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Cultivating hardware engineering interest in high school students using hands-on learning

Blinded Authors

Introduction

A matter of national security for the US is supporting the development of the semiconductor and microchip workforce to address the chip shortage and its negative consequences on the US economy. Higher education institutions are establishing programs to train the necessary workforce and address the CHIPS Act passed by the US legislature in 2022. However, high school students interested in computer engineering often fail to consider the hardware aspects of the field and opt for degrees centered around software. This trend primarily arises from their limited understanding of the roles of hardware engineers and the prevalent misconceptions surrounding computer hardware scientific concepts.

To address this issue, we have undertaken a project funded by the NSF IUSE program to explore the usability and feasibility of hands-on hardware activities for high-school and first-year undergraduate students across various engineering disciplines. These activities aim to balance simulations, real-life circuit design, Field-Programmable Gate Arrays (FPGA)-based applications, and collaboration to develop FPGA-based projects to address real-world challenges. Examples of these challenges include integrating FPGAs with sensors to achieve intelligent home energy management or optimizing air conditioners for precise temperature control. Students also interacted with guest speakers who are experts and role models in computer hardware engineering.

By offering varied approaches to hands-on, collaborative learning, we aim to cultivate situational and individual interest in computer hardware to ultimately contribute to the development of the highly needed computer hardware workforce in the US. This proposal reports on the results of a study that was informed by the following research questions: (1) How do hands-on activities impact high school students' situational interest in computer hardware engineering in a 6-week summer seminar? and (2) How do hands-on activities impact high school students' individual interest in computer hardware engineering in a 6-week summer seminar?

Keywords: STEM education, hardware engineering, interest, situated learning

Theoretical Background

Interest development

Renninger and Hidi (2019) framed the concept of interest as a dynamic interplay between an individual's engagement with a particular content and their enduring motivation to engage with it over time. Promoting interest has been a focus of numerous studies as it is strongly correlated with desirable learning outcomes (Hidi et al., 2004; Krapp & Prenzel, 2011; Renninger & Hidi, 2016; Schiefele, 2012), academic achievement(Grigg et al., 2018; Hidi & Harackiewicz, 2000; Jansen et al., 2016), and career choice (Larson & Rusk, 2011; Silvia, 2006). Since interest evolves over time, researchers commonly differentiate between situational interest, which is short-termed and influenced by external factors, and individual or personal interest, which is intrinsic and long-lasting (Romine et al., 2014).

Drawing from these two distinct forms of interest, Hidi and Renninger (2006) proposed a four-phase model of interest development depicted in Figure 1. This model illustrates a progression from initial phases of situational interest to a more profound cultivation of individual interest. The first two phases encompass the trigger and maintenance of situational interest, while the latter two witness the emergence and maturation of individual interest (Hidi & Renninger, 2006). In this study, our focus lies in understanding whether and how hands-on activities initiate situational interest and the factors that facilitate the transition towards a more enduring individual interest in the realm of hardware computing education.

Traditionally, the instruction of hardware principles has been centered around a lecture-based method, where instructors deliver information unidirectionally, often with minimal classroom interaction or collaboration (Helps, 2015). Nevertheless, there is an increasing acknowledgment of the necessity for a more immersive and hands-on approach to aid students in understanding and applying hardware design concepts effectively within real-world scenarios (Ackovska & Ristov, 2013; Rotgans & Schmidt, 2011). As a result, our pedagogical approach places importance on cultivating an inquiry-based and experiential learning experience, which is expounded upon later. This approach is chosen to actively foster interest and engagement among students.

