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Reality versus Simulation★

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A systematic study of the implementation of simulation hardware (TIMS) replacing software (MATLAB) was undertaken for advanced undergraduate and early graduate courses in electrical engineering. One outcome of the qualitative component of the study was remarkable: most students interviewed (4/4 and 6/9) perceived the software simulations as "fake". Professionals, on the other hand, find such simulations as essentially perfectly replacing data from "real" systems. The implications of this large difference in perception between advanced undergraduate/early graduate students and professionals are discussed. At present, suitable theoretical frameworks related to motivation do not afford satisfactory explanation for this observation.

KEY WORDS: motivation; simulation; working memory; instructional design; engineering education.

INTRODUCTION

Simulations are available to support instruction in many areas of science and engineering. Generally speaking, it is less expensive to develop a simulation than to provide real experience. This is particularly clear with complex devices such as aircraft cockpit simulators. The intellectual merits of developing and providing simulations seem obvious. Here we report an unanticipated finding related to student perceptions of reality versus simulation.

Funding was obtained to develop laboratory courses in electrical engineering. The goal was to develop hands-on laboratory experiences that would support theoretical treatments in core courses. Two technologies were chosen for the task. MATLAB had been used for many years and continued to be available; TIMS was added as the result of the funding.

MATLAB® "is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation" (MathWorks, 2005). MATLAB consists of computer software.

The Telecommunications Instructional Modeling System (TIMS) is "a laboratory teaching system for college and university level telecommunications and signal processing courses." (TIMS, 2005). TIMS is hardware based and includes numerous modules that students can use to study signals in a variety of contexts. While students may create equivalent circuits by bread boarding components, building these devices is very time consuming and fraught with the vagaries of such quick, in-laboratory construction. TIMS hardware is analogous to a cockpit simulator.

In conjunction with the development of curricular materials used in concert with the newly acquired equipment, a study of the implementation was undertaken.

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THE INSTRUCTIONAL DESIGN ISSUE

A learner's success with learning new material can be described in terms of the learner's prior knowledge, ability, and motivation (Schraw *et al.*, 2005). Prior knowledge accounts for the largest amount of variance when predicting the likelihood of success with learning new material (Shapiro, 2004). Ability and motivation make smaller but substantial and important contributions.

Though certainly not trivial, the task of designing instructional materials to account for differences in learner ability is becoming understood. One construct to consider is working memory. Baddeley and Hitch (1974), described working memory, a human memory system connected with processing thought. Although limited in capacity, working memory is used for simultaneous processing and preservation of information (Baddeley, 1986; Just and Carpenter, 1992). Although details of this construct remain "underspecified" after 30 years of effort, working memory is widely accepted by cognitive scientists (Andrade, 2001). The amount of "load" placed upon working memory by a learning task, "cognitive load," has been studied in the context of instructional design for over 25 years (Clark and Mayer, 2003; Sweller, 1999). Numerous studies have led to many guidelines for designing instruction to lower cognitive load. For example, the use of a variety of worked out examples is an effective strategy (Renkl, 2002; Sweller and Cooper, 1985; Tuovinen and Sweller, 1999). In multi-step problems, the scaffolding provided through worked examples is removed by having the learners complete increasing numbers of steps themselves. This research has proceeded to a level where studies of the relative effectiveness of removing the first versus the last sub-step have been reported.

An individual learner's ability often is expressed in terms of a quantity called *g*, a measure of intelligence (Jensen, 1998). Colom *et al.* (2004) suggest that learner ability expressed in terms of *g* accounts for "almost" all of working memory. Suspicions that *g* is strongly connected to working memory are not new, however; they have persisted for some time (for example, see Engle *et al.*, 1999). In a sense, then, much of the past two decades of effort in instructional design has been focused on learner ability.

The observation we report here relates to instructional design issues that are generally lumped together under the term motivation. Much less is known about design strategies for manipulating motivation. Effective teachers have explicit or implicit understandings of motivation for learning and choose learning tasks that operationalize these understandings. Unfortunately, the motivational elements of instruction incorporated into new materials may not always elicit the anticipated reaction from the students.

