The Role of Makerspaces in Developing Sociotechnical Skills for the Education of Innovative Biomedical Engineers

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Abstract

This full paper explores the research question: *How do sociotechnical competencies develop in biomedical engineering undergraduate students utilizing the DesignCube and collaborative design to prototype medical devices?* We examined the *DesignCube,* a Biomedical Engineering Makerspace, as a sociotechnical learning space in which prototyping activities and collaborative design practices support students' joint development of technical capability and sociocultural awareness. Through pre- and post- semi-structured interviews with Ugandan biomedical engineering (BME) undergraduate students, we find that students reported changes in their behaviors regarding patience, collaboration, learning from others, and engaging across cultural and community differences. Our results suggest that the *DesignCube* supports students by jointly developing technical proficiency and sociocultural competence through hands-on, team-based design experiences.

Introduction

Makerspaces have the potential to enhance engineering education in under-resourced communities by providing hands-on, experiential learning opportunities [1]. Makerspaces in formal educational institutions create a safe and structured space for exploration, where failure and iteration are treated as integral to learning [2]. In low-income communities, shared makerspaces may also reduce barriers to participation by providing access to prototyping tools, materials, and supportive infrastructure that students may not otherwise have [1]. In this study, we examine how a shared makerspace in Makerere University, Uganda, shapes biomedical students' sociotechnical learning by stabilizing access to prototyping tools and support that enable sustained collaborative design work.

The Biomedical Engineering Department at Makerere University hosts a four-semester design course sequence (Design I to Design IV). The courses engage students in contextually relevant design and prototyping processes with the goal of producing locally responsive innovations that address community health needs. In Design I, students partner with local health and medical service community partners to scope problems related to healthcare delivery. In Design II (the course context of this study), students are introduced to the *DesignCube* to support early-stage prototyping.

The *DesignCube* is a makerspace equipped with tools and equipment for BME design and prototyping at the university. The *DesignCube* was funded by a VentureWell grant and is supported by Duke University, USA (e.g., resupply of materials). The *DesignCube* provides equipment and materials not readily available in Uganda, such as a 3D printer, specialized electronic components like temperature sensors, and medical equipment like stethoscopes; other readily available materials and tools are also present, like hand tools, low-fidelity prototyping materials, wood, adhesives, etc. Prior to the construction and operation of the *DesignCube*, student teams hired local craftsmen to construct components of their design. Thus, the *DesignCube* reduces barriers to participation in medical device design by lowering the financial and logistical costs of prototyping. While there is limited literature about makerspaces within formal educational institutions in low-income nations, the *DesignCube* is similar to other makerspaces in low-income settings described by Wettergreen et al [3]. Their findings corroborate the efficacy and impact of makerspaces in bolstering engineering education across low, middle, and high-income countries, specifically in the growth of collaborative and social skills, technical skills, and improved self-perception [3, 4, 5, 6].

Scholarship underscores the importance of these sociotechnical competencies that merge technical proficiency with interpersonal and intrapersonal skills [7, 8]. These nontechnical skills are critical to engineering and innovation [9]. Reddy et al. explain that traditional engineering coursework "tends to promote narrowly defined conceptions of 'engineering knowledge' as exclusively technical" [9]. Sociotechnical competencies are those that exist at the intersection of technical and nontechnical skills; the boundaries between the two are blurred [9]. These skills include but are not limited to, collaboration, communication, patience, perseverance, ability to navigate personal differences, and other skills critical to group work and real-world problem solving. Furthermore, these competencies are critical for engineering practice in the workplace and, perhaps more importantly, in response to complex community needs.

The majority of Design II class sessions occur in the *DesignCube,* and the space is integral to the course. Design II is collaboratively structured by design and requires students to work in teams of four. With tables set up to support this cooperation, the DesignCube has the potential to nurture these critical sociotechnical skills. Through collaborative work, students learn to brainstorm, integrate diverse perspectives, and navigate team dynamics that mirror real-world engineering practice. Building on this, we ask: *How do sociotechnical competencies develop in biomedical engineering undergraduate students utilizing the DesignCube to collaboratively* *design and prototype medical devices?* By focusing on these dimensions of learning, this study underscores the unique role makerspaces play in educating biomedical engineers who are not only technically capable, but reflective and socially attuned innovators.

