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THE IMPACT OF A UNIVERSITY MAKERSPACE ON ENGINEERING STUDENTS' SKILLS

by
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ABSTRACT

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Makerspaces are venues for the exploration of personal fabrication technology, hands-on learning, and collaboration. The Red Room at the American University of Beirut (AUB) is an example of a university makerspaces, where making and prototyping equipment are made available to students. Since its opening in the spring of 2019, the Red Room has followed a student-operated management style, with over forty-five undergraduate engineering students having been recruited as members of the managing team, which we refer to as Junior Engineering Design Innovators, or JEDIs for short. The purpose of this thesis is to present the JEDIs' perceptions of this unique experience and its impact on their development as engineers. Results reveal that working in the makerspace improves JEDI's self-efficacy in engineering design as well as in transferable skills such as problem-solving and communication. Membership to the makerspace is shown to be a situated learning experience that prepares JEDIs for their career in engineering. This thesis is unique in that it considers student-staff of university makerspaces in isolation from other users of such makerspaces, thus emphasizing the value of implementing such a staffing model.

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ABBREVIATIONS

ABET	American Board of Engineering and Technology
AUB	American University of Beirut
AUC	American University in Cairo
BDH	Bechtel Design Hall
CAD	Computer Aided Design
CoP	Community of Practice
CRDP	Centre de Recherche et de Développement Pédagogiques
DIY	Do-It-Yourself
EDSE	Engineering Design Self Efficacy
ENIT	Ecole Nationale d'Ingénieurs de Tunis
FGD	Focus Group Discussion
HVAC	Heating, Ventilation, and Air Conditioning
INT	Interview
IRB	Institutional Review Board
JEDI	Junior Engineering Design Innovators
MEP	Mechanical, Electrical, and Plumbing
MIT	Massachusetts Institute of Technology
MSFEA	Maroun Semaan Faculty of Engineering and Architecture
SETC	South End Technology Center
STE(A)M	Science, Technology, Engineering, (Arts,) and Math
WSP	Work-Study Program

CHAPTER 1

INTRODUCTION

1.1. Overview and History of the Maker Movement

The Maker movement refers to the global and interconnected activity of makers, from users of designated makerspaces to individual hobbyists, as well as professionals who engage in making for entrepreneurial or otherwise lucrative endeavors, or to provide solutions for the benefit of the community.

According to the pioneers of the movement, making is a fundamental human activity that we have historically engaged in as a means of survival (Halverson and Sheridan, 2014). The definition of making in the context of makerspaces, however, is linked to the increasingly available digital fabrication technology, which allows the creation of artifacts and devices that were previously only possible to produce on an industrial scale to become accessible to makers at the individual scale. Neil Gershenfeld, Massachusetts Institute of Technology (MIT) professor and director of the Center for Bits and Atoms, refers to this opportunity as "personal fabrication" (Gershenfeld, 2005, p. 11), a concept that is at the base of the first makerspace-type facility: the Fab Lab, shorted from the fabrication laboratory.

The concept of the Fab Lab consists of a selection of commercially acquirable hardware and software put together by Gershenfeld himself as a more accessible, scaled-down version of the multi-million-dollar digital fabrication facility constructed in 2001 at the Center for Bits and Atoms (Euchner, 2005). This facility enabled Gershenfeld to host a course called How To Make (almost) Anything, quickly became popular among students from engineering and artistic backgrounds alike, giving rise to eccentric projects of personal expression such as the ScreamBody, "a portable personal space for screaming” that stores the user’s scream and allows them to release it at a later time (Gershenfeld, 2005, p. 23). The success of this course inspired the initiation of the first scaled-down Fab Lab at the South End Technology Center (SETC) in Boston ”to try out small versions of the big machines used in the fab class at MIT”. In the following years, Fab Labs were established in India, Costa Rica, and Ghana, and now The Fab Foundation comprises over 1750 international Fab Labs (The Fab Foundation, n.d.).

Following the growing interest in personal fabrication in Fab Labs and beyond, the Maker movement began to take shape with the publishing of the first issue of Make magazine in 2005 by the company Maker Media, both founded by Dale Dougherty (Halverson & Sheridan, 2014). In 2006, the magazine started the do-it-yourself (DIY) convention, Maker Faire, which has since then given rise to worldwide Maker Faires in local communities. Through his efforts at promoting the culture of making and facilitating the exchange between makers worldwide, Dougherty is often considered as initiator of the maker movement (Halverson & Sheridan, 2014).

Concurrently to Dougherty’s work, the commercial chain of membership-based makerspaces TechShop was founded in 2006. Mark Hatch, co-founder and CEO of the company, identifies nine “rules for innovation” in his 2013 book, The Maker Movement Manifesto; these rules are: make, share, give, learn, tool up, play, participate, support, and change (Hatch, 2013, p. 1-3). Hatch is globally acclaimed as a leading figure of the maker movement (Halverson & Sheridan, 2014); his definition of a makerspace is simple: “a center or workspace where like-minded people get together to make things” (Hatch, 2013, p. 13).

According to Halverson & Sheridan (2014), the maker movement is now commonly defined by two essential components; the first, as discussed so far, is the widespread availability of personal fabrication technology for use by experts and amateurs alike; the second component, perhaps the one that truly elevates making from a skill or activity to a movement, is the community that brings individual makers or maker groups together, enabling the exchange of ideas, skills, and experiences, both in person and online. Dougherty maintains that these technological and social components are what spur the Maker movement, emphasizing that social relationships are central to the culture of making (Dougherty, 2013).

1.2. Makerspaces and the Maker Movement in the Arab World

The Maker movement is now well-established in Lebanon and the Arab region. The Fab Arab Network is an organization that supports the Maker movement in the Arab world by bringing together more than 50 Fab Labs and makerspaces across 22 Arab countries. In Lebanon, six makerspaces are registered in the global Fab Lab Network; in addition, a small number of local learning centers targeted predominantly towards youth STEAM education fit the definition of a makerspace, even if they do not include the term 'maker' (Centre de Recherche et de Dévelopement Pédagogiques [CDRP], 2020).

In their qualitative study of seventeen makerspaces in Arabic-speaking countries (and ten in German-speaking countries), Basmer-Birkenfeld and her colleagues (2018) describe Fab Labs as "an enabler of people" (Basmer-Birkenfeld et al., 2018, p. 26) that empowers individuals to "develop from consumers to makers" (p. 27) by providing them with the necessary tools and skills needed to overcome the dearth of resources in their respective countries. The strong maker mindset described by the authors is a clear manifestation of the "democratizing nature of making" that the movement itself is founded on (Halverson and Sheridan, 2014, p. 3).

This empowering impact of the makerspaces in the Arab world is further demonstrated by ElHoussamy and Rizk (2018), who explored ten makerspaces across Egypt, Tunisia, and Morocco, and found them to be venues of low-cost production and innovation, often in response to personal or societal needs. Horton (2022) found makerspaces to be particularly empowering in conflict-affected settings, outlining the social and economic benefits of five makerspaces in areas including Syria, Lebanon, and Iraq. Similarly to the previously discussed authors, she also provides examples of how these makerspaces benefit the local community as whole, such as by enabling local, low-cost maintenance of medical equipment for nearby hospitals.

Another aspect of empowerment is related not to makerspaces' potential for production, but to capacity building and skill development among the makers themselves. Learning in a makerspace is rooted in the community of practice that unfolds among the participants (Halverson and Sheridan, 2014). Makerspaces in Arab countries are no exception – ElHoussamy and Rizk (2018) found communities of practice to be the driving force of informal learning in all the North African makerspaces they studied, where collaboration between makers surrounds and enhances structured or formal learning activities such as workshops, training sessions, and internships. Horton's (2022) findings in conflict-affected settings also describe the interplay between formal and informal education, or "skill-sharing" (Horton, 2022, p. 34) while also highlighting the social significance of community learning in conflict-affected communities. Both Elhoussamy and Rizk (2018) and Horton (2022) identified examples in which makerspace involvement and the learning it entails contributed to the livelihood of individuals, whether directly through employment and entrepreneurship opportunities, or indirectly through skill development and capacity building.

In the Arab region just as in the global maker movement, an important group of beneficiaries in makerspaces is students. Makerspaces are often used by university students for educational purposes, such as fulfilling course requirements or assignments (ElHoussamy and Rizk, 2018). In Iraq and Syria, makerspaces enable university students learn and innovate beyond the limited resources at their institutions (Horton, 2022). On the other hand, some academic institutions have their own makerspaces, such as Fab Lab AUC at the American University in Cairo (AUC), Egypt, and Fab Lab ENIT at the Ecole Nationale d'Ingénieurs de Tunis (ENIT), Tunisia (ElHoussamy and Rizk, 2018), in addition to the ArD Techlab and the Red Room at the American University of Beirut (AUB), Lebanon.

At the K-12 level, a study by CRDP (2020) in Lebanon found that middle school students benefit from makerspace activities, whether in school makerspaces or external makerspaces, which contribute positively to both their technical and cognitive skills, in addition to their acquisition of scientific knowledge. Other research studies focused on integrating improvised low-tech makerspaces in school as a way to promote hands-on learning of scientific concepts at the elementary (Shaikh, 2018) and primary (El-Sayegh, 2018) levels (see also El Kahi, 2015).

Despite its emerging potential, the maker movement in the Arab world is faced with multiple challenges. The most evident challenge identified in all the presented studies is funding. While some makerspaces have business models that allow them to be self-sufficient (Birkenfeld, 2018), others refrain from charging their users any fees to remain accessible, thus limiting their revenue (ElHoussamy and Rizk, 2018). Other challenges include access to transportation (Horton, 2022), language barriers (Horton, 2022; Birkenfeld at al., 2018), makerspace registration mechanisms (ElHoussamy and Rizk, 2018; Birkenfeld et al., 2018), or conflict itself (Horton, 2022).

