

WIP: Bridging Cognitive and Motivational Psychology to Combat Shortage of Engineers

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Abstract—The decline in interest among U.S. students in engineering programs of study, which has the potential to severely affect our technology based society, has motivated the formation of a team of engineers and psychologists to examine the psychological foundations of effective engineering education. The team's work in progress is focused on a rigorous examination of the cognitive psychology and motivational psychology aspects of engineering education.

Index Terms—Cognitive psychology, cognitive load, engineering education, motivational psychology, multimedia learning, social embedding, student persistence.

I. INTRODUCTION

Maintaining the technology based society in the U.S. requires a highly skilled engineering workforce. Engineering and computer science, however, are suffering from low popularity among domestic students and U.S. colleges struggle to graduate sufficient numbers of engineers [1]–[5]. This paper describes work-in-progress by a cross-disciplinary team of engineers and psychologists to uncover the fundamental techniques that can be employed to increase the popularity of engineering programs among U.S. students and make engineering education more effective. The team identified two prominent causes for the shortage of engineering graduates: 1) Low awareness of engineering in the general population (according to recent statistics less than half of the general U.S. population and less than a quarter of the female U.S. population is aware of what engineers do [6]), which results in low interest in engineering courses of study among high school graduates. 2) From the high school graduates that do enroll in engineering freshmen college programs, a significant fraction drops out, as they are overly challenged by and lack the persistence to complete the engineering studies. The team is in the process of addressing these two challenges by bridging two areas of psychological research with engineering and computer science. Cognitive psychology contributes rigorous investigations of the applicability and adaptation of techniques for minimizing cognitive load and fostering self-efficacy, such as learning from worked examples and multimedia learning techniques (e.g., segmenting, pre-training, weeding) to engineering education. Motivational psychology contributes investigations of the cultural context and social relevance of engineering and computer science

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on the persistence of the learners and explores techniques for fostering persistence. These efforts are combined to uncover the fundamental psychological foundations of engineering education. From these foundations the team derives guidelines for educational modules that (i) can be employed to increase the awareness of and interest in engineering/computer science among high school students, (ii) reduce the cognitive load in engineering courses, and (iii) increase the interest in and the continuous motivation for pursuing studies and careers in engineering/computer science.

A. Related Work

Engineering educators have over many years made strides in increasing the effectiveness of the instruction of engineering content, for instance by accommodating the individual students' learning styles (see e.g., [7]), and by promoting key characteristics of successful engineering practice, such as teaming skills (see e.g., [8], [9]). Our research is complementary to these efforts in that we seek to identify the psychological underpinnings of learning engineering and computer science content and to formulate guidelines for effective engineering and computer science instruction.

II. COGNITIVE AND MOTIVATIONAL PSYCHOLOGY FOUNDATIONS OF ENGINEERING EDUCATION

The overall approach of our research effort is to bridge two areas of psychological research with engineering and computer science to achieve fundamental advances to the understanding of learning and instruction in the engineering and computer science disciplines. In particular, our research is founded on the two pillars of cognitive psychology and motivational psychology.

From the domain of cognitive psychology we are examining the applicability and adaptation of techniques for fostering effective learning, such as learning from worked examples and multimedia learning techniques (e.g., segmenting, pre-training, weeding). Guided by the existing educational psychology literature, e.g., [10], which has been primarily based on studies with psychology student subjects in the domain of social sciences and elementary probability theory, we are carefully investigating to which extend these previously studied principles and guidelines carry over to the field of engineering and computer science. Depending on the outcome of these investigations we will conduct studies that either refine existing principles and guidelines for effective use in engineering, or lead to the identification of principles that are unique to engineering and the formulation of corresponding guidelines.

From the domain of motivational psychology we are examining the impact of the cultural context and social relevance of engineering and computer science on the persistence of the learners and explore techniques for fostering persistence. More specifically, the statistics reviewed above indicate that a large portion of the U.S. population has little personal experiences with engineering and computer science. This lack of personal involvement with the engineering field means that many learners can not relate to the engineering instruction within their social context and experiences. According to Keller's ARCS model of motivational design [11], however, it is essential that learners are exposed to instruction that can match their previous experiences, needs, interests, and motives. This lack of personal experiences and involvement appears to be a unique challenge of engineering education that is not encountered in the heavily researched social science and elementary probability instruction.

III. PRELIMINARY RESULTS: EFFECTIVE REPRESENTATIONS OF ENGINEERING CONTENT

Our preliminary research on the cognitive aspects has led to fundamental insights into the efficient representation of engineering instructional content. We have found that for high school students with no prior exposure to engineering education, a textual representation of instructional prompts is more effective (effect size Cohen's $f = 0.38$ corresponding to a large effect) than prompts in graphical form [12]. On the other hand, we have found that a representation that combines text and graphics of the learning content is more effective (effect size Cohen's $f = 0.31$ corresponding to a medium to large effect) than a representation that combines text and equations for college level engineering students [13]. These preliminary results, which can be explained by the cognitive load theory, give some initial indication of the importance of the appropriate representation of learning content depending on the level of prior knowledge of the engineering domain. They also indicate that a comprehensive investigation of the cognitive aspects of engineering education (beyond basic content representation) is urgently needed.

IV. DISSEMINATION OF UNCOVERED PRINCIPLES

The main expected outcome of our research are techniques that have rigorously verified levels of effectiveness in (i) instilling a sense of self-efficacy and a high level of interest in and continuous motivation for engineering studies in K-12 students, and (ii) enhancing engineering and computer science courses at the college/university level. We will implement these techniques in instructional modules that introduce K-12 students to engineering and computer science and investigate our experimental variations with K-12 students. The best performing versions of the modules will be made available to high schools across the U.S. along with appropriate teacher guides. At the college/university level we will carry out our exploratory research studies in the context of instructional content within the undergraduate engineering and computer

science curriculum. We will develop instructional modules for the most popular and challenging introductory engineering and computer science courses, such as Introduction to Digital Design and Introduction to Electrical Networks. The developed modules will include the desired experimental variations and will be tested with engineering and computer science students at ASU and community colleges in the Phoenix metropolitan area. The most effective variation of the modules will be offered for permanent integration in the courses at ASU and similar courses at other universities and community colleges.

V. EVALUATION PLAN

Our evaluation strategy combines clinical studies, which employ the accepted research methods and statistical techniques of behavioral sciences research, and longitudinal evaluations, which are conducted with the course enhancements outlined in the preceding section.

VI. CONCLUSIONS

We believe that thoroughly understood cognitive and motivational psychology principles that have been rigorously verified in empirical studies are crucial for effective engineering education. We also believe that such principles, which will be the outcome of this work in progress, will be an important component in the efforts to attract and retain more qualified U.S. students in engineering and thus alleviate the shortage of engineers.

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