Pintrich and Schunk (1996) define motivation as "the process whereby goal-directed behavior is instigated and sustained." This umbrella covers a great deal, from broad-brush issues down to details. For the purpose of this report, we are interested in details. What is it about an instructional task (the content, the task, the environment) that initiates and sustains behaviors on the learner's part aimed at learning? In our case, the learning meant achieving defined and measurable cognitive learning goals in junior/senior/graduate electrical engineering courses.

Dick *et al.*, in their classic text *The Systematic Design of Instruction* (5th ed., 2001), refer to motivation in the index just a few times, and each time they direct readers to Keller's ARCS model (attention, relevance, confidence, satisfaction) (Keller, 1987). The ARCS model continues to attract attention. For example, it served as the basis for discussing the outcomes of a course in which MATLAB was taught to engineering freshmen (Huang *et al.*, 2004). In the Huang study, 5-point Likert items relating to the ARCS constructs were aggregated with relevance reported in terms of the percent students responding 5 (mostly true) or 4 (very true). Relevance showed the highest pre-test scores and came close in the post-test (surpassed only slightly by confidence). However, ARCS scores overall were lower in post-test as compared with pre-test. After the course, students saw MATLAB as *less* relevant than at the beginning of the course. Their qualitative study suggested that interface design might have been responsible.

As more and more instruction is becoming Web-centric, it is not unreasonable that books on Web learning would focus on these design issues. For example, motivation appears once as an index entry in *eLearning* (Clark and Mayer, 2003) citing a paper on problem solving by Mayer (Mayer, 1998).

Thomas Malone set forth to develop a "theory of intrinsically motivating instruction" (Malone, 1981). *Challenge*, *fantasy*, and *curiosity* were among the motivational factors posited by Malone whose work tended to center around the use of games for learning.

While an enormous amount is written about motivation in learning, the writings reflect more of expressions of implicit understandings of success based upon teacher experience. One aspect of motivation that is becoming better understood is that of *goal challenge* (Bandura, 1997 pp. 133–134). If learning goals are too steep for a learner's current context, learning is not successful. On the other hand, when material is simple for the learner, the instruction can become over-designed and lead to diminished performance (Kalyuga *et al*., 2003). Thus, the task must present an optimal learning challenge (Deci and Ryan, 1985). When this type of task is presented, students will perceive themselves as competent enough to be successful and enticed enough by the learning task to sustain their attention. By using appropriate assessments, we can determine reasonably successfully the 'optimal level' of instruction.

Novelty has been discussed in the literature as a motivating characteristic. Recently we discovered an effect of the novelty of animals upon the writing content of young elementary students. When writing about novel animals (legless lizards, hedgehogs), students used more scientific description and jargon than when writing about ordinary animals (rabbits, doves) (Trainin *et al*., 2005). Linebarger *et al*. (2004) suggest that novelty is a factor when studying the emerging literacy skills of students in grades K-1.

Hidi and Krapp and their co-workers have dealt with *interest* as a motivational variable (for example, see Hidi *et al*., 2004). They state: "... a well-developed individual interest describes a relation to a particular content for which a person has significant levels of both stored value and stored knowledge relative to other content with which he or she may be engaged." In their take on working memory, Ericsson and Delaney (1999) suggest that interest makes a big difference in a learner's approach to processing.

Perhaps the closest literature report to the present study is that of Wade and co-workers (1999) in which young readers associated higher interest with "novelty" and "*importance/value*." The subjects in that study, elementary school children, were in an entirely different level and context than the advanced college students and early graduate students studied here.

On balance, however, we do not see a neat theoretical niche from which our study's results can be perceived and understood.