Despite being limited in number of publications, the existing research about makerspaces in Arab countries reveals mindsets and ambitions that are characteristic of the Maker movement and its ideals of democratizing production through personal fabrication. Whether they are established for educational or humanitarian purposes, and whether they target youth or adults, Arab makerspace offer their users opportunities to make, learn, and share, and in the process, retain agency and control in their own lives.

Many of the ideas brought up in this overview, such as communities of practice, school and university makerspaces, and formal and informal learning, will reoccur throughout this thesis, which will be focusing on a particular group of makers in a particular makerspace, at a particular institution, in contrast to the studies presented in this section, all of which compared and contrasted multiple makerspaces in different locations.

1.3. Context of the Study

1.3.1. The Red Room, a University Makerspace

The Red Room at the American University of Beirut (AUB) is an example of academic and university makerspaces, and one of the few in the Arab world. It is located in the Bechtel Design Hall (BDH), a central communal space where students at the Maroun Semaan Faculty of Engineering and Architecture (MSFEA) gather to study, work, and socialize. This strategic location has enabled the Red Room to attract an increasing number of users since its inauguration in 2019. Currently, the Red Room facilitates three main types of making and prototyping: additive manufacturing (3D printing), electronics (circuits, sensors, and Arduino boards), and mechanical tools.

Since its opening in the spring of 2019, the Red Room has followed a student-operated management style, with over forty-five undergraduate engineering students having been recruited as members of the managing team, who are locally known as the Junior Engineering Design Innovators, or JEDIs for short. JEDIs typically join the makerspace as volunteers for one semester, after which they have the option to be employed through AUB's the Work-Study Program (WSP) that allows them to be compensated for their work. At the time of writing, fifteen students are active members of the Red Room.

The JEDI role entails several responsibilities; they oversee all making that happens in the Red Room: they guide guests on the proper use of the available equipment, or handle tasks such as 3D printing or drilling themselves as requested. Guests of the Red Room are typically MSFEA bachelor's and graduate students working on course projects, final year projects, or research in engineering, architecture, or design. Occasionally, the makerspace also receives requests directly from faculty members or other members of the AUB community.

JEDIs not only assist with technical tasks related to the use of tools and equipment, but they also provide support and advising on design and prototyping, thus guiding students to successfully build and assemble components for their projects. To provide the best assistance to the community, members of the Red Room are also responsible to the upkeep of the room, which includes maintenance of the equipment and stock keeping of essential materials.

Since the operation of Red Room is managed entirely by students, it is up to these students to ensure the continuity of the makerspace by recruiting and training new JEDIs to replace those who graduate every year. This training process is embedded in day-to-day activities; after a brief introduction period, new members handle tasks and request themselves under supervision of the older members.

Finally, JEDIs play an educational role towards the faculty. They offer individual training sessions as well as group workshops, often in collaboration with student clubs associated with the faculties. For both curricular and extra-curricular purposes, peer-to-peer training is a pillar of the Red Room's operation, whose ultimate mission is to instill making and prototyping skills in all engineering students.

1.3.2. Objectives

Joining the Red Room as a JEDI is a unique opportunity for engineering students. It is an enriching experience where they immerse themselves in a technical environment with professional and social implications, unlike other student employment and volunteering opportunities in the Engineering faculty. In the words of students themselves, "such an initiative has kept students in direct contact with engineering and with their creative inner-selves, and its positive impact is increasingly rippling through the faculty and its atmosphere after each passing semester" (Saad and Sabbagh, 2020).

The purpose of this thesis is to gain a deeper understanding of the JEDI experience, and how it impacts members of the Red Room in the short and long terms. As such, the research questions are as follows:

RQ1: What is the impact of makerspace membership on engineering students' experience as learners?

RQ2: What are the perceptions of engineering students regarding their skill development in the makerspace?

In the first research question, the focus is on the Red Room as part of the JEDIs' learning journey as engineering students, and whether this experience contributes to their engineering knowledge and skills. The second question is aimed towards JEDIs' development of transferable workplace skills through their role as makerspace managers.

1.3.3. Significance of the Study

Earlier in this chapter, the state of makerspace research in the context of the Arab world was reviewed, showing that this area is still emerging, with more focus on economically or socially oriented makerspaces than academic ones. While some of the studies included one or more university makerspaces – or makerspaces that benefit university students – in their investigation, none were centered specifically on making in a university setting. This study aims to address this gap by focusing on the Red Room, the student-led makerspace at the American University of Beirut, Lebanon.

In particular, this study focuses on a well-defined target population consisting of the members of the makerspace – the group of undergraduate students who are responsible for the operation and management of the Red Room. As will be discussed in the literature review, studies of university makerspace usually target the generality of engineering students – none focus specifically on the student leaders of makerspaces that are partially or fully staffed by students. By focusing on the group of students who are known to have the highest level of involvement in the Red Room, this thesis aims to elucidate the impact of this involvement on a deeper level. This provides a closer look at the makerspace not only as venue for innovation and experimentation, but also as a professional environment that these particular students, the JEDIs, carry a shared responsibility towards.

Research on university makerspaces employs both quantitative and qualitative methods. As will be shown in Chapter 2, a limitation of quantitative methods is that they often demonstrate correlations that cannot be confirmed to be causal without additional qualitative data. By choosing the qualitative route for this study, clearer and more certain conclusions about the collected data can be formed, thus contributing novel insights to the field. The details of the research methods will be presented in Chapter 3.

Thus, the research in this thesis is innovative and significant and may yield valuable contributions to the body of research on university makerspaces. On a more local scale, this research is important for AUB itself, as it is the first academic study to consider the Red Room and the impact of incorporating the maker culture into engineering education at MSFEA's, whose mission is to "prepare students to be engaged citizens and leaders, entrepreneurs, and researchers who deploy their skills with ingenuity, integrity, and a sense of responsibility towards future generations" (American University of Beirut, 2022).

CHAPTER 2

LITERATURE REVIEW

2.1. Theoretical Framework

2.1.1. Theoretical Foundations

Making is a process of learning: learning how to operate tools and devices, how to process and use material, how to program a controller… This learning is supported in two ways: first, through trial and error, or as Dougherty (2013) puts it, "experimental play" (p. 7); and second, through the social exchange of knowledge among physical and digital maker communities (Sheridan et al., 2014).

Makers typically conduct a project from start to finish on their own, passing through design, prototyping, testing, and tweaking phases, and therefore employing a variety of skills. As they often have no previous experience with the needed tools, be they physical or digital, they usually acquire this knowledge on-the-spot, either by looking existing guides and references, or by exploring and tinkering with these tools to understand how they work and how they can be used – simply put, the learning that occurs in makerspaces is achieved through making and for the purpose of making (Sheridan et al., 2014).

This process of learning by doing, specifically learning by making, is strongly associated with Papert's theory of constructionism. Constructionism builds on the theory of constructivism – which, as described by Papert and Harel (1991), states that learning is essentially a process of building knowledge structures – by adding to it that "this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity" (Papert & Harel, 1991, p. 2). The theory of constructionism speaks of a strong connection between physical (or digital) objects and pieces of knowledge in the learner's mind; by building external physical entities, individuals construct new learning that builds upon and fills gaps in their existing knowledge; as such, this phenomenon is personal and highly subjective (Kafai, 2012).

The theory of constructionism accurately reflects the learning that makers undergo as they work on their projects. In fact, this phenomenon is not implicit or subconscious, but deliberate, as exhibited by Sheridan et al.'s (2014) observation in three distinct non-academic makerspaces that makers will often "mess around with materials with no project in mind" (p. 528) as a way of expanding their knowledge. In this sense, failed or abandoned maker projects are not considered wasted, as they play an undeniable role in building the experience needed to ultimately succeed. Today, constructionism is explicitly recognized as the fundamental learning theory underlying Dougherty's (2013) concept of "experimental play" (p. 7) (Kurti et al., 2014; Halverson and Sheridan, 2014; Konstantinou et al., 2021).

This constructionist, hands-on type of learning aspect of making can be traced back to the origin of the Maker movement in the "How to make (almost) anything" course. Gershenfeld (2005) comments that, given the number and complexity of the equipment in the original Fab Lab, it was not possible to train all the students on all the processes within the semester; rather, the students' learning was "driven by the demand for, rather than supply of, knowledge" , thus constituting a "just-in-time" model of education (Gershenfeld, 2005, p.14). Often, the students learned the skills they need on their own; however, Gershenfeld notes that students were enthusiastic to share their newly acquired skills with their peers, describing this knowledge exchange as "something of an intellectual pyramid scheme" (Gershenfeld, 2005, p. 4).

The learning in Gershenfeld's class was enabled by the students' cooperation as a community. This reflects the social aspect of learning in makerspaces, which is an essential implication of the interconnected nature of maker activities. In Sheridan et al.'s (2014) comparative study of three makerspaces – a for-profit commercial makerspace, a village workshop for the local youth, and a family-oriented museum makerspace – social learning occurred in a diversity of ways that take on both pedagogical and participatory structures. Pedagogical activities include formal, pre-organized demonstrations and workshops, while the participatory approach encompasses informal activities of collaboration and support. In either case, "skills and knowledge are treated as tools that allow participants to create new things and access new communities and learning opportunities" (Sheridan et al., 2014, p. 529).

Just as hands-on learning in makerspaces is supported by the theory of constructionism, this social learning is rooted in the concepts of communities of practice (Wenger, 2009), legitimate peripheral participation (Lave & Wenger,1991), and situated learning (Renkl, 2001), which will be discussed in the next sections.

2.1.2. Communities of Practice, Situated Learning, Legitimate Peripheral Participation

The concept of communities of practice (CoP) was introduced by Jean Lave and Etienne Wenger in their research on the learning model of apprenticeship since the late 1980s (Lave & Wenger, 1991). A community of practice is a sociocultural community whose members are bound by a particular purpose, which may or may not be a profession or career path.