Theoretical Framework

Our theoretical framework draws on two complementary lenses to examine how sociotechnical learning emerges through participation in DesignCube. First, we use Hira and Hynes's People–Means–Activities framework to situate makerspace learning as an interaction among (a) *people* (students, peers, mentors, instructors, and community partners), (b) *means* (tools, materials, physical layout, safety norms, access policies, and instructional supports), and (c) *activities* (prototyping, testing, iteration, documentation, troubleshooting, and collaborative coordination) [10]. This framing helps us attend to the established mechanisms through which engagement and learning are produced in engineering makerspaces, particularly how participation is shaped not only by available technologies, but also by social relationships, routines, and support structures that organize design work.

Second, we apply Jenny Davis's Affordances Theory to analyze the *DesignCube* as a sociomaterial artifact that offers different possibilities for action to different users, and not uniformly [11]. Davis's model provides an analytic vocabulary for identifying how the *DesignCube* can request, allow, deny, encourage, discourage, or refuse particular forms of participation and learning, including collaborative behaviors tied to sociotechnical competence (e.g., conflict navigation, patience in iteration, negotiation of roles, and accountability to community needs). We also use Davis's conditions (perception, dexterity, and cultural/institutional legitimacy) to examine *for whom* these affordances become accessible and *under what conditions* they are taken up [11]. Together, these frameworks allow us to connect makerspace mechanisms (people–means–activities) with differential participation and outcomes (affordances and conditions), supporting a nuanced account of how the *DesignCube* mediates sociotechnical development in a low-income BME context. The theoretical framework utilized to code interviews in this research is provided in Appendix A.

Participants and Research Method

The data for this study were gathered from the Design II cohort in 2024 that enrolled 30 undergraduate BME students in their third year of the BME degree program. In Design II, students develop and refine a medical device, integrate user feedback, and develop functional prototypes. Learning outcomes include: 1) demonstrating the ability to create and evaluate cost-effective biomedical prototypes and 2) utilizing design software and prototype methods to iteratively improve BME models.

Data Collection

Ethical approval for the research was obtained at the university in Uganda and partnering universities in the USA (IRB 2024-0461). Consenting students participated in pre- and post-semi-structured interviews conducted in English (30-45 min). Pre-interviews took place after students were introduced to the *DesignCube* but prior to beginning intensive prototyping work. Post-interviews were conducted following the course end, regardless of whether the team's prototype reached functional completion.

Since the research was exploratory in nature, the first iteration of interview questions was based on the research team's curiosities. These questions primarily explored the impact and efficacy of the *DesignCube*. Once the research was grounded in the People-Means-Activities and Affordances frameworks, the questions were refined to the final protocol (Appendix B). Interview protocols included questions designed to elicit expectations and experiences related to collaboration, participation, and working across cultural and individual differences. Key prompts related to this study included:

- What are your expectations for participating in Design II?
- How do you think the *DesignCube* will/will not (in post, did/did not) meet your expectations?
- What do you expect in terms of collaboration with your peers?
- What are your expectations in regard to working with people from cultures that are different from the one you identify with?
- What factors do you think will play a role in influencing your participation in the program?
- What challenges do you anticipate you might face in the program?

This analysis draws on 12 complete pairs of pre- and post-interviews. While our broader analysis considers trends across all interview pairs [12], this paper highlights illustrative excerpts from eight students whose pre- and post- reflections particularly exemplify reported growth in sociotechnical competencies.

Data Analysis

We conducted qualitative analysis of interview transcripts in multiple phases, supported by research training and mentorship from an engineering education researcher at Purdue University. In the first analytic iteration, we used an interview coding mechanism based on the people-means-activities framework of Hira and Hynes and the mechanisms and conditions framework from affordance theory to evaluate the educational impact of makerspaces (Appendix A) [10, 11]. The analysts independently coded transcripts (the second and third authors, who are from Uganda, brought contextual familiarity with cultural nuances in responses). After coding, each analyst wrote an analytic memo for each transcript to capture emerging patterns and preliminary interpretations. The team met weekly with the mentor to discuss analytic progress and to refine interpretations through dialogue, including attention to theoretical alignment, contextual meaning, and the goals of the study [13]. Through these discussions, the team corroborated themes and developed shared interpretations of how the *DesignCube* shaped students' reported learning and engagement in Design II.

Following this first iteration of data analysis, it became clear that students were concurrently experiencing and explicitly reporting growth in both their technical and sociotechnical skills. To examine the sociotechnical trends more closely, the analysts used the memos to inductively analyze and synthesize pre/post shifts within each student who was interviewed. The synthesis was then discussed with the entire research team, including the project manager and research leads. The results below report trends across the broader dataset of interview pairs and use extended quotes from eight students as illustrative cases.

