Interactive visualization to teach engineering design competencies

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Abstract: Interactive visualizations have several known benefits to learning in the science and engineering domain, such as: promoting scientific discovery learning and scaffolding inquiry. While some interactive visualizations address lab related skills, most focus on domain-based conceptual understanding. The affordances of interactive visualizations and simulations could make them an effective tool to learn broader scientific abilities such as design. We suggest the use of interactive visualizations to develop engineering design competencies such as structuring open problem, divergent and convergent thinking, and multiple representations. We identify the pedagogical features in the interactive visualizations that promote design competencies. We report on a study to develop design competencies in engineering undergraduate students using interactive visualizations.

Keywords: Design competency; interactive visualization, pedagogical features

Introduction

An important objective of engineering education is to develop engineering design competency [1] among students. While design competencies have been defined using different terminologies [3], most categorizations include competencies such as structuring open problem, information gathering, divergent and convergent thinking, and multiple representations. Many universities worldwide have tried to achieve this objective through special design courses [11], but there are challenges such as extra faculty time and separate infrastructure involved in running these courses. Thus design courses are not common in university curricula, which translate into lack of design competencies among students [8].

Another approach to developing design competencies is via instructional material, containing self learning components for students. Engineering design is hands-on; it needs varied idea generation and feasibility testing of generated ideas which requires substantial decision making. To achieve these characteristics, the material should contain opportunities to generate ideas as well as the means to test feasibility of ideas by allowing manipulation and feedback. A possible solution is to use interactive visualizations and simulations integrated in the instructional material.

Interactive visualizations facilitate self-paced learning as well as provide feedback to the user [2]. They add value to traditional instruction by promoting higher order learning outcomes through mental model constructions [7]. For science and engineering education, interactive visualizations promote scientific discovery learning by scaffolding inquiry [6]. While typical interactive visualizations in science and engineering focus on conceptual understanding [10], there are some that address lab related skills [12]. Simulations that address the development of design competency are usually in the form of special software tools [4], and even these are content-oriented and not competency based.

In this paper, we address two research questions: i) How to develop interactive visualizations to teach engineering design competencies? ii) Do interactive visualizations improve design competencies among students? We identify pedagogical features necessary in the interactive visualizations to promote design competencies. We test the effectiveness of the materials in a controlled quasi-experimental study, in which we found those students' design competencies improved by learning with the interactive visualizations.

We consider interactive visualizations for an Electronics Circuits course, which is part of a four-year undergraduate engineering program in Mumbai University, India. Electronics Circuits is a fundamental subject and finds application in almost all streams of engineering. Content for this study is selected from topic of BJT amplifier design.

1. Developing interactive visualization to teach design competency

In order to address the first research question, we begin with the engineering design competencies of: structure open problem, information gathering, think divergent and think convergent, and multiple representations. In this paper, we focus on the structure open problem competency. Figure 1 shows an overview of the steps to develop interactive visualization to develop design competencies.

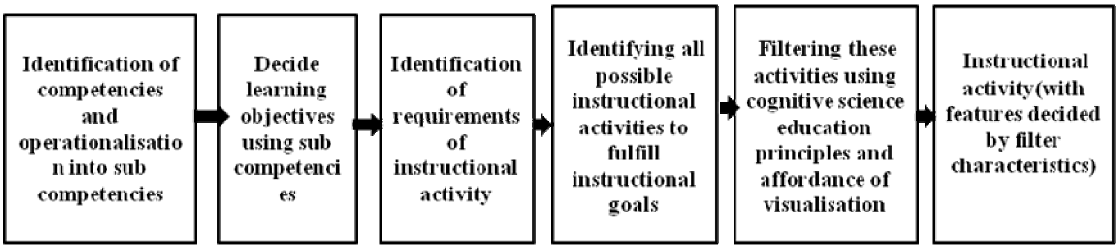

Fig.1. Steps to develop instructional activity

Our first step was to break down and operationalise design competencies into measurable units which we call sub-competencies. For example, the competency of 'Structure open problem' (SOP) is operationalised into four sub-competencies: Student should able to i) identify specifications in open-ended problem (SOP1), ii) use specifications to structure problem (SOP2) , iii) sequence steps of design process (SOP3) and iv) write structured problem statement (SOP4).

In next step, we decide the learning objectives for the visualization using sub-competencies. For example, for amplifier design, the learning objective corresponding to SOP1 - identify specifications in open problem - was "Student should able to identify faithful amplification as important specification to design the amplifier." We then identified the requirements in the instructional material that can fulfill the learning objectives. For example, to understand importance of faithful amplification as a key specification, instructional material should focus learners' attention to faithful amplification and should contain explanations and exercises related to its role as an important specification.