STUDY AND RESULTS

Curricula were developed for four communications and signal processing courses in electrical engineering; two of these courses were studied. The students include advanced undergraduate and beginning graduate students in a competitive and highly regarded academic program. A series of quantitative and qualitative studies was put into place at the time the curriculum was implemented.

As so often is the case, the study concerned the post-grant course rather than a pre-implementation/post-implementation study or a random assignment to one of either a revised (treatment) or parallel standard (control) course. Attempts were made to account for this design issue. During the four assignments developed for the courses, students were twice included in treatment and twice in control. Students were randomly assigned to one of two groups. Half of the students used the TIMS materials for activities 1 & 3 and the extant materials for activities 2 & 4. The remaining students used TIMS materials for activities 2 & 4 and extant materials for activities 1 & 3.

No quantitative learning differences were demonstrated in this study. Most of the outcomes were quite unremarkable, and are described elsewhere (Srinivasan, 2004; Srinivasan *et al*., 2003a, b). The interviews, however, uncovered some striking student perceptions.

Most of the students interviewed (4/4 in one group; 6/9 in another) commented on the nature of the experience vis-à-vis reality as suggested by these typical comments:

> Student 1: ... when I think of the MATLAB I just think of a program that could just have been manufactured by somebody whereas in here, I feel like these are actual more physically real.
> Student 2: ... when you're getting the signals on the computer all you're doing is typing the equation and getting a graphic, but when you're getting it on the lab equipment, you're actually setting frequencies and
> [Interviewer]: It seems more real?
> Student 2: Yeah, it seems more real, that's a good way to put it.
> Student 3: ... the signals are actually real. I can ... yeah, I can see what's going on.

A few students correctly perceived that the hardware system also as providing a simulation of sorts:

> Student 4: MATLAB still helps too, because you see it, but you're still not actually doing it, you know, you're still, I don't know it's kind of, because here you're actually working with specific components, you know at MATLAB you're still

just typing in stuff and you don't know what's going on, you know, in the background. You are actually looking.

Student 5: It's more for practical training. As an Engineer I stressed that I needed more practical training than theoretical. SO just reading the book was different and hearing the class was different. And, of course, we were doing some things on MATLAB too, but here we just saw what was really happening in the communication world.

[Interviewer]: Well, in MATLAB do you think it's not really happening?

Student 5: Well, it's happening, but you are only simulating those things.

DISCUSSION AND CONCLUSION

In providing appropriate instruction in many technical areas such as electrical engineering telecommunications courses, three options often are possible: real hardware used in real or laboratory settings; specially designed simulation hardware; and software.

Nearly any signal created using a modular hardware study system can be well-simulated using software and a modern computer. That is, a computer costing less than 5% of the simulation hardware can produce what amounts to any necessary equivalent signals.

To experts (professors), the three signal sources that can be used for study are equivalent, and our choice of sources in academic life would most likely be based upon cost. To novices (students), the signal sources seem quite different, and anything other than the real systems is perceived as fake. That more than half of the students interviewed would value strongly "real" experiences over software simulations or simulation hardware sufficient to comment upon this in a spontaneous manner was an unexpected outcome of the studies connected with this project. With MATLAB the students don't have a sense of partaking in what they perceive as authentic experience. They seem to need/want authenticity to be able to make the connections the experts make with the simulation.

Huang *et al.* (2004) attributed motivational issues pertaining to MATLAB to an interface design. Had the qualitative component of that study included an opportunity for learners to discuss the learning content in an open-ended way, perhaps they, too, would have noted an outcome similar to the one reported here.

While we are confident that we are reporting a noteworthy and important observation, we are not certain how best to incorporate this knowledge into instructional design. We are quite sure, however, that simply telling students "these experiences are the same" is, at best, an incomplete solution. From the perspective of a trained professional, learning how to understand and manipulate a properly simulated signal from a computer is, in all important respects, the same learning as from a 'real' system.

There are many gaps between novices and experts, and it is unlikely that we can address all or even most of them during effective instruction. That such a gap should persist so long into professional training seems to us to be quite remarkable!

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