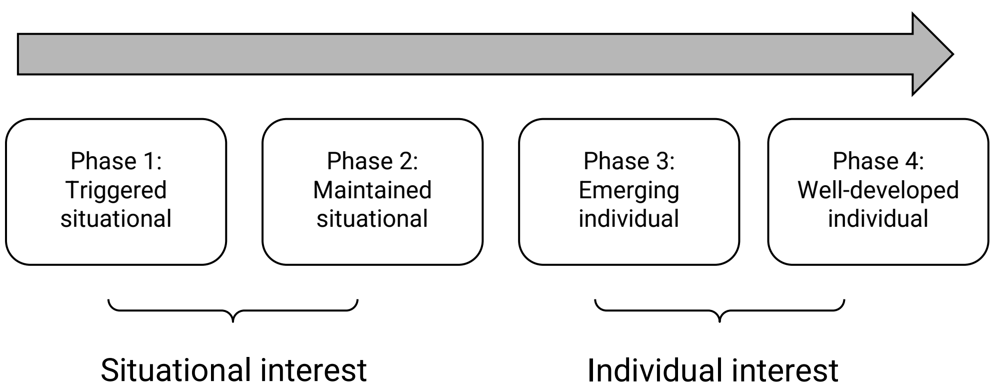


Figure 1. Hidi and Renninger (2006) Four-phase interest development model

Methods

Study context

As part of a project funded by the NSF IUSE program, we are developing a series of activities for an undergraduate course tailored for incoming freshmen within the College of Engineering at a large southeastern R1 institution. For this study, we scaffolded the activities to cater to high school students who participated in an honors seminar in a summer residential program at this university.

The residential research program is designed for motivated students who are entering their senior year and offers them a platform to actively participate in research endeavors. The honors seminar classes within this program are intentionally capped at 12 students, ensuring a focused learning environment. Additionally, students are granted the opportunity to express their preferences regarding the specific seminar classes they wish to enroll in. Our seminar entitled "Hands-on Introduction to Computer Hardware: A Game-Based Approach" took place twice a week, with each session lasting an hour and a half, over a period of six weeks.

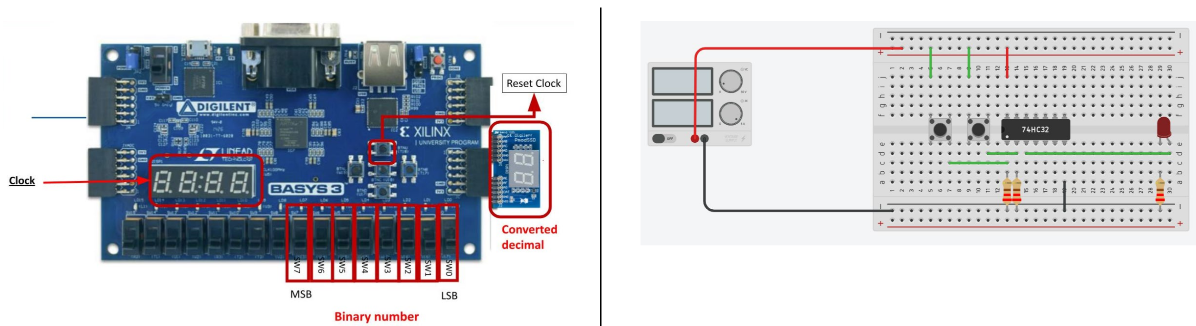
Instructional module

To provide students with hands-on learning experiences in hardware engineering, our seminar incorporated a range of instructional activities. These activities aimed to cover various science and math topics, including binary arithmetic, Boolean logic, combinational circuits, sequential circuits in the form of finite state machines, and memory read-and-write processes.

Field-Programmable Gate Arrays (FPGA)-based activities

FPGAs are integrated circuits with the capacity to be customized for different functions and are well-suited for learning and teaching digital logic and computer architecture. In a bid to optimize the pedagogical capabilities of the FPGA board, we created enhanced configurations using external components such as LEDs, OLEDs, and seven-segment displays. These configurations afford students practical approaches to understanding the topics. Figure 2 on the left depicts the configuration used to facilitate conversions between decimal and binary numbers. In this activity, students were asked to use the seven switches highlighted in the red box to introduce the binary number (on for a one and off for a zero) and verify the answer in the seven-segment display attached to the right side of the board.

Besides, students were engaged in an open-ended project. This team project entailed devising a solution for a real-world problem or challenge that could be effectively tackled through the implementation of an FPGA.



Binary conversion activity using an FPGA

Truth table activity using breadboards and electronic components

Figure 2. Hands-on activities

Simulation and physical interaction with circuits activities

Although FPGAs offer substantial flexibility in digital design and are powerful educational tools, they may hide the foundational understanding of circuits and microchips. To address this balance, we offered interactive simulations within the web-based platform Tinkercad and hands-on construction of circuits employing breadboards, resistors, capacitors, push buttons, and various integrated circuits (ICs) to achieve specific functionalities. A visual representation of one such circuit is depicted on the right of Figure 2. This circuit facilitated the generation of truth tables for distinct logic gates by utilizing the push buttons as inputs and the red LED as the output indicator.