The major next step was to decide specific instructional activities which incorporate the identified requirements. We first listed many activities which may address the learning objectives. We then selected the appropriate ones by filtering the activities through the lens of cognitive strategies for effective learning and principles of multimedia design. These include formative assessment [2], scaffolding [6] and dynamically linked multiple representations [9]. We included several self-assessment questions at key decision points, for example, to decide which should be the next step in the design process. We provided rich feedback for each of students' responses to guide them to make correct choices. Scaffolding was given in the form of 'Design Tips' which relate to the key decisions learners need to make, in order to achieve successful design. For example, a Design Tip for amplifier design is, "Q point location should be near the centre of the load line to get faithful amplification". Learners are given the opportunity to manipulate variables when design choices have to be made based on specific values of variables. Feedback is provided in the form of visual changes due to variable manipulation. Since the analysis of electronic circuits requires multiple representations in the form of waveforms, graphs, and equations, the visualization displays the relevant representations which get dynamically updated as the variables change. Fig. 2 shows screenshots of a self-assessment question and variable manipulation.

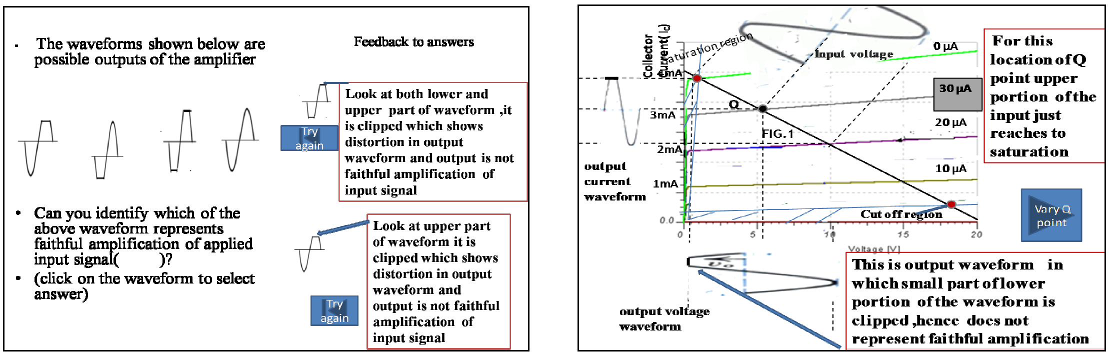

Fig.2.Screen shots of self assessment question and variable manipulation

2. Testing effectiveness of interactive visualization

Methodology

We conducted a two group post-test quasi-experiment to test the effectiveness of the interactive visualization we developed for structure open problem competency.

Sample. Our sample consisted of students from 2nd year Electronics engineering (N=71). Students had some familiarity with the content in the visualization, as they had learnt it in the theory course on the same topic. They were also familiar with using ICT materials. However, they were not exposed to design in this topic.

Procedure. . Students were randomly assigned to two groups. The experimental group consisted of 37 participants (22 male, 15 female) and the control group had 34 participants (20 male, 14 female). The equivalence between the two groups was tested on basis of their previous semester's grades and no significant difference was found between them. Two sets instructional materials on the same topic were developed. The experimental group received an interactive visualization as described in the previous section. The control group received instructional material that is traditionally used in the design lab. The instructional material of the control group was in digital format (PowerPoint slides) and contained several diagrams and explanations as needed but did not contain variable manipulation activities or formative assessment questions and feedback. Students in both groups studied material for 30 minutes, after which they attempted the post-test. This contained an open question based on instructional material for which students were asked to write (on paper) their design.

Instrument. To assess the development of students' design competencies (and sub-competencies) we used assessment rubrics [5], which had a 4-point scale : 0-Missing, 1-Inadequate, 2-Reasonable but needs improvement, 3-Good. Each rubric item corresponded to one sub-competency (SOP 1-4). These rubrics were validated prior to the experiment. Inter-rater reliability testing was found to give an 86% agreement between 3 instructors.