Results

Pre-Interviews: Initial hesitation surrounding group work and material availability

Across pre-interviews, students described Design II primarily as an opportunity to develop technical (biomedical) engineering skills through hands-on prototyping in the *DesignCube*. Their expectations focused on gaining practical experience in device innovation and strengthening capabilities such as coding:

> *"[this course is] giving me hands-on experience and a clear understanding as to how devices are being innovated from day one"; " I expect to improve my coding skills. Since the majority of the work we are going to do and everything we are going to work upon, coding is involved, so I see that that's one skill that I'm going to improve"* (Student 1).

Alongside these technical expectations, some students expressed uncertainty about whether they would be able to prototype with materials that were best suited to their design needs. Students anticipated that constraints in access could shape materials selection and, by extension, what they could build:

> *"we shall reach a point of material selection, and I think we shall have issues with selecting materials, [because] I think we shall find that most of the times, the materials that will be best suited for different innovations, for the different activities, will [maybe not be] in our access"* (Student 2).

Students also anticipated that working in groups could introduce challenges that might complicate design progress. When asked about group dynamics, one student explained the possibility that different perspectives within a team could create strain and reduce cooperation:

> *"[as a] limitation…we are working in groups. There can be a group where different members have different perspectives about the design course…I think that puts some sort of strain on [group members]...the whole group may not be cooperative"* (Student 3). The students understood the importance of group dynamics in the *DesignCube*, but preferred to primarily focus on the prototype and considered all other learning as secondary: "*I expect to come up with a prototype as expected [from our group]. I expect to gain knowledge from [my group members], but I expect to see them (consider the contribution of group dynamics) outside the design (prototyping process)"* (Student 4).

At the same time, some students were already considering how this team dynamic could strengthen their skills as engineers. Some students expressed a distinct interest in group work and acknowledged the skills they would gain by doing so. One student described, *"[this teamwork in the DesignCube] is helping me in such a way that I'm capable of now understanding everyone's weaknesses and understanding someone's strength"* (Student 1). Students also emphasized relational outcomes of sustained collaboration and connection, describing friendship and networking as potential benefits: *"Then the other [expectation] is friendship, because now…working together as a team really helps you to know someone, and for purposes of networking and knowing each other after the course. I believe this doesn't just end here"* (Student 5). Another student remarked: *"I believe I can't know the whole of Kampala, but I might [have someone in my group who] is totally different, who is like a Musoga (ethnic group in Uganda) helping me out on this, so that's why I see we shall work together as a team"* (Student 1). Additionally, across a multitude of excerpts, students expressed confidence that they knew they could rely on other students in the *DesignCube* who potentially did have specific skills if their personal knowledge fell short on coding or 3D printing, for example. Largely, however, most students spent the majority of pre-interviews discussing their expectations for the development of their technical biomedical engineering skills.

Post-Interviews: From resource uncertainty and collaboration skepticism to sociotechnical competencies and reflection

In pre-interviews, students' expectations were accompanied by hesitations about whether they would have adequate access to materials for prototyping and whether the DesignCube would provide the practical conditions needed to carry out the design work effectively. In post-interviews, students directly revisited these concerns and described how their experiences in the DesignCube compared to what they initially anticipated. First, students expressed relief that they did not need to worry as much about material availability as they had once thought. A student described, *"The DesignCube met my expectations…with a number of tools that we used. Of course, most of the materials, most of the wires, most of the LEDs. Most of the bread boards that we used. We got them from the DesignCube. There were a few components we had to buy, which is okay"* (Student 6). The same student reflected on the role of immediate support, stable internet connectivity, and the organization of the space in enabling them to research, code, and iterate on prototypes:

> *"During all our kinds of activities that we carried out in the DesignCube, there were usually people…who offered us with immediate advice that we needed. That greatly helped us. The steady internet connection in the DesignCube, it really helped us because of some of the things, for example, the coding that we needed to operate the microcontroller of the Arduino. We had to [do] a lot of research about developing it and coming up with it. Another thing would be of course, the prototyping space. It offered us a very good prototyping space the way it's organized".*

With these resource and infrastructure affordances favoring their expectations, students spent more time during post-interviews discussing recognized growth in sociotechnical skills. In particular, those developed through collaboration, navigating group dynamics, and working across differences in personalities, work styles, and expectations. One student reflected on the social demands of Design II and how ongoing engagement with peers required them to learn about different students: *"[Design II] was, I don't want to say overwhelming, because I'm not this social person. I found it hard to always be engaging with others, but I learned my experience was not so bad, not so good because I had to learn about different characters"* (Student 5). Furthermore, they described collaborations as enabling peer learning with access to information and perspectives held by teammates: *"I really enjoyed collaborating with different people because you would engage with someone who is very informed… they would really give you information that you've never come across on [the] internet"*. The team dynamics introduced in the *DesignCube* in tandem with the structured support students received inspired in students consideration of others and recognition of what can be learned from individuals outside of themselves. Students who may not have previously enjoyed social interaction during prototyping were provided with a designated space to do so. As a result, they learned the advantages of collaboration. One student summed their experience with their classmates:

> *"I learned how to deal with people, because each and everyone has their way of behaving. Some people are good [at] working under pressure. And, some people do not tolerate working under pressure. They are usually quick in implementing what is supposed, like to do--the next steps--and some people prefer last minute doing of things. In order to stay together, or in a good working kind of relation, as a group, we learned to actually learn to prorate all. I learned very different kinds of behaviors and ways, how people do their things".* (Student 6)

Students also remarked about the ways the *DesignCube* provided opportunities for them to learn patience, particularly when peers did not meet deadlines and the team had to remain functional:

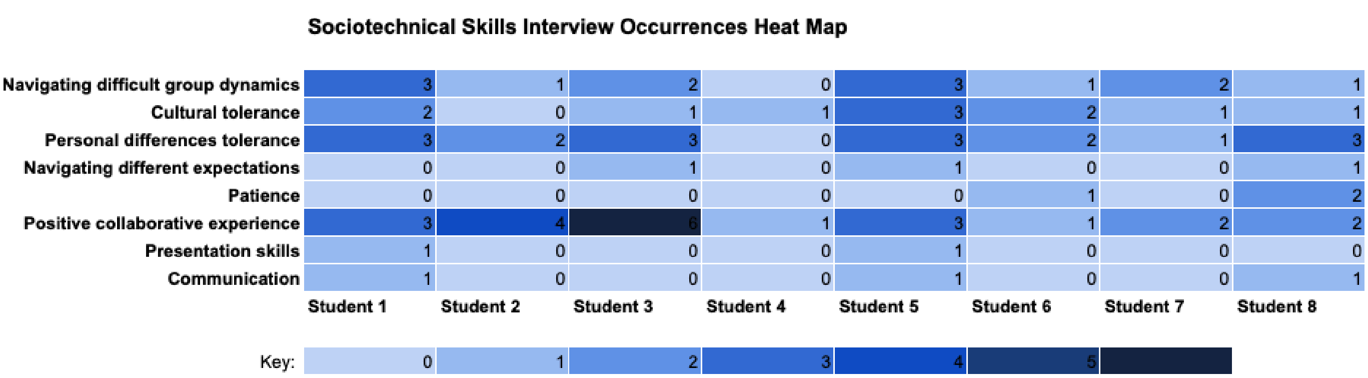
“My experience is, I've learned to be patient with some people because not every time that you expect something to be done, [it gets done], though you expect it [to be]. Sometimes someone may fail to meet a deadline in some circumstances… So it has taught me to be patient working with peers” (Student 6).

Others appreciated the *DesignCube* as a space that facilitates group work as a result of reducing logistical barriers for providing a consistent space to meet, collaborate, and learn: *“the fact that even the space was available for us to use also helped us, because then, again, looking for rooms to where...where we can come together to... to make the prototype would have been an issue, but it was made available for us”* (Student 7). Perhaps most starkly, this student describes their revelation that the *DesignCube* provided about collaboration and delegation:

“And also, I realized that not all times that you can do work alone. You have to give out work to people for people to start to work together and make the project go forward…We also learn from them behavior, values, and also other related personal issues” (Student 8).

Figure 1 aggregates these students’ responses across each pre and post interview to quantify occurrences of responses regarding specific sociotechnical competencies. We surveyed each interview to identify responses that included self-reported growth in the following sociotechnical competencies: improved ability to navigate difficult group dynamics, improved tolerance of different cultures, improved tolerance of personal differences, ability to navigate different expectations, improved patience, engagement in a positive collaborative experience, reported growth in presentation skills, and reported growth in communication skills. Darker colors signify higher occurrences of self-reported growth in the sociotechnical competencies listed in the y-axis. Definitions of the codes of sociotechnical competencies are in Appendix C.

Figure 1: Heat map of sociotechnical occurrences, including pre- and post-interviews.



