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BOARD # 202: Engaging Pre-College Students in Electrical Engineering: Role-Playing and Model-Building to Foster Engineering Identity and Values (Work in Progress)

Ms. Kristin Spangler Chisholm, University of Delaware

Kristin Chisholm is a second-year Ph.D. student in Educational Statistics and Research Methods at the University of Delaware. Her research focuses on STEM education, fostering diversity in STEM fields, and the measurement of educational outcomes in STEM disciplines. In 2024, she was awarded the NSF Graduate Research Fellowship.

Leveraging Photolithography and Integrated Circuits to Foster Electrical Engineering Identity and Values in K-12 Learners

Introduction:

The engineering field has made significant strides in promoting diversity and inclusion. However, electrical engineering (EE) continues to face notable challenges in this area. While other engineering disciplines have seen a narrowing gender gap, women remain significantly underrepresented in EE, with a male-to-female ratio of 8:1 [1]. Despite its critical importance, EE is often overlooked in K-12 education, where STEM programs tend to focus on mechanical engineering or general science. As a result, EE concepts frequently remain unexplored until college [2]. This lack of early exposure, among other factors, contributes to declining enrollment in EE programs compared to other STEM fields [2, 3].

To enhance diversity and interest in electrical engineering (EE), various initiatives have focused on hands-on workshops, integrating creativity into STEM education, and altruistic projects, such as designing solar-rechargeable reading lights, which have been particularly effective in engaging girls [4, 5]. Other efforts include organizing tours, funding science fairs and camps, and supporting robotics teams [6]. Despite these initiatives, gender disparities persist, with boys often receiving greater encouragement to pursue EE careers through support from home, school, and technology-related hobbies [7]. To overcome these challenges and create more equitable opportunities in electrical engineering (EE), it is essential to adopt approaches that engage learners through hands-on and creative activities and address the social and cultural factors that influence identity and value formation.

This paper addresses these challenges by introducing an innovative educational approach incorporating hands-on modeling activities and principles to foster engineering identity and values in children and their families. Grounded in the Tripartite Integration Model of Social Influence (TIMSI) [8, 9], this approach leverages photolithography—a key process in creating integrated circuits (ICs)—as a creative and interactive tool to introduce foundational electrical engineering (EE) concepts. TIMSI emphasizes the importance of social influences, such as mentorship and collaborative experiences, in shaping identity and value formation [8]. By connecting EE concepts to family knowledge and culturally relevant contexts, this framework helps participants internalize the significance of engineering personally and societally [10]. The study integrates these elements within informal learning environments to address equity gaps, promote inclusion, and inspire greater interest and long-term engagement in EE.

To achieve these goals, photolithography serves as a pivotal EE concept to engage children and their families in both the technical and creative aspects of the field in an accessible and meaningful way. Integrated Circuits (ICs), commonly known as microchips or simply chips, are small semiconductor devices that contain a network of interconnected electronic components, such as transistors, resistors, and capacitors, all embedded in a single piece of material, usually silicon. These components perform various functions, from processing and storing data to controlling electrical signals in electronic devices [11]. ICs, foundational to modern electronics, provide an entry point to EE. Photolithography, a process in IC manufacturing, can be simplified into three primary steps:

1. Coating a silicon wafer with a light-sensitive photoresist using spin-coating for uniformity.
2. Exposing the wafer to UV light through a mask, creating a pattern by altering the photoresist's chemical structure.
3. Developing the wafer with a solution to remove either the exposed or unexposed areas, leaving the desired pattern for etching or deposition [12].

About the activity:

In partnership with a local science and nature museum, this study adopts a family-centered approach to create an engaging learning environment where children and their families explore electrical engineering (EE) concepts together. The activity begins with a discussion led by the researcher, inviting families to share their existing knowledge about computer integrated circuits (ICs) or computer chips. Families examine disassembled circuit boards from various appliances, learning to identify computer chips and their significance. The conversation transitions to explaining how computer chips are made, accompanied by a short demonstration or model of the manufacturing stages.

