In this work, a novel intervention was deployed whereby VHDL simulations were used to initiate written reflections. The results show that the method was successful in promoting metacognitive behaviors. However, the results were inconclusive as to whether or not concrete learning gains or self-corrective actions resulted from the exercise.

The recommendation for instructors is for future deployments to consider the deployment of follow up quizzes immediately following the reflection quizzes to further assess results.

References

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Benson, D & Zhu, H . 2015. Student Reflection, Self-Assessment, and Categorization of Errors on Exam Questions as a Tool to Guide Self-Repair and Profile Student Strengths and Weaknesses in a Course. In: Proceedings of American Society of Engineering Education Annual Conference.