Discussion

Initially, students approached the *DesignCube* with mixed apprehension and optimism—concerned about material constraints and the potential strain of group dynamics, but expecting to gain technical skills and complete a successful prototype. Post-interviews show that the *DesignCube* largely alleviated these material concerns and reframed collaboration as central, rather than peripheral, to learning. The availability of tools, reliable infrastructure, and on-site support allowed students to move beyond resource anxiety and focus more fully on collaboration. Importantly, using the makerspace prompted sustained reflection on interpersonal dynamics: students became more aware of differing work styles, strengths, weaknesses, and social expectations, and many reported growth in patience, communication, delegation, and mutual reliance. What began as a primarily technical endeavor thus evolved into a social learning experience, where the *DesignCube* functioned not only as a site for prototyping but also as a structured environment that cultivated consideration of others, highlighting both the challenges and the value of collaborative engineering practice.

Using People-Means-Activities as an organizing analytical lens, we classified the students' sociotechnical skills under each aspect and then applied Davis's affordance mechanisms as interpretive categories [10, 11]. We mapped students' pre- and post-accounts to identify what the *DesignCube* enabled, for whom, and under what conditions. For example, in the first coding pass using the People-Means-Activities framework, analysts consistently observed that students' explanations of learning outcomes were not confined to 'Means' or 'Activities'; instead, references to 'People' and to collaborative processes repeatedly appeared across post-interviews, prompting a second analytic pass focused on sociotechnical growth across pre/post pairs. These trends suggest that sociotechnical development emerged from a specific interplay of people, means, and activities in the makerspace, and from the affordances the *DesignCube* offered under specific conditions. *Students' accounts show how Means (tools/materials, internet, workspace), People (peers, immediate mentor support/feedback), and Activities (coding, prototyping, iteration) interacted: stabilized means supported sustained activities, which increased reliance on and learning with people, where sociotechnical competencies became salient.*

Using Davis's affordance mechanism framework, we saw that students' pre-interview hesitancies indicate that anticipated scarcity could *discourage* participation and *deny* imagination even before making began, whereas post-interviews suggest the DesignCube *allowed* and *encouraged* sustained iteration by providing material access and a legitimate, organized workspace [11]. The presence of peers and on-site support further *enabled* help-seeking and knowledge-sharing, making collaboration an everyday mechanism for progress rather than an added requirement. In this context, the *DesignCube*'s affordances covered technical (tools, materials, workspace) and also social and cultural assets. The *DesignCube* created a dependable place for teams to meet, a space where distributed expertise was recognized and integrated, and where students could learn to work across and draw strength from difference while accomplishing high-impact design tasks.

These affordances were conditioned by *perception* (students' shifting understanding of what was available), *dexterity* (technical and social capability built through repeated participation), *and institutional legitimacy* (a dependable, sanctioned place to meet and build).

While students did report impacts of the *DesignCube* through the lenses of Means (e.g., access to 3D printers) and Activities (e.g., soldering), many students specifically highlighted the influence of People on their academic experience [10]. Group members were integral to students' learning, growth, and success. Furthermore, students' perception of their experience in the *DesignCube* was shaped by other students: "*During all our kinds of activities that we carried out in the DesignCube, there were usually people…who offered us with immediate advice that we needed. That greatly helped us"* (Student 6)*; "There is cooperation from my teammates, because, of course, I cannot accomplish the whole project alone"* (Student 3).

From this work, we deduce that when resources are readily available, students with already developed technical skills have the ability to take creative risks, iterate freely, and engage in authentic problem-solving without fear of material waste from failure. Moreover, investment in staffing, mentorship, and training ensures that these spaces are inclusive and supportive learning environments where students can develop confidence, resilience, and strengthen sociotechnical skills like collaboration and conflict resolution. Expanding access to such environments is therefore not only an investment in student learning but also in the broader capacity of communities to cultivate creative, collaborative, and ethically minded problem-solvers.

These findings resonate with makerspace literature emphasizing hands-on learning, iteration, and design practice [1, 2, 3, 4, 5] but they also invite a more critical interpretation in low-resource contexts. Based on students' accounts in this study, the reduction of material uncertainty appeared to create conditions that enabled students to shift attention from purely technical affordances to sociotechnical demands of collaborative engineering work, such as negotiating roles, timelines, practicing patience, and interdependence. This phenomenon is not exclusive to low-income engineering contexts [14, 15]. At the same time, treating material sufficiency as the primary prerequisite risks narrows how we conceptualize design education in contexts marked by "perceived" scarcity. Otherwise, we inadvertently reinforce external dependency and position privileged institution models as the necessary gateway to authentic engineering learning. This framing could neglect pluralistic approaches that value diverse epistemologies and locally grounded practices around resource optimization, repair, improvisation, and design with locally available resources as legitimate and powerful forms of engineering knowledge. Davis's affordance lens helps avoid a deficit narrative that scarcity does not simply 'limit' learning, it changes what the space can request/allow/encourage, or not, and who is positioned as capable [11]. People-Means-Activities further shows that 'Means' are not merely materials, but include legitimacy, norms, and access pathways, which can be designed to value local practices as engineering practices [10]. Inspired by this framing, our future work will examine how makerspaces might intentionally cultivate both (a) access to baseline tools needed for engineering prototyping and (b) pedagogies that elevate constraints as a site of learning and innovation.