Children then participate in a hands-on activity using 3D-printed masks, blacklight pens, and a UV light box to create designs such as cars, turtles, or flowers, effectively simulating the photolithography process used in IC manufacturing. Kid-friendly materials, including 3D-printed masks, canvases, and black light pens, make the process accessible and fun. Instead of traditional IC patterns, children craft creative and relatable designs, such as butterflies or cars, fostering both engagement and understanding (Appendix Figure 1)

The activity concludes with a design challenge where children create a pattern, decompose it into three individual layers, and then reassemble the layers to achieve the final design. This hands-on experience highlights the importance of technical precision and creative problem-solving in designing integrated circuits. By linking these activities to participants' everyday experiences and family knowledge, the study seeks to make EE concepts more accessible, relevant, and engaging for diverse learners.

Research Question:

Does participation in a photolithography-based hands-on activity in an informal environment influence children's EE identity and/or value orientation?

Theoretical Framework:

The Tripartite Integration Model of Social Influence (TIMSI) provides a powerful lens for understanding how individuals integrate into social systems, particularly within STEM fields. Developed by Estrada and colleagues [8, 9] and grounded in Kelman's social influence theory, TIMSI explores how social interactions shape motivation, engagement, and persistence, particularly for underrepresented minorities in STEM [13, 14]. By focusing on three key processes—self-efficacy (rule-orientation), identification, and internalization of values—TIMSI explains how individuals come to see themselves as part of a scientific community [8, 15]. This model emphasizes how identity formation and aligning personal values with community norms are essential for fostering long-term engagement in STEM fields.

Mentorship and research experiences are pivotal in facilitating the processes outlined in TIMSI. These interactions encourage individuals to identify with STEM communities and internalize the field's values, reinforcing immediate engagement and long-term persistence [15]. TIMSI aligns with Cameron's [16] three-factor model of social identity, which highlights centrality, ingroup affect, and ingroup ties as key dimensions of identity. Both models underscore the importance of social mechanisms in shaping how individuals internalize the norms and values of a community. While TIMSI focuses on integrating underrepresented students into STEM fields, broader social influence models, such as Flache et al. [17], reveal how diverse beliefs and behaviors can persist in communities. These frameworks highlight the complex interplay between social dynamics, identity formation, and value internalization.

TIMSI's application to undergraduate STEM students has shown that identity and internalized values are critical for career persistence. Research experiences and mentorship foster scientific identity by providing opportunities for students to engage in meaningful work and take ownership of projects [18]. These experiences enable students to internalize the values of STEM communities, such as collaboration, innovation, and perseverance, making them more likely to persist in STEM careers. Although self-efficacy plays an important role, TIMSI emphasizes that identity and value alignment are even stronger predictors of sustained motivation and long-term commitment to STEM fields [8].

Developing engineering identity is particularly important for addressing disparities in recruitment and retention within the field [19, 20, 21]. However, this process is often hindered by racialized and gendered perceptions of engineering, which disproportionately affect underrepresented groups, such as Black women [22]. These barriers undermine the ability of individuals to identify with the field and internalize its values. Increasing the visibility of engineering to children, particularly through culturally relevant and family-centered approaches, can help combat these disparities by fostering a sense of belonging and emphasizing the societal relevance of engineering [2, 8]. Addressing these gaps in identity development is critical for creating a more inclusive and diverse engineering community.

TIMSI has been adapted to focus on identity and value formation for pre-college electrical engineering (EE) learners. This adaptation incorporates relatable examples, hands-on activities, and mentorship to scaffold identity development and value internalization. By connecting EE concepts to family knowledge, or "funds of knowledge," and everyday experiences, TIMSI emphasizes the relevance of engineering in familiar contexts, making it easier for learners to identify with the field and adopt its values [10, 23]. Hands-on activities, such as those where children take on the role of electrical engineers, make abstract concepts tangible and foster the development of engineering identity and the internalization of the field's core values [4]. These strategies are designed to cultivate a sense of belonging while highlighting the societal importance of engineering.

This study designed an EE activity specifically for children to address the developmental needs of pre-college EE learners. Research shows that children engage with STEM concepts differently from adults, relying more on physical manipulation and sensory experiences for problem-solving [24, 25]. This makes hands-on activities, like the photolithography activity used in this study, particularly effective for introducing EE concepts and promoting engagement. Children's openness to new evidence and exploratory learning further supports their ability to form connections between abstract concepts and personal experiences [26]. The activity fosters the curiosity and creativity necessary to develop engineering identity and internalized values by tailoring the lesson to align with these cognitive and developmental characteristics.