According to Wenger (2009), a community of practice comprises three fundamental components: a domain, a community, and a practice. While these components are described separately to help identify what does, or does not, constitute a community of practice, it is important to note that they overlap. The domain of a CoP consists of a field of interest that members share a competence in and commitment to. The community consists of the individuals themselves, specifically in the relationships between them - it is essential for the members of a CoP to engage in joint activities where collaboration and knowledge exchange are central. Lastly, the practice component requires that individuals in the CoP be active practitioners, and not just enthusiasts. This practice is rooted in a shared repertoire of resources among the community consisting of individuals' experiences, stories, and approaches, that are passed along to other members over time (Wenger, 2009).

Learning is central to a community of practice. Much of Lave and Wenger's empirical and theoretical research focused on understanding the mechanism by which this learning occurred, culminating into the emergence of the idea of legitimate peripheral participation. This term describes the mechanism by which new participants – such as apprentices – acquire the knowledge necessary for the practice through active membership in the CoP. The concept is discussed extensively in the work of Lave and Wenger (1991); according to the authors, there is no such thing as an illegitimate peripheral participant, and the legitimate peripheral participant is not opposed by a central participation; rather, the authors contrast legitimate peripheral participants to full participants, who are closer to mastery of the domain. As such, legitimate peripheral participation is a position of empowerment for the newcomers, whose role is not to merely observe and shadow the full participants; rather, they are active contributors who first undertake tasks at the periphery of the practice – such as maintaining machines and finishing products produced by full participants – and then assume more and more responsibility.

As such, legitimate peripheral participation entails that the apprentice's learning is situated in the social context of the CoP itself; according to Lave and Wenger (1991), the location of knowledge is the complex sociocultural relationships between members of the community. This proposition is the core of the theory of situated learning. In essence, Lave and Wenger (1991) believe that learning is situated in the learner's lived-in world, their activities, and their interactions with other members of the community.

Despite its powerful implications for formal education, the notion of situated learning has proven to be both ambiguous and controversial. The ambiguity stems from the fact that some of the scholars who adopted the theory use it as descriptively, while others use it prescriptively (Renkl, 2001). The controversy stems from the fact that the situatedness theory rejects the notion that learning is the result of cognitive processes and describes it instead as an intrinsic characteristic of social practice (Lave and Wenger, 1991), which has earned the theorists a number of critiques described by Renkl (2001). Nevertheless, the proposition of situated learning inspired an evolution in the methods of schooling, giving rise to such approaches as problem-based learning and other approaches that emphasize problem solving in real-life situations (Renkl, 2001). According to Johri and Olds (2011), the principles of situated learning may be particularly useful in engineering education, where the aim is to form engineers who are capable of keeping up with novel technologies, working in interdisciplinary contexts, and developing complex and innovative solutions suitable for the rapidly changing world. It follows that providing engineering students with situated learning experiences is critical when it comes to providing student with such necessary workplace skills that reach beyond the knowledge and technical skills targeted by engineering curricula.

2.1.3. Self-efficacy in Engineering Education

The concept of self-efficacy was introduced by psychologist Albert Bandura as a "unifying theory of psychological change" (Bandura, 1977) with a broad range of applicability in research (Bandura, 1986). Bandura (1977) describes self-efficacy as a cognitively based source of motivation consisting of one's belief in their own ability to perform the actions necessary to achieve a specific outcome: "efficacy expectations determine how much effort people will expend and how long they will persist in the face of obstacles and aversive experiences" (Bandura, 1977, p. 194). This definition is represented in Figure 1.

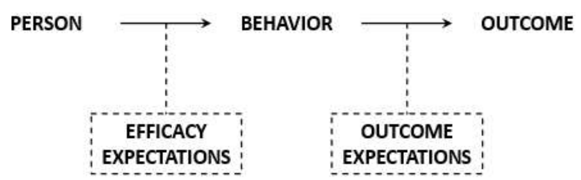

Figure 1 Diagrammatic representation of the difference between efficacy expectations and outcome expectations (reproduced from Bandura, 1977)

According to Bandura's theory (1977), self-efficacy may be measured along three dimensions: magnitude of the difficulty of the actions that need to be taken to achieve anticipated outcomes, generality of these actions; whether they are limited to specific situations or applicable in a variety of contexts, and strength of the efficacy expectation itself; i.e. how much one believes in their ability to perform these actions. The theory further posits that these three dimensions are affected by the four sources of self-efficacy: performance accomplishments, which come from one's previous experience of successes and failures; vicarious experience, which consists of comparison of oneself to other individuals' performance; verbal persuasion, such as encouragement from others; and emotional arousal, where emotions such as fear or anxiety may hinder performance (Bandura, 1977).

On the relationship between self-efficacy and academic performance, Mamaril et al. (2016) find that performance accomplishments alone do not predict future achievements and persistence in threatening situations as effectively as efficacy beliefs as a whole. The authors' review of studies investigating self-efficacy in engineering education leads them to conclude that self-efficacy is a predictor of both academic achievement and students' persistence in their engineering program. Finally, the authors find that students with a high degree of self-efficacy are motivated to perform better due to their own enjoyment and interest in the material (Mamaril et al., 2016).

Mamaril et al. (2016) outline the three levels of measurement used in the assessment of engineering students' self-efficacy: general academic self-efficacy measures, domain-general self-efficacy measures, and domain-specific self-efficacy measures. The development of skill-specific measures and research studies that employ them is usually based on pre-existing standards or frameworks of engineering education. For example, Carberry et al.'s (2010) highly used Engineering Design Self Efficacy (EDSE) scale uses items that reflect the eight-step engineering design process put forward by the Massachusetts Department of Education's Science and Technology/Engineering Curriculum Framework (2006). Another important reference is the American Board of Engineer and Technology (ABET), specifically the General Criterion 3: Student Outcomes (ABET, 2022), which details such learning outcomes as complex problem solving, engineering design, communication, teamwork, and others. In her development and validation of the Engineering Skills Self-Efficacy Scale for

College Students, Marmaril (2014) adapts items from previous surveys including Carberry et al.'s (2010) and aligns them with ABET's General Criterion three.

2.3. Makerspaces in engineering education

2.3.1. Educational Makerspaces and Engineering Skills

Due to the constructionist nature of making, makerspaces are inherently sites of learning where formal and informal learning practices are juxtaposed (Sheridan et al., 2014). Since the rise of the maker movement, makerspaces have been incorporated into K-12 education systems around the world, especially in the interest of engaging students in science, technology, engineering, and mathematics (STEM) education and especially design and engineering practices (Martin, 2015). According to Kurti et al. (2014), educational makerspaces should "encourage playfulness", "celebrate unique solutions", and encourage "exploration and productive failures" (p. 10) in order to successfully engage students and promote "inquiry-based learning" (p.9). Furthermore, Konstantinou et al. (2021) found, through a review of relevant literature, that educational makerspaces have the potential to improve students' performance in school as well as promote their communication, collaboration, critical thinking, and creativity skills (the four C's).

While the discussion above is centered on educational makerspaces in the context of K-12 schooling, concepts such as self-driven learning, tolerance to failure, and community learning are central to the maker movement as discussed in section 2.1. They can thus be extended to university makerspaces, particularly when considering engineering education and the learning objectives of engineering programs.

According to Dym et al. (2005), engineering education at the university level typically culminates, through project-based assignments and capstone (or final-year) projects, in engineering design, a “systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints” (Dym et al., 2005, p. 104). The American Board of Engineer and Technology (ABET), which sets the accreditation criteria for engineering of engineering programs, emphasizes the “iterative, creative, decision-making process” of engineering design, where engineers apply their knowledge and expertise to transform available resources into “a high-quality solution under the given circumstances” (ABET, 2022, p. 4). In its accreditation criteria, ABET details seven student outcomes (General Criterion 3) that engineering programs must provide their students, which include “an ability to apply engineering design to produce solutions that meet specified needs”, in addition to communication, collaboration, and self-learning skills, among others (ABET, 2022, p. 5-6). Thus, skills required of successful engineering graduates transcend scientific knowledge and its direct application in practice and design and involve personal and interpersonal skills necessary for innovative engineering practices. According to the World Economic Forum, the top 10 skills for employment in 2020 featured problem solving, critical thinking, creativity, and leadership, all of which are highly sought-after in the engineering job market in particular. According to Barrett et al. (2015), university makerspaces provide an opportunity to endow engineering students with such transferable skills, which may not be addressed in traditional learning strategies, thus “answering the need for more practice-based engineering” at the undergraduate level (Barrett et al., 2015, p. 3).A unique feature of many university makerspaces is that they are managed entirely or in large part by students as either volunteers or student-staff, typically under the supervision of one or more faculty members, as described by Barrett at al. (2015) in the United States and Wong and Partridge (2016) in Australia. Such management models allow participating students to have a high degree of authority and ownership of the makerspaces and the making and social activities within it (Forest et al., 2014), while also fostering an inviting and supportive environment that encourages other students to enter and use the makerspace (Choi et al., 2021; Galaleldin and Anis, 2017), thus helping the community of makers among the student body thrive.

2.3.2. Communities of Practice in University Makerspaces

While making and the maker movement as a whole may be considered as an example of a community of practice, the focus in this section will be on the establishment of such communities locally in individual university makerspaces.

A prominent example of this is presented by Galaleldin & Anis (2017) in their interpretation of semi-structured interviews with a diversified group of engineering students who use the Richard L'Abbé Makerspace at the University of Ottawa, where they found that the makerspace effectively enabled the creation of a CoP by allowing students who share a "passion for hands-on engineering" (the domain) "to expand and develop their knowledge and expertise in various areas of engineering practice" (the practice), "creating an informal, resourceful, learning environment for students" (the community) (Galaleldin & Anis, 2017, p. 10). The authors note that members of this CoP are self-aware, they identify as members of the makerspace community and engage with it by using the space to work on personal projects. In fact, allowing students to "explore extracurricular interests" (Galaleldin & Anis, 2017, p. 10) further bolsters the practice component of the CoP as they actively engage in making, learning, and sharing. This, in turn, feeds into the community aspect, adding to the various activities, such as workshops, courses, design challenges, and volunteering and work opportunities, that help in “scaffolding and integrating students in the CoP” (Galaleldin & Anis, 2017, p. 10).