The results of this research, drawing upon the People-Means-Activities and Affordances framework, exemplify that the success of a makerspace does rely significantly on collaboration and the presence of social support [10]. This outcome suggests that makerspaces can be a vital part of engineering education when appropriately staffed and made available to student working groups. These "People" characteristics of a makerspace may be just as important as access to materials and tools. Furthermore, students in a makerspace do perceive and report growth in their sociotechnical skills and mark them as important to their engineering education. Germaine for many settings is our key conclusion: students can experience and report growth in sociotechnical competencies without access to cutting-edge engineering components or machinery. Makerspaces like the *DesignCube* support holistic student learning by strengthening the intersection between technical and nontechnical skills to educate well-rounded engineers prepared for real-world challenges.

Limitations

This research did not include interviews with all students enrolled in Design II in a given academic year. Furthermore, there was some data attrition in that not all students who participated in a pre-interview completed a post-interview. The coding mechanism utilized in this research does embed personal bias into trend outcomes. Each analyst in their own contexts of the United States or Uganda repeatedly differed in their application of the mechanism, but analysts agreed on trends that arose during analysis of the data. This research, while potentially applicable to other low-income contexts, had a small sample size and is most relevant to undergraduate BME education in urban settings like Kampala, Uganda.

Another key limitation of this study is that use of the *DesignCube* was fully embedded within the Design II course, making it difficult to isolate the specific effects of the makerspace from those of the project-based course itself. Because the majority of project-based learning activities in Design II take place within the *DesignCube*, students' reported development of sociotechnical skills cannot be conclusively attributed to the makerspace environment alone. However, students consistently identified the *DesignCube* as integral to their learning and skill development and the space was the sole contributor of material provision and resource availability.

Lastly, we have only been able to explore how the *DesignCube* helped BME students develop their skills in BME projects. We can not make claims regarding generic or broadly applicable projects, because these endpoints were not measured.

Conclusion

This research found that when given access to the *DesignCube,* undergraduate BME students in Kampala, Uganda self-reported improvements in sociotechnical skills such as collaboration, presentation skills, tolerance, and group dynamics. These outcomes are parallel to growth in technical skills and are critical to highlight as unique and beneficial impacts of an appropriately-resourced maker space in low-income contexts.

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References

[1] J. O. Hossain *et al.*, "Making on the Move: Bringing Mobile Makerspaces to Under-Resourced Communities," *2024 IEEE Global Humanitarian Technology Conference (GHTC)*, Radnor, PA, USA, 2024, pp. 303-310, doi: 10.1109/GHTC62424.2024.10771544.

[2] D. Turakhia, D. Ludgin, S. Mueller, and K. Desportes, "Understanding the educators' practices in makerspaces for the design of education tools," *Educational technology research and development*, vol. 72, no. 1, pp. 329–358, Nov. 2023. doi:10.1007/s11423-023-10305-1

[3] Wettergreen, M., A. Saterbak, A.J. Kavalewitz, A.M. Nunez-Thompson, V. Leautaud, T. Mkandawire, M. Petney, C.A. Dos Santos, Z.M. Oden. "Makerspaces in Low-, Middle-, and High-Income Countries to Support Student Development of Engineering Design Skills." *International Journal of Engineering Education*, Vol. 36, No. 4, pp. 1234–1251, 2020.

[4] Y. Kwon, Y. Lee and S. Kim, Case study on 3D printing education in fashion design coursework, *Fashion Textiles*, 4(1), 2017.

[5] M. Lagoudas, J. Fryod and J. Wilson, Assessing impact of maker space on student learning, in *American Society of Engineering Education Conference Proceedings*, 2016.

[6] Morocz, R. J., Levy, B., Forest, C., Nagel, R. L., Newstetter, W. C., Talley, K. G., & Linsey, J. S. "Relating Student Participation in University Maker Spaces to their Engineering Design Self-Efficacy"*, Paper presented at the 2016 ASEE Annual Conference & Exposition*, New Orleans, Louisiana, June 26-29, 2016. DOI: 10.18260/p.26070.

[7] P. Willmot and B. Colman, "Interpersonal skills in engineering education". Loughborough University, Jan. 2016.