Methods:

A quasi-experimental one-group pretest-posttest design will be implemented in future iterations of this project [27]. The current draft, however, is a work in progress and includes only qualitative data collected before the survey's development. Future data collection will involve a pre-post survey to assess the impact of the photolithography-based activity on children's EE identity and value orientation. This survey was adapted from a TIMSI-based scale for undergraduates in STEM and tailored for K-12 learners of EE in collaboration with a professor of education specializing in measurement and a professor of electrical engineering [15] (Appendix Table 1).

For the current qualitative data, a pragmatic perspective guided a case study approach to analyze the memos [28]. Analysis was conducted using directed content analysis, where the memos were reviewed with predefined themes of identity and values, derived from prior research. This approach allowed the author to systematically identify evidence in the data that aligned with or challenged these themes [29].

Data Collection:

Preliminary qualitative data were collected during two three-hour museum sessions, engaging approximately 60 visitors. The author observed family interactions, recorded memos, and gathered qualitative feedback on the activity. These memos were analyzed to generate initial findings. Additional data collection, using the surveys, is planned between February and June through further museum visits, with findings to be compiled in time for the conference.

Preliminary Findings:

The activity appeared to foster identification with the engineering community, as evidenced by the children's responses and discussions with their parents. Children related the activity to familiar experiences at home, describing it as an "art project" and referring to the masks as "stencils." These connections suggest that the activity helped children integrate engineering concepts into their identities. This aligns with research on identity development in STEM education, highlighting the importance of connecting learning experiences to students' experiences and prior knowledge [8, 16, 18].

Participants developed an appreciation for the societal relevance of engineering through discussions on integrated circuits' technical and broader implications. Parents asked about the CHIPS Act and chip materials, and the children listened in, indicating an emerging understanding of engineering's applications. Families shared stories of grandparents working in chip factories, revealing personal connections. These interactions highlight the potential to leverage families' "funds of knowledge" [10], helping children view electrical engineering (EE) as relevant, practical, and aligned with their personal and cultural values, bridging abstract concepts with real-life applications.

The preliminary qualitative findings indicate that using photolithography as a tool to teach integrated circuit (IC) design effectively engages children, introducing them to both the creative and technical dimensions of electrical engineering (EE). However, further refinement of the survey instrument is necessary to ensure its validity in measuring changes in students' EE identity and values. Cognitive interviews and pilot testing will help align the survey items with children's experiences and better capture the constructs of interest.

While short-term changes in identity and values are anticipated, sustaining engagement in engineering will likely require continued exposure and support [9]. TIMSI's focus on systemic and social factors underscores the critical roles of mentorship, cultural context, and institutional backing in promoting long-term persistence in STEM fields [8, 9]. The museum setting offers a unique platform for informal learning, but integrating these experiences into formal educational pathways could amplify their reach and impact.

An interesting avenue for future research involves examining the influence of family presence during these activities. Comparing outcomes from sessions conducted with and without family participation could provide deeper insights into the societal influence of familial involvement, particularly its impact on identity and value formation in young learners.