By analyzing a quantitative and qualitative survey administered to a high number of senior engineering students and members of the Innovation Studio, academic makerspace at Georgia Tech, Forest et al. (2014) also found that Innovation Studio in question encompasses a community of practice that they describe as “a physical, intellectual, and practice space” (Forest et al., 2014, p. 7). They also noted that the community aspect is highly valued by many users, and many alumni keep in touch with acquaintances from the Innovation Studio after graduation. The community is particularly reinforced by peer mentoring interactions, which make up a considerable portion of users’ time spent in the makerspace. The authors also found that, similarly to the Richard L’Abbé makerspace, the Innovation Studio encourages the pursuit of personal projects, especially ones that have an engineering focus. From this discussion, it is clear that the Innovation Studio presents the domain, community, and practice necessary to make up a community of practice.

Another perspective on social interactions in academic makerspaces is offered by Choi et al. (2021), who examined students’ perceptions of boundary spaces unfolding in two university makerspaces through qualitative interviews. The authors define boundary spaces as “the ‘in-between’ spaces that bring together diverse individuals, disciplines, and activities” (Choi et al., 2021, p. 3) and argue that boundary spaces constitute a significant learning resource: “learning can happen as individuals navigate boundary spaces, by making sense of, and overcoming or better appreciating, the differences and diversity within them" (Choi et al., 2021, p. 15). The authors identified seven types of boundary spaces from their interview results: (1) engineering and non-engineering disciplines, (2) novice and expert users, (3) academic/professional and personal activities, (4) theoretical and hands-on activities, (5) students and staff, (6) one sub-discipline or specialization of engineering and another sub-discipline or specialization of engineering, and (7) school-related and entrepreneurship/industry-related activities (Choi et al., 2021, p. 10). The authors believe that these boundary spaces "provide students with experiences that more accurately reflect the complex, open-ended, and enjoyable work of practicing engineers" (Choi et al., 2021, p. 19), and thus contribute to filling the gap in traditional, book-based engineering education. In this sense, it is plausible to describe these boundary spaces as evidence of the communities of practice in each of these makerspaces, as they bring together a vast and diversity of individuals who are interested in the domain of making and allow them to practice this interest as a community.

The formation of communities of practice in university makerspaces entails that the student learning that occurs within these makerspaces, whether personally motivated or related to coursework, is in fact situated learning. The acquisition of maker skills and associated engineering knowledge is situated in the context of making itself, particularly through the social interactions that lead to the exchange of knowledge and skill as well as the collaborative construction of knowledge (Galaleldin & Anis, 2017), all of which, as suggested by Choi et al. (2021), realistically reflects the practice of engineering.

According to Mylon et al. (2019), simply building and equipping a makerspace "will not attract makers if there are too many barriers to access, or they lack an atmosphere that makes students want to come back and bring their friends" (p. 4). This statement is corroborated by Galaleldine and Anis's (2017) observation that, for many engineering students, the desire to make new friends with similar interests plays a big role in their decision to take part in makerspace activities. makerspace activities present an opportunity to build relationships (Forest et al., 2014). However, Forest et al. found that being required to use the makerspace was, for many students, the "hook" (p. 20) that made them start to use makerspace and lead, subsequently, to increased voluntary participation. However, it is worth noting that while course-related makerspace activity is a significant precursor to joining the makerspace, it is not a definite guarantee of it (Galaleldin and Anis, 2014); this initial exposure is most effective when students initially have the motivation to use the makerspace, but hesitate to do so for certain reasons, such as not knowing how to operate equipment (Hilton et al, 2020); in this case, requiring them to take the first step through course work allows them to eventually pursue this interest and become regular users. Similarly, Andrews et al. (2021) recommend that engineering curricula give students early exposure to makerspaces by assigning course projects that make use of them, particularly in order to overcome hesitations related to the lack of a sense of belonging to the makerspace.

In this way, moving from first time makerspace use to regular voluntary use and identification as a member of the community is a prime example of legitimate peripheral participation in the context of university makerspaces. In student-run makerspaces such as Richard L'Abbé Makerspace, the transfer of knowledge from employees and volunteers to less experienced students constitutes a form of apprenticeship that is illustrative of legitimate peripheral participation (Galaleldin and Anis, 2014); eventually, these legitimate peripheral participants garner enough experience to become the mentors for the next generation of first-time users, thus sustaining the makerspace's purpose over the years.

2.3.3. Skill development in University makerspaces

Self-efficacy is a significant factor of students' involvement in makerspaces. In fact, it is cited by Galaleldine and Anis (2017) as one of the main reasons students choose to participate in one university makerspace. Since university makerspaces often play a significant role coursework related to design, engineering design self-efficacy is an effective measure of the impact of makerspace involvement on engineering students and has been commonly used as such in makerspace research.

Morocz et al. (2016) used the EDSE instrument developed by Carberry et al. (2010) to survey students at the Georgia Institute of Technology who are enrolled in a freshman engineering course with emphasis on design and which incorporates the university's makerspace in the curriculum. The authors were able to correlate the level of participation in the makerspace during the course positively with motivation and negatively with anxiety towards conducting engineering design. However, they approach these results with caution, suggesting that this correlation may not mean that makerspace directly influences self-concepts such as motivation and anxiety, but rather that students with a positive disposition towards engineering design are more likely to frequent the makerspace than peers with lower self-efficacy. On this note, they emphasize the important of encouraging students, especially freshmen, to use the makerspace by reducing the barrier that anxiety constitutes and "highlight[ing] the non-threatening and collaborative nature of makerspaces" (Morocz et al., 2016, p. 1).

This critical interpretation of positive correlations between engineering students' makerspace involvement and their self-efficacy of students echoes Hilton et al.'s (2020) interpretation of the results of their large-scale, long-term quantitative investigation of the impacts of the academic makerspaces across three universities in the United States: "the differences between no involvement and voluntary involvement groups […] could be because the makerspaces helped students gain confidence, motivation, and expectation of success. Alternatively, students who already had greater confidence, motivation, or expectation of success may naturally become voluntarily involved in makerspaces" (Hilton et al., 2020, p.8).

Additionally, research by Andrews et al. (2021) at the University of Texas at Austin also explored the impact of makerspace involvement on students' engineering self-efficacy in design, innovation, and technology. The authors administered a quantitative survey in pre-post format at the start and the end of engineering courses that required or encouraged the use of the makerspace in projects. They found that students who used the makerspace made significant gains in terms of self-efficacy in design, innovation, and technology, whereas those who did not use the makerspace only progressed in technology self-efficacy (Andrews et al., 2021). Similarly to the previous authors, Andrews et al (2021) acknowledge the potential of university makerspaces with regard to self-efficacy while noting that the research methods did not control for other factors that may have an effect on students' self-efficacy, such as other courses and exact activities within the makerspace, and therefore the positive correlation may not be caused exclusively by makerspace use.

A study by Galaleldin et al. (2017) at the Richard L'Abbé Makerspace investigated the impact of university makerspace on several engineering competencies among users of the facility. The survey used had both close-and open-ended items, with the latter providing support for the interpretation of purely quantitative results. In alignment with the previous discussion, the authors found that the competency that most students reported improving at through use of the makerspace was design skills, followed by communication and teamwork skills, then problem solving skills (Galaleldin et al, 2017). Unlike in other studies, the mixed data allowed the authors to identify specific features of the makerspace that allowed users to develop these and other skills, in addition to examples from the data of how students employed these skills. It also goes beyond engineering self-efficacy by also considering such transferable skills as communication, teamwork, and problem solving. As such, the authors demonstrated that the makerspace is a venue for professional development that equips its users with a range of competencies coveted by job market (Galaleldin et al, 2017).

In the same vein, Morocz et al. (2014) conducted a study with engineering seniors enrolled in the capstone project in addition to members of the Makers Club associated with the Invention Studio, the makerspace at Georgia Institute of Technology. They used quantitative and qualitative components to assess the impact of the using the makerspace on these students and reported a significant positive impact on design and manufacturing skills, as well as on teamwork skills, friends, and outlook on engineering (Morocz et al., 2014). Notably, the study also established some positive impact on academic performance and employment, which further highlights the impact makerspaces have on both academic learning and skill development. The latter consists of both technical and social skills, and these findings serve to demonstrate the potential of makerspaces in the formation of engineers.

In more recent research, Bouwma-Gearhart et al. (2021) state that makerspaces "can afford non-technical aspects of developing engineering practice" (p. 20), while emphasizing the "intersection of the technical and social aspects of engineering" (p. 20). These findings, derived from semi-structured interviews with faculty, students, and staff from six university makerspaces, strongly substantiate the point made above. In a different publication by the same team, the results show that makerspaces are well disposed "for the cultivation of well-rounded future engineers" (Choi et al., 2021, p. 17), especially through the problem-solving and communication skills observed by the authors throughout the study. They also position university makerspaces as a step forward from traditional engineering education and an opportunity to bridge the gap between education and employment by providing students with a realistic experience of engineering (Choi et al, 2021).

CHAPTER 3

METHODOLOGY

3.1. Research Questions

In all the previously cited works and other studies about university makerspaces where student-staff (or volunteers) have a high degree of autonomy and authority in the operation of these spaces, the research does not focus on this particular group of student leaders (Morocz et al., 2016; Hilton et al., 2020; Galaleldin et al., 2017; Carbonell et al., 2019) . In some studies, a few members of the managing group are acknowledged as participants in the methods description (Forest et al., 2014) or in the discussion of the results (Choi et al., 2021; Bouwma-Gearhart et al., 2021; Galaleldin & Anis, 2017), but in all of these studies, quantitative or qualitative data coming from such students was not distinguished from that coming from other users of the makerspaces in question. In contrast, this thesis aims to understand the experience of being a Red Room JEDI from the perspective of JEDIs themselves. Two main aspects of this experience are of interest; firstly, membership to the makerspace is viewed as an extracurricular learning experience that enriches JEDIs' learning from classes and coursework, and the impact of this experience is addressed in RQ1; secondly, being a JEDI is considered as an early work experience for undergraduate students as they have a responsibility and accountability towards the Red Room, and the impact of this role is addressed in RQ2. As such, the research questions are the following:

RQ1: What is the impact of makerspace membership on engineering students' experience as learners?
RQ2: What are the perceptions of engineering students regarding their skill development in the makerspace?