[8] B. Schulz, "The importance of soft skills: Education beyond academic knowledge," *NAWA J. Lang. Commun.*, vol. 2, no. 1, pp. 146–154, 2008.

[9] Reddy, E. A., Kleine, M. S., Parsons, M., & Nieusma, D., "Sociotechnical Integration: What Is It? Why Do We Need It? How Do We Do It?," in 2023 *ASEE Annual Conference & Exposition*, Baltimore, MD, Jun. 2023, Paper 10.18260/1-2-44239.

[10] A. Hira and M. Hynes, "People, Means, and Activities: A Conceptual Framework for Realizing the Educational Potential of Makerspaces," *Proc. ASEE Annu. Conf. Expo.*, Jun. 2018

[11] J. L. Davis and J. B. Chouinard, “Theorizing affordances: from request to refuse,” *Bull. Sci., Technol. Soc.*, vol. 36, no. 4, pp. 241–248, Dec. 2016, doi: 10.1177/0270467617714944.

[12] P. Atukuri, “Learning in the Tension Between Design Process and Prototype,” forthcoming, 2026.

[13] Sullivan, P. (2011). *Qualitative Data Analysis Using a Dialogical Approach*. SAGE Publications Ltd. ISBN 9781446268391.

[14] Chen, P., Wang, R., & Ma, Y. (2025). “Promoting junior high school students’ creativity in maker education: The design thinking approach”. *Thinking Skills and Creativity*, 56, 101764. https://doi.org/10.1016/j.tsc.2025.101764

[15] Zembylas, M. (2025). “Rethinking positionality statements in research: From looking back to building solidarity.*” International Journal of Research & Method in Education, 48*, 1–13. https://doi.org/10.1080/1743727X.2024.2420171

Appendix A: Coding Mechanism

Code	**Definition**
Condition: Cultural and Institutional Legitimacy	References to the way one's location and position within the larger social structure and the related norms, values, rules, and laws of a social system inform student-technology-curriculum relations.
Condition: Dexterity	Refers to the capacity of an individual to enact the functions of the artifact (both tangible and non-tangible). These capacities can be physical or cognitive. "An individual must be able to physically manipulate the object in required ways and have the knowledge set that enables manipulation"
Condition: Perception	References to the individual's perception of what affordances are possible or not possible before, during, or after engaging in the program. Note: Perception can be shared at any time during the program, however, to qualify as perception the individual should speak from assumption and not experience.
Mechanism: Allow	References to line of action that a learner can take when they are not prompted to but also there are no obstacles to taking them.
Mechanism: Demand	References of only one line of action possibilities. Demands exert a STRONG DEGREE OF FORCE. Demands might be present in the form of physical, social, and/or symbolic prompts.
Mechanism: Discourage	References to lines of action that are OBSTACLES. Whatever is discourages is nonobvious and requires extra effort on part of the learner to enact it. Meaning, the action is available and plausible, but it is not straightforward.
Mechanism: Encourage	References to lines of action that are made easy and APPEALING. The action is generally obvious, expected, and seamless to execute. Most often this is the line of action that was the main purpose behind the design

Mechanism: Refuse	References to lines of action that are implausible and/or impossible. These note that the actions are PROHIBITED from the obvious design of the space and tools.
Mechanism: Request	References of emphasis on a particular set of actions, deemphasizing other action possibilities. The learner may abide by a request, ignore a request, or address it only partially. Alternatively, it can be explained as a technology or tool that PERSUADES action in one direction but leaves alternate options open.
Program Component: Curriculum	References to aspects of the program related to curricular activities, elements, and tasks.
Program Component: DesignCube	References to DesignCube aspects and engagement that captures the People, Means, and Activities as it is happening in and through the DesignCube (makerspace).

Appendix B: Interview Protocol

Semi-structured in-depth Interview Protocol; Before Engagement in the Program and DesignCube

1. Tell us about your motivations for being part of this program (design course/ summer intercultural learning)

- What prior experiences influenced your motivation?
- What future aspirations influence your motivation?
- What are your expectations from your participation in this program?
- What do you think are the strengths or limitations of this program?

2. Tell us about your expectations of the program.

- What activities do you expect to engage in?
- What do you expect in terms of collaborations with peers, faculty/staff, and community?
- What are your expectations for working with people from cultures that are different from the one(s) you identify with?
- What are your expectations of the design process we will apply?

3. Tell us about your expectations of the DesignCube space at Makerere.

- What are your expectations for the tools and materials resources that will be made available via the DesignCube?
- What do you think is/are the potential of Design Cube to meet your expectations?
- What do you think is/are the potential of the Design Cube to support you to build a functional prototype?
- What do you think is/are the potential of the different activities (at the Cube, to the hospital, travel around town, etc) during the program to meet your expectations?

