Assessing Virtual Laboratories in a Digital-Filter Design Course: An Experimental Study

Wei-Fan Chen, Member, IEEE, Wen-Hsiung Wu, and Te-Jen Su, Senior Member, IEEE

Abstract—One hundred thirty-three undergraduate students in a digital filter design course participated in an experimental study. Two independent variables which occurred in a virtual laboratory environment were studied: 1) instructional treatments (online text-only materials, online texts with illustrations, and online texts with simulations); and 2) prior Internet experience (high and low). Three dependent variables were measured: 1) a knowledge achievement test; 2) intention to use instructional treatments; and 3) interaction levels with instructional treatments. The experimental research design of the study was a $3 \times 2$ randomized posttest design. Multivariate Analysis of Variance (MANOVA) was used to analyze collected data. The main effects and the potential interaction of the two independent variables were examined. Results indicate that the presentation of waveform variations and the change of parameters in the course content renders significant higher learning outcomes than online text-only materials and online texts with illustrations ($\lambda (8, 248) = 0.637, p < 0.05$).

Index Terms—Digital-filter design, e-learning, human-computer interaction, virtual laboratory assessment.

I. INTRODUCTION

DIGITAL-FILTER design is typically designed to impart the concepts of digital signal processing, sampling theorem, Fourier transformation, convolution, Z transformation, infinite impulse response (IIR) filter, and finite impulse response (FIR) filter. This course involves complicated mathematical equations and dynamic waveform variations. From the perspective of computer-aided learning, software simulations designed as a virtual laboratory enhance students’ active learning experience [1], encourage self-learning by providing hands-on exercises [2], [3], and improve the effectiveness and efficiency of engineering instruction and learning [4]–[6]. Previous studies in engineering education research have covered a variety of disciplines, such as chemical engineering [4], [7], computer engineering [8], electrical engineering [5], [9], and mechanical/aerospace engineering [2], [3], [10].

In the field of digital-filter design, several previous studies developed computer software to simulate digital-filter design concepts. For example, Stouraitis and Taylor [11] developed a software package called DF-PAK for dual level courses such as digital-filter design; Turner et al. [12] developed a system, “DIGICAP,” which allowed designers to evaluate the structures and implementation effect of different digital filters; Nieleniger [13] simulated the digital IIR filter biquad section using PSPICE. Those studies focused on helping learners understand the concepts required in the digital-filter design course with the aid of a simulation system. However, they tended to create simulations for certain particular concepts, not for the course as a whole, which may ignore several important concepts, such as the fundamentals of digital signal processing, theory and architecture of digital filter, and design of digital filter. In addition, previous studies rarely investigated the impact of such a simulation system on student learning experience.

Two major problems were identified in reviewing current research in assessing virtual laboratories. First, assessment of irrelevant learning outcome variables: the majority of the current research focused on assessing student affective measures instead of evaluating genuine human learning performance as related to different types of learning objectives. Second, weak methodological design in conducting experimental research: most research used a relatively small sample size and also failed to validate the measurement instrument by reporting reliabilities of dependent measures.

This experimental study explored the effect of simulations in a virtual laboratory environment on engineering undergraduate students’ learning achievement and attitude. Based upon the purpose of the study, three research null hypotheses may be drawn as follows.

1) No significant differences in student test achievement, intention, and interaction levels when they learn by using varied types of virtual laboratory instructional treatments.
2) No significant differences in student test achievement, intention, and interaction levels when they have different prior Internet experiences.
3) No significant interaction in student test achievement, intention, and interaction levels between the two studied independent variables: virtual laboratory instructional treatment and prior Internet experience.

II. COURSE DESCRIPTION

Digital-filter design is one of the most important topics in digital signal processing, a critical course in modern electronics/electrical engineering education. The content of the course can

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TABLE V

<table>
<thead>
<tr>
<th>Tests</th>
<th>Null Hypothesis 1</th>
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<tbody>
<tr>
<td>Knowledge test</td>
<td>Rejected (T3&gt;T1; T3&gt;T2)*</td>
</tr>
<tr>
<td>Intention measure</td>
<td>Rejected (T3&gt;T1; T2&gt;T1)*</td>
</tr>
<tr>
<td>Interaction measure</td>
<td>Rejected (T3&gt;T1)*</td>
</tr>
</tbody>
</table>

*Significant at .05 level; T: Treatment

While virtual laboratory simulations may be manipulated to influence students’ learning positively, particular attention must be given to guidelines derived from learning with simulations and experimental methodology, and consideration of learner characteristics and learning styles. Only by initiating a systematic program of investigation where independent variables are judiciously manipulated to determine their relative effectiveness and efficiency of facilitating specifically designated learning objectives will the true potential inherent in virtual laboratory simulations be realized.

APPENDIX

The respondents need to answer the following questions in the seven-point Likert Scale, i.e., score 7 if you strongly agree with the statement, 4 if you neither agree nor disagree, and 1 if you strongly disagree.

1) I find that virtual laboratory simulation allowed flexible interactions.
2) I interacted with virtual laboratory simulation in a clear and comprehensible manner.
3) My interactions with virtual laboratory simulation did not require much effort on my part.
4) I find virtual laboratory simulation easy to use.
5) I find it easy to access the knowledge I needed from virtual laboratory simulation.
6) Using virtual laboratory simulation gave me more incentive to learn.
7) Using virtual laboratory simulation added to the fun of learning.
8) Using virtual laboratory simulation improved my learning experience.
9) Using virtual laboratory simulation enhanced my knowledge and skills.
10) Using virtual laboratory simulation enhanced the effectiveness in learning.
11) I find the virtual laboratory simulation useful for learning the course.
12) If I have access to virtual laboratory simulation, I have the intention to use it.
13) When I have access to virtual laboratory simulation, I expect to make use of it.

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REFERENCES


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