Participants

Ten students participated in the seminar, of whom six, including two self-identified girls and four boys, provided informed consent. These students came from various high schools across the United States.

Measures and data sources

Participants were engaged in a semi-structured focus group at the end of the seminar. The focus group protocol was designed to explore students' perceptions of the activities and whether they triggered situational interest in hardware computing or provided meaningful engagement toward the topic. This design aimed to address the first research question: How do hands-on activities impact high school students' situational interest in computer hardware engineering in a 6-week summer seminar?

The focus group session was recorded using Zoom to facilitate transcription, and the participants' responses were coded using an a-priori codebook. This codebook was developed based on the learner characteristics, feedback wants, and feedback needs outlined by Renninger (2009) in the first two phases of interest development (Hidi & Renninger, 2006).

Also, we adapted Romine et al.'s (2014) instrument to measure Student Interest in Technology and Science (SITS). The SITS instrument assesses individual interest in science and technology, specifically to understand students' ideas about learning, careers in science and technology, and computer engineering. We adapted the survey to focus on computer hardware rather than biotechnology, which was the focus of the original instrument. These close-ended items in the survey used a 4-point Likert scale from strongly disagree to strongly agree. Participants completed the same survey on the first and last week of the seminar.

Due to the limited sample size, we refrained from conducting inferential statistical analyses. Instead, we calculated descriptive statistics to address the second research question: How do hands-on activities impact high school students' individual interest in computer hardware engineering in a 6-week summer seminar?

Results and Discussion

Situational interest

Table 1 depicts the results of coding the transcriptions derived from the focus group session. Findings suggest that students exhibited characteristics of transitioning from triggered situational interest to a more sustained state of situational interest. For instance, one participant stated, "I'm interested in engineering. And so like, there's definitely lots of different things in FPGAs that can be used for in engineering. So it is relevant to what I want to do." This quote exemplifies the progression observed, as the student's interest transformed from character identification to a sustained personal engagement (Renninger, 2009)

Table 1. Situational interest results

Phase 1: Triggered situational interest	Phase 2: Maintained situational interest
Learners - Found guest speakers as helpful role models - Attended to content with enthusiasm. Exemplar quote: "This is something really cool that I learned that I didn't know." - May encountered either positive or negative emotions. Exemplar quote: "I was just like this seem like a little bit pointless because it was like so easy." Learners wanted - To help others understand the level of effort required when working with this content. Exemplar quote: "It's kind of hard to comprehend like how you have such a small thing, but it does so much."	Learners - Are mastering the topic. Exemplar quote: "I got some understanding of how vending machine works." - Revisited content that had previously captured their interest. Exemplar quote: "I thought about a time when I was at my house, and I realized the air conditioner was wrong. So I was like, Okay, but I can solve this problem with an FPGA by, you know, putting some sensors around." Learners needed - Help in exploring the topic. Exemplar quote: "I would like to know how you efficiently put all that stuff into video game developing"

Individual interest

Survey results indicated that the six-week seminar increased participants' overall individual interest. Table 2 contains descriptive statistics, including the means (M), medians (Mdn), and standard deviations (SD) for each survey factor pre-seminar and post-seminar. The results for ideas about careers and computer hardware portrayed the greatest increase between pre and post. This finding indicates that the hands-on activities with FPGA boards and simulated circuits during this 6-week summer seminar may be an effective approach for improving students' inclination to pursue further studies in hardware-related topics.

Table 2. Descriptive statistics

	Pre			Post		
	M	**Mdn**	**SD**	**M**	**Mdn**	**SD**
Ideas about learning	3.73	3.80	.34	4.00	4.00	.00
Ideas about careers	3.42	3.50	.31	3.85	3.85	.10
Ideas about computer engineering	3.77	3.90	.29	4.00	4.00	.00
Ideas about computer hardware	3.08	3.00	.58	3.83	4.00	.26

Significance

Given the increasing demand from both the industry and the US government for greater student involvement in hardware development and manufacturing processes, it becomes paramount to develop effective methods for nurturing student interest and persistence in hardware engineering topics. The findings of this study indicate that highly immersive hands-on experiences involving circuits, educational tools like FPGAs, and real-world project applications contribute to improved interest in computer hardware engineering. Future research should explore how interest development evolves over time and define ways to provide enduring support for students interested in joining the engineering workforce.

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