Results

Students' responses to the post-test question were scored via the rubrics. Fig. 3 shows the number of students obtaining scores of 0, 1, 2 and 3 on each sub-competency. We see that the lower scoring students (0 and 1) largely belong to the control group while larger fraction of students scoring 2 and 3 belong to the experimental group. For three of the sub-competencies, namely identifying specifications (SOP1), using specifications (SOP2) and sequencing design steps (SOP3) the experimental group showed higher performance. A Mann-Whitney test showed that the difference in the scores between the groups is significant for SOP1 ($\rho = 0.025$), SOP2 ($\rho = 0.00$), SOP3 ($\rho = 0.00$). For SOP4 (write structured design statement), both groups scored low and the difference is not significant ($\rho = 0.158$). Our results show that the treatment for the experimental group, that is, interactive visualizations developed to explicitly address design competencies, was effective in students' achievement of most of these competencies.

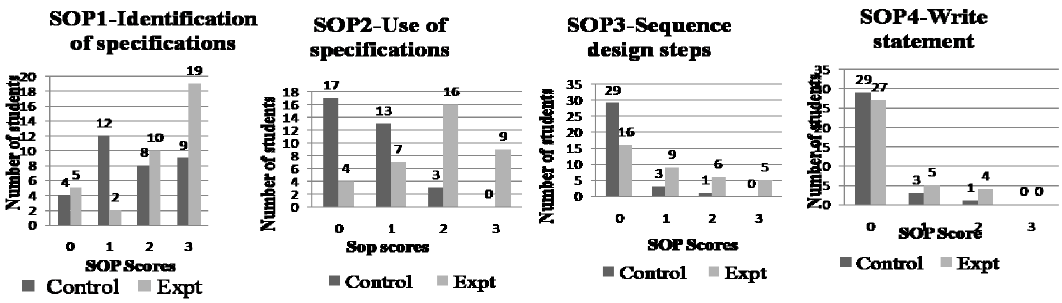

Fig.3. Frequency bar charts of scores on sub-competency Structure Open Problem

3. Conclusion and Future work

We identified pedagogical features in visualizations such as decision task based self-assessment questions with rich feedback, variable manipulation and linked multiple representations, which were useful in developing design competency of structure open problem. Students who learned using interactive visualizations with these features showed higher achievement of design sub-competencies of identify specifications in open-ended problem, use specifications to structure problem and sequence steps of design process.

We are in the process of identifying the features which may be useful to develop the sub-competency 'write structured problem statement'. We plan to conduct interviews with students determine what features in the material may help improve this sub-competency. Future work includes conducting multiple experiments in different topics, and repeating the process for other engineering design competencies.

References

[1] "A framework for the assessment of engineering education," working draft by Joint Task Force on Engineering Education Assessment.

[2] Chen, Y.-L., Hong, Y.-R., Sung, Y.-T., & Chang, K.-E.(2011) . Efficacy of Simulation-Based Learning of Electronics Using Visualization and Manipulation. Educational Technology & Society, 14 (2), 269–277.

[3] Crain, R.W., Davis, D.C., Calkins, D.E. and Gentili, K.(1995), Establishing engineering design competencies for freshman/sophomore students, ASEE/IEEE Frontiers in Education.
[4] Grimes, D., Warschauer, M., Hutchinson, T., & Kuester, F. (2006). Civil engineering education in a visualization environment: Experiences with VizClass. Journal of Engineering Education, 95(3), 249-254
[5] Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D. T., Gentile, M., Murthy S., Rosengrant, D. & Warren, A. (2006). Scientific abilities and their assessment, Physical Review, Special Topics, Physics Education Research, 2, 020103.
[6] Fund, Z. (2007). The effects of scaffolded computerized science problem-solving on achievement outcomes. Journal of Computer Assisted Learning, 23(5), 410–424.
[7] Gobert, J., & Buckley, B. (2000). Introduction to model-based teaching and learning in science education. *International Journal of Science Education,* 22*(*9*),* 891–894.
[8] May, E. & Strong, D. S. Is Engineering Education Delivering What Industry requires?
[9] Ploetzner, R., Lippitsch, S., Galmbacher, M., Heuer, D., & Scherrer, S. (2009). Students' difficulties in learning from dynamic visualisations and how they may be overcome. Computers in Human Behavior, 25(1), 56–65.
[10] Windschitl M, & Andre, T. (1998). Using computer simulations to enhance conceptual change: the roles of constructivist instruction and student epistemological beliefs. Journal of Research in Science Teaching, 35(2), 145–160.
[11] W ilczynski V. , Douglas S. M. (1995). Integrating Design Across the Engineering Curriculum: A Report From the Trenches. Journal of Engineering Education , 235-240.
[12] Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: an effort to enhance students' conceptual understanding of electric circuits. Journal of Computer Assisted Learning, 23(2), 120-132.