Work in Progress - Instructional Strategies for Pre-College Engineering Education

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Abstract - **Infusing engineering instruction into pre-college education has been the focus of a number of outreach programs, such as the Infinity project, which have primarily focused on curriculum development. In contrast, our goal is to provide a set of guidelines for the design of engineering instruction that promotes problem solving skills and cognitive flexibility in pre-college engineering education programs. Based on the existing educational psychology theories and engineering education research, we have identified four high priority research areas that need to be addressed for systematically building up a fundamental understanding of effective instructional design for pre-college engineering education: 1) Representations of engineering concepts, worked examples, and practice problems that promote students' problem solving and cognitive flexibility, 2) Problem-solving practice designs that promote students' learning, 3) Peer-model pedagogical agents, and 4) Examination of the role of spatial abilities, prior knowledge, and gender on the strategies examined in the preceding three areas.**

Index Terms – Cognitive flexibility, Instructional design, Problem solving skills, Research priorities.

INTRODUCTION

Infusing engineering instruction into pre-college education has been the focus of a number of outreach programs, such as the Infinity project. Despite the fact that engineering problem solving skills are crucial for the successful completion of these programs, there is a pronounced lack of research investigating the relationship between the instructional methods used in such programs and students' success. Therefore, the purpose of this work in progress is to systematically examine how pre-college students' learning and perceptions about learning are affected by the instructional design of engineering education. Unlike other outreach programs that focus primarily on curriculum development, our goal is to provide a set of guidelines for the design of engineering instruction that promotes problem solving skills and cognitive flexibility. Based on the existing educational psychology theories and engineering education research, we have identified four high priority research questions that need to be addressed for systematically building up a fundamental understanding of effective instructional design for pre-college engineering education. Our research questions are embedded in the context of the cognitive-affective theory of learning with media (CATLM) [1]. Our research questions assume a learning program consisting of (i) an introductory module introducing the learning objectives, (ii) a theoretical module explaining the conceptual and procedural knowledge, (iii) an application module presenting worked examples, and (iv) a practice problem module.

REPRESENTATION OF CONCEPTS, EXAMPLES, AND PRACTICE PROBLEMS

How should engineering concepts, practice problems, and worked examples be represented to promote students' problem solving and cognitive flexibility? Within this overarching question, we have identified four specific research questions:

I. Do Students Learn Better when Instruction Presents Abstract or Contextualized Engineering Diagrams?

This question is aimed at examining whether asking students to practice with a set of richly contextualized problems fosters their problem solving transfer, especially far transfer. In the abstract representation, an electrical system, for instance, is presented as an abstract circuit diagram without specifying which components the different circuit elements represent or what their purpose is. In contrast, in a contextualized problem, the device under consideration (e.g., I-Pod) is presented along with a representation of the different electrical components of the system in basic circuit elements. Although abstract representation may be used to introduce and emphasize points at the lower levels of thinking, to promote cognitive flexibility, students need to transition from solving abstract problems to solving real world, highly contextualized problems.

II. Can Animations Help in Understanding Engineering Principles Better Than Static Diagrams?

Despite the increasing development of animated representations of engineering problems, still open is the question of whether visual representations should be animated to help students' visualize the relationship between the elements of the system [2] or help students change their misconceptions in a domain. We find it therefore necessary to investigate the effectiveness of instructional engineering animations, considering both local animations of the system parts of interest (e.g., an animation of a branching point of an electric current) as well as global animation of the system

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(e.g., an animation of the current flow around the entire circuit) in comparison with the more traditional static diagrams.

III. Do Students Learn to Solve Engineering Problems Better when Multiple Representations are Integrated?

Although most engineering education practices recognize the benefits of presenting multiple representations of knowledge, still missing is research regarding how students connect the different representations with each other. According to the spatial contiguity principle of instructional design, students learn better when multiple sources of visual information are integrated rather than separated [3]. Therefore, we will investigate whether different methods to integrate engineering equations and diagrams, such as static integration (all equations are integrated in a diagram) and dynamic cumulative integration (equations are progressively filled in), help students' problem solving and cognitive flexibility.

IV. Do Students Learn Better When Signaling Methods Select Relevant Information?

Signaling methods are aimed at promoting students' learning by reducing extraneous processing. One of the challenges of teaching novice students is that they lack the necessary background knowledge to help them distinguish between what is relevant and what is not relevant in a problem situation, especially when the problem includes multiple representations [4]. Signaling methods may help overcome this challenge by guiding students' visual attention to relevant pieces of information during learning. In our research we examine the signaling effects of non-agent (i.e., arrows) and agent cues (i.e., pointing gestures).

PROBLEM SOLVING PRACTICE DESIGNS

Once we have established the optimal knowledge representation design, we will investigate the effectiveness of a set of problem-solving practice methods. In past research, we have investigated the benefits of having learners transition from studying worked examples to independently solving problems [5]. However, it is still not clear if the advantage of gradually increasing the practice of solving more steps is dependent on the order of the steps that need to be solved. Also, the impact of different types of adapting feedback to incorrect solution attempts needs to be investigated.

PEER-MODEL PEDAGOGICAL AGENTS

Although recent reviews of pedagogical agent research do not support the idea that their visual presence promotes deeper learning, this limitation may be due to the facts that the vast majority of past research was conducted with college students (who may not be as motivated by the presence of agents as younger students) and that most studies did not use a theoretical framework to guide the agent's design [6]. For pre-college engineering education, we find it therefore necessary to examine an agent design that is consistent with social cognitive theories of learning, including research on observational learning and modeling [7]. We expect that students who learn with the presence of a peer-model agent throughout the program will learn more and give more favorable learning perceptions than their counterparts.

IMPACT OF INDIVIDUAL DIFFERENCES

Regarding individual differences in engineering education, a significant effort has been made in the past to better understand the role of students' learning styles [8] and teaming skills. However, less clear is the relationship between students' spatial abilities, prior knowledge, gender, or attitudes on learning engineering topics. Therefore, it is of high priority to examine the role of students' individual differences in two ways. First, for each of the above research questions, it is important to compare the performance of high and low prior knowledge students, high and low visuo-spatial ability students, and boys and girls. Second, it is vital to assess the participants' self-efficacy and beliefs (i.e., value, interest) in math, science, and engineering, their academic motivation, and future goals.

CONCLUSION

We have outlined four key research areas for systematically establishing the fundamental underpinnings of effective instructional design for pre-college engineering education. In our work-in-progress we are examining the outlined areas through experiments with a diverse pre-college student population in engineering outreach programs.

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