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Appendix

Figure 1- Example Masks and Complete Design

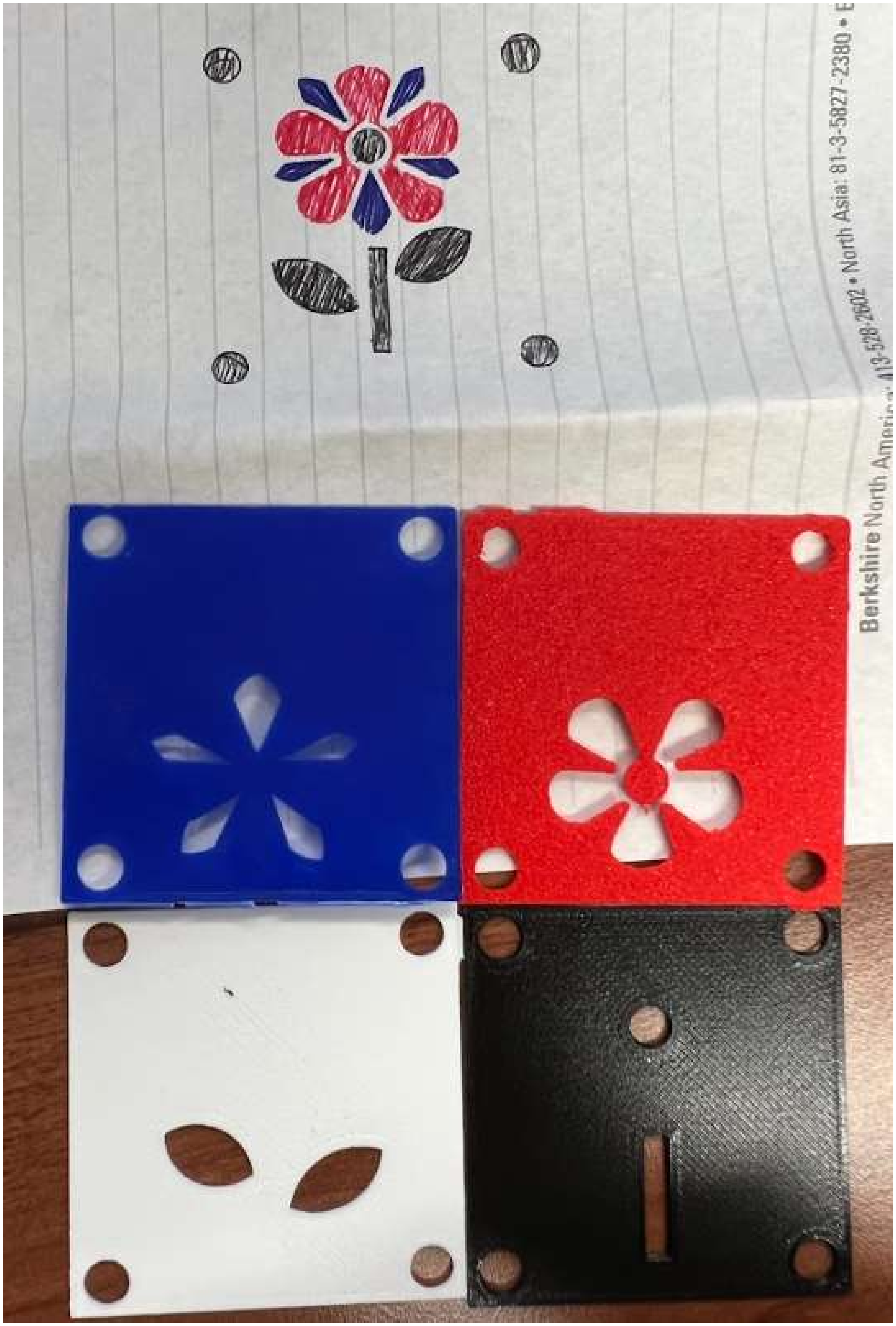

Table 1- Original and Adapted Survey Items

Electrical Engineering Values

Original Items

1. A person who feels that discovering something new in the sciences is thrilling.
2. A person who thinks scientific research can solve many of today's world challenges.
3. A person who thinks it is valuable to conduct research that builds the world's scientific knowledge.
4. A person who thinks discussing new theories and ideas between scientists is important.

Adapted Items

1. I get excited about discovering something new.
2. I believe that technology can help solve important problems.
3. I think it's important to work on projects that help us learn about technology.
4. I enjoy discussing new ideas and inventions with others.

Electrical Engineering Identity

Original Items

1. I have a strong sense of belonging to the community of scientists.
2. I derive great personal satisfaction from working on a team that is doing important research.
3. I have come to think of myself as a "scientist."
4. I feel like I belong in the field of science.
5. The daily work of a scientist is appealing to me.

Adapted Items

1. I feel like I would fit in with people who design and create new technology.
2. I would love to create and fix important devices when I grow up.
3. I see myself working on new technology in the future.
4. I feel like I belong with people who work on technological projects.
5. I find the work of inventing and designing technology to be exciting and fun.