3.2. Qualitative Research

The previous discussion of university makerspaces in Chapter 2 touched upon the contributions of both quantitative and qualitative research methods to the field of study. It was shown that, while quantitative data collection allows the researcher to efficiently identify correlations on a large sample size, it fails in providing accurate and certain interpretation of these correlations. Conversely, qualitative research can be more complex and time consuming, especially during the analysis process, but it has the potential to unveil meaningful relationships between the subjects' lived experiences and their own perceptions of them (Finlay, 2017), as it "involves the collection of people's experiences, views and opinions in their own words" (Braun, Clark, & Rance, 2015, p. 2).

Because this study is concerned with studying an impact of an experience on a group of people, the qualitative methods of semi-structured focus group discussions and interviews were chosen as a way to explore these impacts in depth through direct interaction with the research subjects. These methods are suitable for the context of this study because the target population – current and past JEDIs – are known, and they are accessible to interact with in the context of focus group discussions or interviews.

Chapter 2 presented the conceptual framework of this thesis makerspaces as communities of practice and engineering skill development in university makerspaces, with the complementary theories of constructionism, self-efficacy, and situated learning. This framework guided the development of the research questions and data collection protocol as per the recommendation of Maxwell (2022). In this protocol, the researcher is a participant-observer, as she is a member of the extended Red Room community (though is not and has never been a JEDI) and thus previously acquainted with most of the participants. The research protocol was submitted to the Institutional Review Board (IRB) at AUB and approved as for exemption on April 4th, 2023, as per the provided approval letter (see Appendix).

3.2.1. Research Instruments

The focus group discussions and interviews employ the same discussion guide presented in Table 1. However, it is expected that the two methods differ in the type of data they provide, as focus groups allow for interactions between participants, as well as them as agreeing, disagreeing, or expanding on what their colleagues say, thus allowing for a broader range of inferences to be made than one-on interviews. In this study, interviews were conducted in cases where participants were not available to join any of the focus group.

Motivation	Can you describe your initial interest in the Red Room?
	Please elaborate on your motivations to join the Red Room.
	When was the first time you went inside the Red Room?
Activities	Tell me a success story you experienced in Red Room.
	Can you explain what sort of activities happen in the Red Room?
	What type of projects come out of the Red Room?
Skills	What's a skill you didn't realize was important until you worked in the Red Room?
	Can you share something (technical) you learned in the Red Room?
Community	How would you describe the culture at the Red Room?
	Who did the Red Room introduce you, who you may not have met otherwise?
	Can you elaborate about the people who access the room, the amount of time they spend, and how often?
	What sort of memories did you make in the Red Room?
	How would you describe your relationship to the Red Room?
	How would you describe your relationship to the faculty?
Engineering	What were your favorite courses in the major?
	What careers do you envision for yourself?
	What helped you deciding your next steps after graduating?
Career	How did working in the Red Room impact your career choices after graduation?
	How did the JEDI experience affect the way you work in your current role?
	What lessons learned in the Red Room did you carry with you into your professional life?

Table 1 RQ2 Discussion guide

Given the conceptual framework described in Chapter 2, the discussion guide's questions were designed to inquire directly and indirectly on each of the following topics: motivation to join the Red Room, activities within the makerspace, skill development, community and belonging, engineering education, and career.

The semi-structured nature of this guide grants us the flexibility to elaborate on participants responses spontaneously on the spot (Braun, Clarke, & Rance, 2015), in order to extract potentially valuable data that may otherwise be left uncovered. Accordingly, this form of qualitative data collection invokes skill and quick thinking on the part of the interviewer who must quickly recognize a potential lead towards an insightful conversation.

3.2.2. Sampling and Data Collection

The target population in this study is current and previous Red Room JEDIs (Junior Engineering Design Innovators). From a total of forty-nine in total from Spring 2019 to Spring 2023, 22 JEDIs participated in this study, of which seven alumni and fifteen currently enrolled students, with three of these no longer active in the makerspace. Data collection consisted of nine separate events with different participants; six were focus groups discussions (FGDs) with two or more participants, and three were individual interviews (INT). These events were held either in a private setting, either in person or online, according to the availability of each participant. Details of the data collection process are summarized in Table 2.

Participants were recruited through personal communication, LinkedIn messaging, and email using an IRB-approved invitation script and oral consent form. Participation in the study was voluntary and posed no risk nor benefits for participants.

In-person events were audiotaped, and online meetings were recorded through the platform used (Webex).

Event	Meeting mode	Participant number	Semester joined	JEDI status
FGD 1	In person	Participant 1	Fall 2021-22	Active
		Participant 2	Fall 2022-23	Active
		Participant 3	Spring 2018-19	Active
		Participant 4	Fall 2021-22	Active
		Participant 5	Fall 2022-23	Active
		Participant 6	Fall 2022-23	Active
FGD 2	Online	Participant 7	Spring 2018-19	Graduated
		Participant 8	Spring 2018-19	Graduated
FGD 3	In person	Participant 9	Fall 2022-23	Active
		Participant 10	Spring 2022-23	Active
		Participant 11	Fall 2022-23	Active
		Participant 12	Fall 2021-22	Active
		Participant 12	Fall 2022-23	Active
FGD 4	In person	Participant 14	Fall 2021-22	Graduated
		Participant 15	Fall 2021-22	Active
FGD 5	In person	Participant 16	Fall 2021-22	Inactive
		Participant 17	Fall 2019-20	Inactive
INT 6	In person	Participant 18	Fall 2021-22	Inactive
INT 7	Online	Participant 19	Spring 2018-19	Graduated
FGD 8	Online	Participant 20	Spring 2018-19	Graduated
		Participant 21	Fall 2019-20	Graduated
INT 9	Online	Participant 22	Fall 2019-20	Graduated

Table 2 Data collection and paticipant details

3.2.2. Analysis

The approach to analyzing the data collected through the suggested protocol is thematic analysis, “a method for identifying, analyzing and reporting patterns (themes) within data” (Braun & Clarke, 2006, p. 79). Thematic analysis is a versatile method of presenting and interpreting data to elucidate semantic (i.e. surface-level) or latent (i.e. underlying) meanings organized into congruent themes (Braun, Clarke, & Rance, 2015, p. 6). This method is founded on a process of coding of qualitative data, i.e. labeling units of data, essentially individual quotes, with keywords or phrases that are then collected, merged, and split, into themes that address the research questions (Braun, Clarke, & Rance, 2015).

In the analysis, mix of deductive and inductive codes are used; the former are derived from the conceptual framework as well as the topic addressed in the discussion guides, and the latter emerge from the data itself, particularly from unexpected ideas that arose from the flexibility of semi-structured interviews (see Braun, Clarke, & Rance, 2015, p. 6 for definitions of deductive and inductive analysis). Braun, Clarke, and Rance (2015) state that “coding evolves as it progresses” (p. 10) and that “this process of looking at codes, coded data and the whole data set, and developing the ‘shape’ of each theme, is a recursive one” , thus emphasizing the iterative nature of code development and subsequent analysis, especially when the inductive approach is involved.

In this thesis, presentation of findings will be organized into two chapters. Chapter 4 will showcase the results through the themes and sub-themes identified through semantic coding. Chapter 5 will present the analysis and discuss those themes from a theoretical perspective, referring back to the conceptual framework underlying this research.

3.3. Validity of the Study

According to Merriam and Grenier (2019), three main quality criteria should be considered to ensure the trustworthiness of any qualitative study and its finding: internal validity or credibility (p. 25), reliability or dependability (p. 27), and external validity or transferability (p. 28). In this thesis, internal validity is ensured through the strategy of member checking, which means that the researcher "ask[s] the participants to comment on [their] interpretation of the data" (Merriam & Grenier, 2019, p. 26). In the present study, the outcomes of the coding and analysis were reviewed by two of the study's participants who accepted the author's interpretations as valid. Meanwhile, reliability is ensured through peer review, which, in a thesis study, peer review is embedded into the research process as the research is reviewed by the members of the committee (Merriam & Grenier, 2019, p. 26-27). The committee in this case includes one advisor who is involved in makerspaces and the Red Room in specific, and a co-advisor from a different faculty who is not initially familiar with the makerspace. Finally, external validity is challenging in qualitative research due to the fact that "small, nonrandom samples are selected purposefully in qualitative research" (Merriam & Grenier, 2019, p. 29). This challenge can be overcome by "maximizing variation in a purpose-selected sample" (Merriam & Grenier, 2019, p. 29); in the case of this thesis, the sample included current and previous JEDIs of different status, who were active at different times from the inception of the Red Room and experienced it in different circumstances, from when it was still new and less frequented, to it becoming a well-known feature of MSFEA, thus achieving variation in the sample.

CHAPTER 4

RESULTS

4.1. Coding of the Data

The raw interview data was first transcribed verbatim from the audiotapes for each focus group discussion and interview. Then, the data was coded according to the process described in Figure 2. We then started the coding process with three broad themes that are deductively derived from the discussion guide: informal learning, community, and engineering. Then, these three themes underwent a first round of refining, and nine preliminary subthemes emerged in total: hands-on learning and peer learning; culture, belonging, reasons for joining, and technical skills; soft skills, transfer of skills, and influence career interests and path. These themes were informed both deductively and inductively. Line-by-line coding of the data reuslts in twnety-one unitary codes, two of which had further ramificiations. Among 22 participants across 9 data collection events, the number of participants who provided data relevant to each code was counted to ensure significance of the code.

