Work in Progress: Students' Misconceptions About State in Digital Systems

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Abstract **- In introductory undergraduate courses on digital systems, students have difficulty understanding the state concept. We expect that students have subtle, persistent misconceptions about state because it is an abstract concept and has nuanced meanings in different disciplines as well as colloquial English. To learn how students conceive of state in digital logic, we interviewed undergraduates in computer engineering or computer science at the University of Illinois at Urbana-Champaign who had just completed a first course in digital logic. In the one-hour interviews, students talked about their thoughts as they solved digital logic problems. These interviews were then transcribed and analyzed using qualitative methods.**

Index Terms – Learning models, state, digital logic

INTRODUCTION AND BACKGROUND

The development of standardized assessment tools in computing is a difficult task, but it holds tremendous promise and potential [1]. Computing education research currently suffers from the problem that there is great interest in pedagogical reform and improvement, but there are few tools to objectively or empirically compare the new pedagogies that are developed. Creating standardized assessment tools will enable instructors and researchers to directly compare new pedagogy techniques and decide which to adopt.

Because of the success of a physics assessment tool called the Force Concept Inventory in catalyzing pedagogical reform in physics education [2], we hope to create a similar assessment tool -- the Digital Logic Concept Inventory (DLCI). To create the DLCI we must create wrong answer choices on the instrument that are based on student misconceptions. In this paper, we describe students' misconceptions about state in sequential logic.

Because there has been little misconceptions research done on student conceptions of state we used a research paradigm called *grounded theory*. Grounded theory is a rigorous qualitative research methodology that should be used when there are no specific theories about how people think in a given context. This structured analysis method helps new theories to emerge from generated data through an iterative, open-ended inquiry process [3].

To minimize bias and to increase rigor, strict coding schemes are used to focus observations and reduce premature conclusions. Our methodology is described in detail in our previous work [4]. In summary, though, the process can be completed through four steps.

Step 1: Select portions of data to analyze based on the research question and considerations of bias and efficiency. The data came from "think-aloud" interviews of students as they responded to questions about digital logic.

Step 2: All researchers analyze the data independently without a predefined coding scheme. When researchers forgo a predefined coding scheme, they can craft a fuller description of student actions and misconceptions.

Step 3: All researchers meet and discuss every annotation and observation that was made. To ensure critical analysis by the group, a unanimous decision is needed for the inclusion of an annotation in the final coding.

Step 4: The same process of independent and joint analysis of Step 3 is repeated to analyze the codes to identify themes, theories, and hypotheses.

INTERVIEWS ABOUT STATE AND SEQUENTIAL CIRCUITS

We interviewed 16 undergraduates in computer engineering or computer science at the University of Illinois at Urbana-Champaign who had just completed a first course in digital logic. In the one-hour interviews, students vocalized their thoughts as they solved digital logic problems.

We ran two sets of interviews about state and sequential circuits. The second set of interviews was necessary because of what we learned from the first set. In this paper we will share some of the questions that were ineffective and why they were ineffective.

During the first round of interviews we asked students to solve several "textbook problems" of sequential logic design as well as a few conceptual questions. Students were asked to solve standard design problems, such as designing counters and sequence recognizers. The students we interviewed either solved the problems quickly and easily or became so bogged down in the design that it was difficult to discern anything from the garbled thoughts.

We also asked several conceptual questions regarding the relationships between flip-flops and input variables and various attributes of state machines. We asked these questions hoping to elicit responses about the limits of what students did and did not know about finite state machines. Our previous work has shown that non-traditional problems give unique insights into what students believe and understand [4]. These conceptual questions also turned out to be ineffective, because there are no standard definitions for some of the terms we used, (nor did we provide a definition) consequently, students gave different answers, some of which were not obviously incorrect.

We encountered two difficulties with students' answers to the questions in Figure 1. First, students had different definitions for a state transition. Some students defined a state transition to be a change in state, and some students defined a state transition to be any arc in a state diagram. As we debated the merits of each set of responses, we learned that both definitions were acceptable. If a state transition is a change of state, then the correct answer to (a) would be $\min\{m\text{-}1, 2^n\}$ and the answer to (b) would be 0. If a state transition is any arc in the state diagram, then the correct answer to (a) would be 2^n, but the answer to (b) would depend on the second problematic definition that we found.

> Answer the following questions for a state diagram with *m* states, *n* input variables, *o* output variables, and *t* state transitions.
> a) What is the maximum number of state transitions leaving each state?
> b) What is the minimum number of state transitions leaving each state?

FIGURE 1
CONCEPTUAL INTERVIEW QUESTION

Second, students disagreed on the definition of the phrase "leaving each state." Some students defined a *state transition leaving a state* as any arc on a state machine that originates from a state. This definition meant that all states would have the same minimum number of state transitions leaving the state, 2^n. Other students defined a *state transition leaving a state* as any state transition arc that did not return to the original state. With this definition an acceptable answer to (b) would be 0.

Because multiple answers for each problem would be acceptable, we could not accurately identify any misconceptions from these interviews even though students were inconsistent with their use of definitions. Nevertheless, we feel that it is important to highlight this ambiguity in common terminology. During previous work, the concept of state transitions was identified by a group of digital logic experts as an important and difficult concept [5]. Students may misunderstand state transitions in state diagrams because the term *state transition* is ambiguous, not because the concept is difficult. Standardized terminology is needed if we hope to identify or alleviate student misconceptions.

For the second round of interviews, we tried a different approach to identify student misconceptions about state. We created simple sequential circuits (Figure 2) and asked students to "fill-in-the blanks" on related timing diagrams.

In Figure 2, because the states of the flip-flops and how they affect *z* is unknown, students should decide that the blank (the "?") is unknown. Nevertheless, most apparently assumed that the circuit was combinational, and they determined *z* would be 1 from 20 to 25 ns because *z* was 1 when *x* and *y* were both previously 1. Students used simple

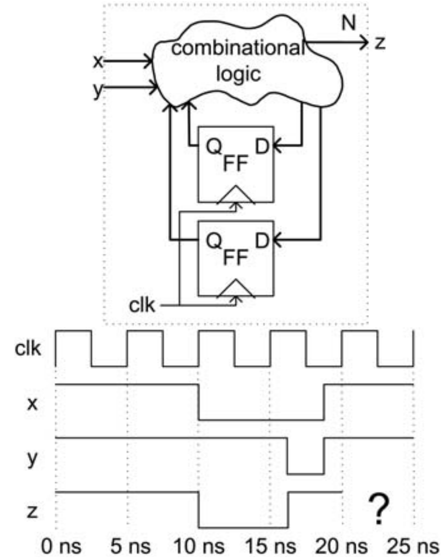

FIGURE 2
SIMPLE SEQUENTIAL LOGIC CIRCUIT WITH TIMING DIAGRAM

pattern matching rather than the underlying concept of state to solve the problem. In similar problems, some students even recognized non-combinational behavior in the timing diagrams, but still relied on pattern matching to solve the problem.

CONCLUSIONS, FUTURE WORK, AND ACKNOWLEDGMENTS

Our interviews have revealed ambiguity in the terminology of digital logic design and that students do not fully grasp the behavior of sequential logic circuits.

We have interviewed students on several more questions about state and sequential circuits; we are in the process of analyzing how students understand state in these settings. Our findings from these interviews will be used to create new interview questions and items on the DLCI.

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