4. What factors do you think could play a role in influencing - either fostering or hindering - your participation in this program?

- What challenges do you anticipate you might face in this program?
- How do you expect to overcome them?
- What is one word you would use to characterize your expectations overall?

After Engagement in the Program/DesignCube

1. Tell us about your experiences from this program (focus on social/cultural)

- What social/cultural activities did you engage in?

- What were your experiences in terms of collaborations with peers, faculty/staff, and community?
- What are your experiences working with people from cultures that are different from the one(s) you identify with?
- How did working with people from cultures that are different from yours play a role in the outcomes of the program (engineering, cultural enrichment)?

2. Tell us about your experiences from this program

- How did the program meet or not meet your expectations before starting the program?
- How would you say the program was contextually relevant or not? And why?
- How would you say the program was culturally relevant or not? And why?

3. Tell us about your experiences using the DesignCube space

- What parts of the design process have you applied?
- What engineering and prototyping activities did you engage in?
- What are your experiences with the tools and materials that were made available via the DesignCube?
- How did the DesignCube meet or not meet the expectations you had (before starting the program)?
- What factors fostered your engagement in the DesignCube space?
- What factors hindered or challenged your engagement in the DesignCube space?
- How did you overcome any challenges?
- If you could make some changes to the space, what would you do?
- What is one word you would use to characterize your experiences overall?

Appendix C: Definitions of sociotechnical competencies

Navigating difficult group dynamics	Student expressed that in a group dynamic, they struggled with prototype-based issues. Example: *"You know, sometimes you can lean [on] a team and a teammate does something that that really puts you off. And you you get, you get like you get angry, and sometimes you may talk, talk back to them in a way that you think is appropriate, like you think is not so much of an issue, but to them they perceive it, like, you know, maybe undermining them, or you're talking badly to them. So I think maybe perception perception was also an issue." (Student 5)*
Cultural tolerance	Student expressed that they learned patience and tolerance for differences in cultural aspects of team members (language, religion, etc.) Example: *"I remember there was, there were times that I would have to go to church in the evening or… usually I go to mass in the evening, but we'll be able to plan our meetings within that within the time before. So, both of us were able to go to church like even when we were doing that designing of the prototype" (Student 7)*
Personal differences tolerance	Student expressed that they learned patience and tolerance for differences in personal aspects of team members (timeliness, meeting preferences, etc.) Example: *"[We] improved on how we worked as a team [because] we get to know if someone is supposed to do something, and then maybe they are having… they're going through some personal, a personal issue. Then we give them some space to rectify their or to rectify the matter, or someone is going to be late for a given team meeting. Then, the informers earlier would also be able to understand it, basing on how they are passing through a given situation" (Student 8).* Example: *"We just go to understand each other better,*

	and like learnt how learnt, like, figured out reason how to accommodate each other" (Student 5)
Navigating different expectations	Student expressed that they learned patience and tolerance for differences in group members' goals and expectations for the course (attention to detail, academic aspirations, motivations for being in the course, etc.) Example: *"There can be a group where different members have different perspectives about the design course may find the group has some members that are really enthusiastic about design…but then the the other group members maybe have a negative perspective about it. So like, we are just doing it for maybe academic formality just to pass exams." (Student 3)*
Patience	Student expressed that they tolerated delay, frustration, or personal differences; student explicitly mentions "patience". Example: *"I've learned to be patient with some people because not every time that you expect something done to be done, though you expect it to be done" (Student 8).*
Positive collaborative experience	Student expressed that they perceived a benefit and positive experience from collaboration within their group. Example: *"It was good, it was… we didn't have any… our arguments would be… we would finally like, agree on a certain point, like one comes forward and like explains their point. And then we all come like we see, we come to the same terms at the end of it all, regardless of the differences that come up, you would all end up at the same place" (Student 7)*
Presentation skills	Student expressed that they gleaned confidence and comfort in presenting information in front of a small crowd. Example: *"You you notice that maybe at the beginning of the of the semester…I personally would come in front to present and you all shake you like you're you're you're you're a bit nervous. But by the end of the semester I was*

	used to everything, and I can say my presentation skills were also improved" (Student 5).
Communication	Student expressed that their ability to verbally share information to individual group members, faculty, or other stakeholders improved. Example: *"Yes, presentation skills, communication skills, yeah, those ones, those ones I can say we have, we have, fully have, fully improved" (Student 1)*