Once the fine-grained codes were identified and quantified, the explorative phase of the coding process was complete. The following step was to group codes with low frequency and rearrange all codes into the final subthemes: learning by doing, learning from each other, growing as a community, promoting making, managing the makerspace, and beyond the Red Room. The first and second half of these subthemes were grouped into two broad themes: proficient makers, and facilitators and educators, respectively. These two themes reflect the two essential roles that JEDIs play in the Red Room: their role as makers and operators of the makerspace equipment, and their contribution to engineering students' learning by supporting making and educational activities.

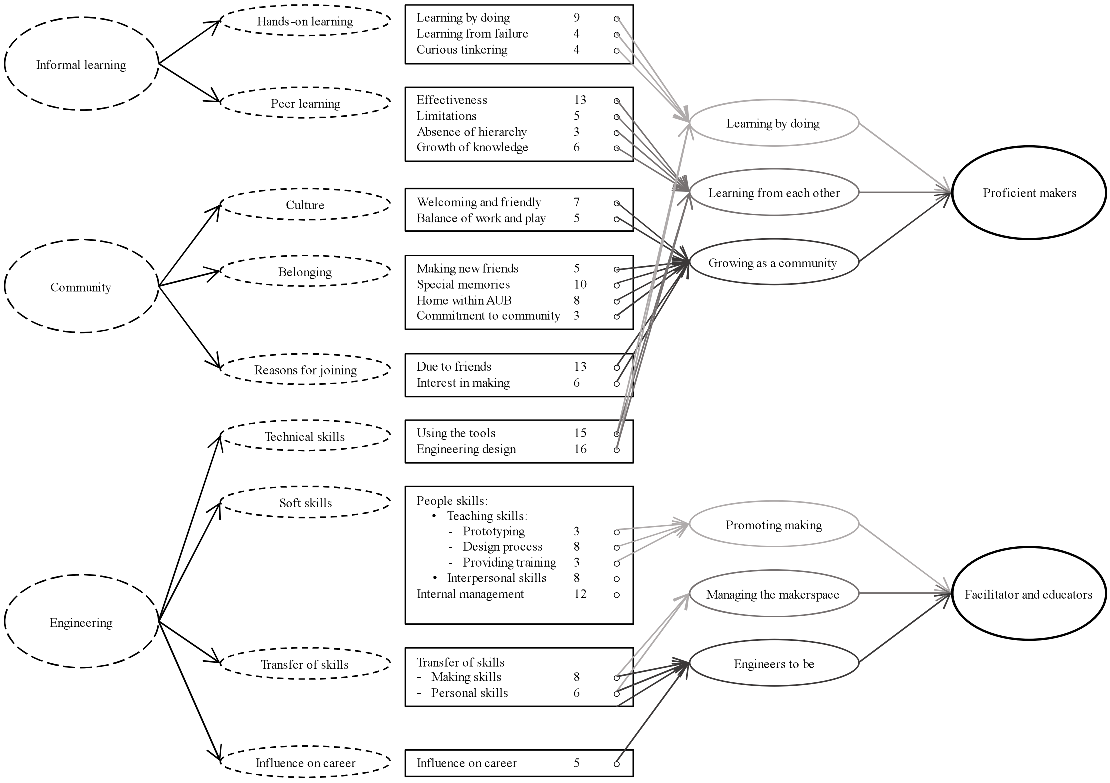

Figure 2 Coding of interview data

The codes were validated through member checking with two participants who were asked to review and validate the interpretation of the data after analysis was completed.

4.2. Proficient Makers

4.2.1. Learning by Doing

On a typical day in the Red Room, JEDIs can be found handling 3D printing jobs requested typically by students and faculty members; as described by to Participant 16, "this printing is done for projects, FYPs, things related to university, whether they are by students or researches by master's students or professors." Participants had many stories to tell about particularly challenging or impressive prints that they remember working on, such as a flexible anatomic foot (Particpant 1), or a "giant anatomical heart" (Participant 17); the challenge comes from complicated print geometries and physical limitations due to how the printers build the print itself, as Participant 1 explained: "I remember that it took a lot of time and the way I had to think about where I'm putting my supports, how I'm allocating my material, everything about that, how am I shifting the weight of the print so that it doesn't fall because of it being, you know, heavier from one side."

Most JEDIs start off with no or very little knowledge of how 3D printers work and how to operate them, and so they learn through sustained hands-on application. Through their work in the Red Room, JEDIs "got introduced to different materials" (Participant 11) and "gained quite a few skills in that area, maintaining printers, […] different materials, how you would choose what you want to fabricate a certain design with." (Participant 19). Similarly, Participant 16 commented: "something I was proud of [is] just learning about 3D printing, now I know about 3D printers and all the materials, and when I print by myself, it was something so nice to me." Thus, being a JEDI entails continuous learning through experimentation and practice: "I learned a little bit of SolidWorks [3D modeling software], while helping people with prints" (Participant 14). Participant 9 proudly described a design project they completed, where they "went, took dimensions, completely designed all the parts from start to finish with printing."

A natural aspect of hands-on learning is failure, which JEDIs recognize as an essential part of hands-on learning. According to Participant 20, the JEDIs "developed the experience of how to actually do that [3D printing] [through] a lot of trial and error." Many times, a process does not yield the expected results, and they have to understand the reasons it failed and how to avoid them, as in a story by Participant 10: "I printed a disk with, like, a marble that rolls around using a motor and stuff then rolls into another disk. […] It was a pretty big disk, […] so the first time we printed it failed, which was devastating. […] The second time, […] I made it smaller, printed less, and it worked out well." According to Participant 20, the JEDIs "developed the experience of how to actually do that [3D printing] and that was a lot of trial and error there." Such critical analysis and iterative improvements are characteristic of the process of engineering design.

Experiential learning is complemented by JEDIs' self-directed efforts to widen their knowledge through research. For example, they stay up to date on the latest developments in the field of 3D printing, or learn about the various materials and their properties, or even "do some research about different types of resin, the optimal way to 3D print, look at new updates…" (Participant 1). Similarly, when faced with situations they have no answer to, JEDIs "[would] always have to go back and look stuff up on [their] own" (Participant 22). In addition to information seeking and research, JEDIs get the chance to make, tinker, and explore the tools that they have access to, for example by making small repairs around the room itself, such as printing replacement legs for a chair (Participant 1) and fixing a broken cabinet and the room's door (Participant 3), but also tinkering and experimenting with the technology itself: "there was some type of memory chip I think that told the 3D printer how much material there was a left. […] Someone reprogrammed this chip with an Arduino, and they were able to use PLA from any generic filament, and we were able to print, even though the print was really bad, it was like, something really cool" (Participant 7). Another story is one where some JEDIs printed a miniature tree using two filaments in different colors, which had never been attempted on the existing equipment. About this last story, Participant 8 commented: “[they put] their sense of initiative in something fun for them […] and I think we learned something; I learned something at least.” Participant 14 emphasized the continuous learning that JEDIs experience, saying: "we learn, we learn, as we go, we learn."

While the discussion so far has focused on the idea of learning by doing and how it is essential for JEDIs, this constructionist process is not an individual one. Indeed, working and learning in the Red Room are collective processes, rooted in interaction, collaboration, and support among the JEDIs, as will be discussed in the next section.

4.2.2. Learning from Each Other

Peer learning is a pillar of the Red Room’s operation. As it is a student-managed makerspace, each generation of JEDIs are responsible for the recruitment and training of newer members. As such, new JEDIs begin their journey under guidance and encouragement from their peers, sharpening all the skills needed to manage the makerspace as they go through the hands-on applications discussed in the previous section. Participant 18 described this process as follows: “there were older students, and they were experienced in the Red Room. […] I used to go to my shift, and they used to tell me [how everything works]. And then I got the hang of it and then we had to do our own print so we could get used to printing.” In short, the trainers briefly introduce the basics of the Red Room, its mecahnical and electrical equipment, and the two types of printers to the newcomers. Once this short training is complete, students are approved as JEDIs upon completion of their first 3D print, known as the JEDI print, which participant 13 described as “always a memorable thing”. Participant 13 emphasized the importance of older JEDIs’ support and enouragement in this process, saying: “when I first made [my JEDI print], I kept [my trainer] beside me and told them, ‘I can’t do it without you!’”

After this initial first print, the training is essentially embedded into the operation of Red Room; JEDIs then rely on experiences throughout everyday work to expand their knowledge. This learning is made possible by the level of trust between older and newer JEDIs, as Participant 22 explained: “It was very hands-on, there was also a lot of trust involved, I’d say. They [older JEDIs] trusted us to be able to do things on our own after showing us once or twice. […] I never felt like there was this huge oversight, like they were looking over our shoulders...” New JEDIs were thus enabled to operate the Red Room independently, with older ones providing support and encouragement where needed. Indeed, trainers persistently “push the new JEDIs to do stuff they haven't done already so they can learn” (Participant 3); on that topic, Participant 1 state: “I’ll always encourage every JEDI, if they have time, that if there's still one more tool that you don't know how to use, go try it, go ask another JEDI how this works.” While this peer training model implies a trainer-trainee relationship between JEDIs, this relationship is actually collaborative rather than hierarchal. Participant 4 described this dynamic as follows: “When we trust each other, like you know this guy has seniority, he knows what's going on more than the other. There isn’t any level between us, but there is seniority in the way we learn.” As such, JEDIs learn and benefit from the experiences of their more experienced peers, as exemplified by Participant 9: “I honestly fell in love with CAD [Computer Aided Design] […], so I started improving my skills little by little and learning different softwares. But as much as you learn, you can always benefit from the experience of someone who has done it longer than you. […] From when I first started here, […] my experience with CAD has grown exponentially, just from learning from students." The lack of hierarchy in the Red Room is emphaized by Participant 14's statement that "you can always learn new things even if you were the older person in the room, because some people come in with different skills." Indeed, students who join the Red Room all have their unique skills and approaches, which they are enthusiastic to share with each other; for instance, this same Participant 14 learned how to better use the Red Room's mechanical tools from a colleague who is more knowledageable; similarly, Participant 22 recounted: "even though I hadn't learned CAD on my own, I just learned enough and asked the other Red Room members, […] even the 3rd years and 2nd years who use CAD, for their advice."

As each JEDI shares their own skills, experiences, and anecdotes with their peers, the amount of knowledge shared among the JEDIs continuously increases; Participant 4 explained: "we learn from each other's errors. […] Now we have so much experience because we know what the errors are." Participant 14 expressed a related idea: "we give you how we do it and then we'll give you all the possibilities that you would face because we faced them." This shows that there is ever-growing repertoire of knwoledge and know-how among the JEDIs, which Participant 3 described as such: "So you end up learning from each other and then when you pass on this knowledge, each one accumulates a certain amount of knowledge and they learn something new and they pass it out to new people […] The knowledge will keep cultivating between students." It is important for members of the Red Room to ensure not only the growth and continuity of the makerspace. As stated by Participant 4, they "want someone who can have this [JEDI] experience all the way so they can teach people after them" – that is, students who are willing to stay in the Red Room for more than one year. In addition, Participant 1 emphasized the importance of recording their learning to keep it available for future generations: “we had to put an extensive effort to kind of combine all of [our predecessors’] knowledge and us also doing a lot of research about everything else that they didn’t teach us, other things that are evolving, other updates are happening, things are changing.”

Ultimately, learning in the Red Room is community-driven, benefitting from the fact that JEDIs are university peers, as suggested by Participant 20’s statement: “you're learning it from a student that's only like a year older than you, that student is just trying to give you as much information as he can, and then you also learn along the way, throughout experience. […] And at the end to finish it all off, you're going to have to teach other people, which is like, you need to have a very good understanding to be able to do that.” Participant 22, who was an active member over several semesters, reflected on their experience with transitioning from trainee to trainer, highlighting the trust, support, and communication among JEDIs: “we realized we took the roles that [those who taught us] played for us. We kind of applied the same principles of trusting. […] We trust that everyone is competent enough to have seen something once or twice, and more or less know how to operate something. And even if they don’t, if at any step, they feel like ‘I don’t know how to do this’, there’s an open line of communication and they can just ask any question without any embarrassment at all.” Some participant found this easy-going nature of peer-to-peer training, to be conducive to a comfortable and friendly learning experience that they find to be “definitely more efficient than having a professor mentoring students every year. […] The student side of you shows up a bit more. The Red Room becomes a bit more fun” (Participant 21). According to

Participant 20, this peer-to-peer model "gives you a very different way of learning how things how things should happen […] and how everything you learn at the Red Room, how you would actually apply it." Despite these generally positive opinions, some participants had reproaches about the training process being too unsupervised: "people don't have as much incentive. Because it's a chiller working environment, people don't feel the pressure to learn right away." (Participant 17). Participant 21 made a similar remark, stating that "some students don't take it seriously unless a professor gets involved, unless someone comes in and checks in on whether they are doing their job or not." From a different perspective, Participant 16 felt that their own learning journey in the Red Room was compromised, saying: "I would have preferred […] that they provide us with something like a training. […] After a month, I still needed to have someone around to make sure of everything I was doing."

To conclude, the participants' input shows that JEDIs' applied, hands-on learning in the makerspace is reinforced by their interactions – not only do they learn from each other, but also with each other, leading to a collective learning experience: "what's nice is we're learning something that's in a work environment but doesn't feel like a work environment, because you are learning from your friend and you're learning this together and working on stuff together. It feels like you're working on a project together" (Participant 3). In this statement, the term "friends" evokes an additional social layer to these interactions, which will be discussed in the following section.

4.2.3. Growing as a Community

Since the Red Room's inception, new members joined in different ways at different times. The very first group of JEDIs formed as students responded to the initial call for volunteers in 2019 out of interest in the opportunity to learn something new. Paritcipant 7 explained: “I received an email at first, and I think it was from Dr. Harb, and he was talking about a makerspace which sounded really good for me, so I decided to join.” A semester later, a group of friends became curious about the new room that had appeared in BDH. Four respondents from FG6, FGD8 and INT9 recounted the same story of how they one day decided to talk to the first JEDIs, and how it led to them joining the Red Room themselves. Participant 17 recounted: “we went in and we saw everything, we were like ‘oh, that’s cool, can we join?’ And they took our numbers,” while Participant 21 said they “thought it was a really nice opportunity to get engaged in, like, MSFEA and what was going on at the time.” Over the rest of the semester and up until the start of the lockdown in 2020, the Red Room community consisted of these inital JEDIs, in addition to some of their friends, “we also got a bunch of other friends on board with us later on. […] They saw us working in the space which they used to come in and volunteer for no reason whatsoever. They just had fun volunteering, chopping off supports, like, they used to have fun doing that. And that kind of influenced them to join later on and be the JEDIs that they are now” (Participant 22). This dynamic shows that the community the JEDIs are part of is not restricted to official members of the makerspaces, and that the boundary between these members and other students is blurred. This extended network of friends is beneficial to the makerspace, as it facilitates the recruitment of new members: the volunteers that Participant 22 referred to all became JEDIs after the 2021 return to campus, thus forming the third generation of JEDIs. In Spring 2021-22, the second generation of JEDIs graduated, and at the same time, the community continued to grow with new and younger JEDIs joining in. Once again, the fourth generation of JEDIs consisted in large part of friends of JEDIs from the previous generation. For example, Participant 6 “learned about the Red Room through [their] friends as well […] and [they really enjoyed spending time here, so [they] wanted to become officially part of it;” similarly, Participant 5 “ended up actually applying for the Red Room” after joking with their friends about becoming a JEDI.

Such testimonials show that friendships constitute a significant point of entry through which students learn about the Red Room. However, the decision to become a member typically stems from their interest in makerspace itself and the opportunity to use it that drives them to join. After seeing their friends work in the Red Room, Participant 13 “got excited to learn such a skill,” while Participant 2 “thought it was very interesting” when their colleague “started explaining to [them] about the Red Room, printers, mechanical bench” and thus joined “ as soon as [they] got the chance.” For some students, their motivation to join the Red Roomwas the desire to expand their skills and gain experience: "I've always been interested in manufacturing and design, and especially due to the fact that I plan on continuing the track of design, materials, and manufacturing, this is a big boost in experience for additive manufacturing” (Participants 11). As the Red Room started to provide more entry experiences to the student community, such as tours and workshops, its reach grew and more students became interested in volunteering. Participant 9 was introduced to the Red Room through the mandatory first-year engineering course that included a 3D printing activity, and subsquently became a member of the team. Participant 10 visited the Red Room on the new students orientation before their first semester, and went on to become a JEDI a few months after: “I got a tour of the room and it was really cool, and I really wanted to learn because it really seems like it’s a growing industry, and you should know this stuff” (Participant 10). Another example is Participant 16, who recounted: “during online learning, we received an email […] that they want new volunteers or JEDIs. I didn’t know anything about it [the Red Room] or even about 3D printing at all, but I wanted to do something like a student activity, to work on something, so I applied.”

By bringing together students from different demographics such as majors and year of study, the Red Room allows new friendships to form among its members. Some members “got closer” to (Participant 18), and “became like real friends” with (Participant 16), students they were previously acquainted with when they worked together in the makerspace. Additionally, “it was a really good place to meet new people" (Participant 20); Participant 3 said: “some of the people here, I don't think I would have met them if weren't for the Red Room;” Participant 14 mentioned “all the younger people […] by two or three years”, while others mentioned “getting to know the older engineers” (Participant 15) or JEDIs “who were all older than [them]” (Participant 11). As previously mentioned, the community inside the Red Room is “not just JEDIs, , friends of JEDIs as well. […] It was a great community to be a part of, one of the most important parts of [this] experience, no doubt” (Participant 22).

These friendship are made possible by the amicable culture within the Red Room, which was described as a “very warm and very friendly environment” (Participant 3), “very friendly, very welcoming” (Participant 19). In contrast, Participant 21 described it as “friendly but formal”, noting the importance of maintaning a professional image of the makerspace; “we would see each other from morning to night, nonstop. But when things got serious, […] we would kind of like, straighten up, get ready for, you know, whatever professional thing we have to do” (Participant 21). Participant 20 explained: "a lot of our time was spent anyway at the other room because there's always need for help there. And even sometimes there would be the younger

JEDIs that would need help anyway. So, we'd always be there to help them and just hang out with them" (Participant 20). Indeed, JEDIs are enthusiastic about the tasks and activities required by the Red Room; describing it as “a place you look forward to being in, and not just complaining about having a shift” (Participant 9) and “a place [where] you like what you’re doing, [and] time runs very quickly” (Participant 14). According to Participant 2, “most people are ready to leave whatever they're doing to just go work if there’s something, even if it’s not their shift;” similarly, Participant 3 explained that if “somebody can’t make the shift, […] the JEDI doesn’t even have to ask. […] you see other JEDIs already working, like ‘[…] it’s okay I can take care of this.’”

JEDIs will often spend time in the makerspace even if there are no tasks for them to complete – the makerspace is their go-to place to place for studying, hanging out, or just passing time between classes. Participant 2 said: “friends from outside the Red Room know that if they need me, they’re going to find me here;” participant 15 said that they are in the Red Room “almost every single day, 7:00 AM to like 7:00 PM, other than classes;” similarly, Participant 5 commented: "we have a place we go to, […] it feels like home. I spend more time in this room than I spend time in my house.” Such statements show the significance that the Red Room truly holds for its members, who consider it their “home inside of AUB” (Participant 20). This homeliness comes back to the welcoming culture of the Red Room; Participant 14 explained that “it's not about the room, it's about the people inside”, and for Participant 16, “it feels like a small community;” lastly, Participant 18 expressed: “I used to feel like, comfortable inside. I used to feel safe. I used to feel like this is where this is where I want to be.

In addition to sharing their feelings about their makerspace, participants excitedly shared that they have “a lot of good memories” (Participant 22) in the Red

Room: unboxing new equipment and sitting inside the boxes (2); playing music and singing (18) or dancing Dabkeh together (12); helping new graduates get ready for their commencement ceremony (Participant 12), “having a laugh over [the] drawings on the whiteboards” (Participant 22)… Participant 17 added: “I was there for three years. I remember the first time we went into the Red Room, the first few prints we did, the 4 A.M. nights in the Red Room when we’d be working on a project…” Even after leaving AUB, some alumni visit the makerspace when they have the chance, such as Participant 22, who said: "last time I visited in January, I spent a good time in the Red Room just sitting there remembering everything."

In short, the participants we talked to exhibit a strong sense of belonging to the makerspace. This belonging is rooted in Red Room as a space, its activities, its members, and the relationships between them. The following statement Participant 22 illustrates this sentiment: “I feel like there's this community that the existence of a space like the Red Room created. […] Like, there’s a sense of a continuous community. I would also say I’m an alumnus of the Red Room, not just AUB, like that’s the sense of belonging I feel to it.”

4.3. Facilitators and Educators

4.3.1. Enabling Makers

One of the JEDIs’ everyday tasks is conducting 3D printing jobs that are requested from the Red Room. This task is not only a technical one, as JEDIs also have to “talk to the to the students who want to 3D print and like discuss the different materials” (Participant 18). Much of the 3D printing is for students’ academic projects such as coursework and FYPs, but JEDIs also welcome personal projects and sometimes receive requests from other entities from the university, such as the Archaeological Museum. In addition, prototyping support is not limited to 3D printing, as the JEDIs also assist makers with the other tools available in the Red Room, as explained by Participant 3: "there are some people that need to use the tools and they either ask us to use it for them or they want to learn how to use it;" when other students visit the Red Room, the JEDIs "help them with their projects, just sanding or like drilling or whatever they may need" (Participant 5). Given their position as "usually higher level, more experienced engineering student" (Participant 21), JEDIs also assist students who "come [to the Red Room] for advice" (Participant 14) with the process of designing and refining their ideas, as Participant 20 explained: "[Students] just come in with an idea and they wouldn't know how to execute it. And we'd help them, even with designing a CAD model, just, anything we could do, we're there to help." Paticipant 21 opined that "full poential" of the Red Room is achieved when it is full of students, JEDIs and other, working on their projects, "using all the tools, the dremels, the whatever, the soldering, electronics […] to do, like, this small thing, this little tweak to their PCB, or this little tweak to whatever" (Participant 21) using help and experience from each other.

In addition to supporting making and students' hands-on activities as needed, JEDIs also provide some instructional activities through individual training as well as group workshops. According to Participant 20, "something that really stands out is all the workshops that we did, and, like the hackathons, all the events that were done with the help of the Red room." Participant 22 told us about his experience running a stand for the Red Room in an event in the university's main library, as well as other presentations for departments outside the faculty of engineering. Some workshops were offered for students from specific courses that required them to use 3D printing. Participants in the study described one of these workshops as a “crash course” (Participant 5) that they design to be as comprehensive and informtive as possible, so the visiting students would be “one hundred percent equipped to come and print” (Participant 1) when they start working on their projects. Participants also expresed that they enjoy teaching and spreading the knowledge of the Red Room to others, especially when students show enthusiasm and excitement to learn in return. Participant 1 described this as follows: "[There are] students that ask questions, that are enjoying what they’re doing, they’re so happy because they just got a rubber duck, it's 3D printed and it’s amazing. This is what you like to see, you know, these are the things that keep you motivated, that that make you feel like all the work that we've done for this workshop did not go to waste" (Participant 1). Even outside the context of workshops and training, JEDIs always prefer to show students how to do something on their own rather than do it for them, as their goal is to spread the culture of working with one’s one hands, as shown by Participant 15’s statement: "When I'm working on whatever [someone’s] using in, I always ask them, ‘so you care about what I'm doing? should I explain to you what I'm what I'm doing as I’m doing it?’ Sometimes they say yes and I tell them exactly, and I teach them how to do it themselves." (Participant 15)

These events, moments, and interactions constitute the informal side of learning offered by the Red Room, and are the foundation of the student-led model that the Red Room follow. While discussing the idea of students teching students, Participant 3 commented: "When you're learning something from a peer or from a friend or from a student, it's different from learning from professor or somebody in charge like a lab instructor, because you feel like when you learn from a friend, making a mistake would be okay. You won't be afraid to make a mistake. You won't be afraid to make a mistake and learn from it." (Participant 3)

Given their role are facilitators of making, the JEDIs' job is very social one. Between technical tasks and engagement with students, the Red Room exposes its members to a range of essential workplace skills.

4.3.2. Managing the Makerspace

As the only staff of the makerspace, JEDIs are responsbile for the upkeep of the Red Room and all the equipment within it, "like cleaning up, making sure that everything is in the right place" (Participant 18). They typically coordinate all tasks and print requests through phone messaging, emails, and an online planner, all of which allow them to stay on top of the various tasks and deliverables as well as be informed of important annoucnement. According to Participant 20, "we would work together to make sure we always have what we need at the Red room, to order stuff whenever we needed to, talk to whoever about anything we need to have fixed," which shows that JEDIs are also in charge of resources in the Red Room, ensuring enough materials and supplies are available for students' projects is essential; as such, "resource management is very important" (Participant 14) for the makerspace, especially towards the end of each semester when project deadlines approach: "It was the day before the deadline, everyone wanted to finish up everything they're doing and […] like 30 people rushed into the Red Room and we have to deal with that with the shortage of material with a shortage of people there, like JEDIs there" (Participant 22).

As such, there are often periods where the Red Room will receive a large crowd of student working on a common project; "when there's actual projects, it's full - you could see twenty people" (Particpant 14). A particular example is given by Participant 22: "we had a lot of traffic, I remember, from first year students working […] wooden bridge for one of the courses. That was our first job, being able to handle so many people and organize so many people trying to come in and use the tools." This instance highlights the importance of managing not only the space itself, but also its users; as Participant 8 puts it, "students are students, they're here to learn, and you have to take into account that it's made for their leaning". Many times, students coming into the Red Room are angry or stressed about their projects not being done on time, and the JEDIs have to be patient and understanding towards them: "if a student came in angry about a print that didn't work out or something, we need to understand that, at the end of the day, a person might get angry about anything. […] The idea is that we cannot overreact because we are working here" (Participant 22). Participants emphasized the importance and value of people skills in the Red Room, as illustrated by Participant 21's words: "composure to deal with everyone all throughout is, I could say, the main skill here in addition to all the design skills that could have come."

Such social skills are useful in many situations, especially when it comes to managing the social aspect of the Red Room, where students often come just to study or to socialize. The JEDIs agree that "one or two people is fine" (Participant 13) in terms of friends hanging out in the Red Room, as long as the they are not distracting JEDIs or disturbing other students who need to use the space for hands-on work. They also note that keeping the Red Room open to guests is essential, as it shows that it is available and accessible to everyone and invites students to come in and inquire about the makerspace: "I don't mind that anyone comes in to ask about the Red Room or to show them what's available," said Participant 16. As such, JEDIs have to regulate who is coming in and when, while prioritizing activities related to prototyping and making over socialization; this means that they have to balance their status as members of the student community against their role as managers of the Red Room by reinforcing the responsibility and accountability they have towards it: "we are all students here but at the end this is a professional environment to a certain extent. We get essentially paid to look after this room which has [expensive] equipment, with no cameras, and door is open. If we can't at least protect the room, then what are we doing here?" (Participant 9). Thus, the JEDIs "really appreciate it when someone walks into the room and, you know, makes account for [them]" (Participant 1).

4.3.3. Engineers to Be

Before getting involved in the Red Room, JEDIs are, at the base, undergaduate engineering students. When asked about the relationship between their JEDI role and engineering, some participants commented that working in the Red Room confirmed or reinforced their choice of major, while others found that it offered them a new perspective. Many, though not all, JEDIs are from the mechanical engineering major; some highlighted the close connection between engineering design and makerspace activities: "I did not like my major [mechanical engineering] at first. Then I learned about design, which is a big part of why I became a JEDI" (Participant 4). Other participants from mechanical engineering were more interest in heating, ventilation, and air conditioning (HVAC), controls, or mechanical, electrical, and plumbing (MEP), while participants from the electrical and computer engineering department had interests such as networks and robotics. Some participants had a minor in biomedical engineering or are currently pursing graduate studies in the field.

Some participants had not been exposed to hands-on design through coursework when they first started frequenting the Red Room; one industrial engineering student explained: “I love my major, but I also like technical things, so I got to learn a lot here [in the Red Room], and I got to meet a lot of people that know a lot of stuff. This made me love my major even more, but love a part of it that I was not considering beforehand” (Participant 2). Additionally, one electrical and computer engineering (ECE) alumni, currently pursuing a Master’s degree in biomedical engineering, said “it [the Red Room] gave me a lot of appreciation for a different field than what I was in” (Participant 19), and that they would not have learned about 3D modeling in design if it weren’t for the makerspace. For another student in the same department, being a JEDI constituted a big shift in perspective regarding engineering and their future: “[I] think about how I can take all the knowledge that I acquired in this room a step further and maybe even work in that field one day, even though my major [CCE] is something completely different, it's very far, but now I'm trying to find common ground where I can link these two together, because I found a part of me inside this room that I don’t want to ever lose.

Beyond their specific, individual majors, participants also expressed their perceptions of the skills they acquired in the Red Room relative to engineering work as a whole. They revealed a positive impact of this experience on their outlook on engineering, as in the example of Participant 3: “If you’re part of a maker space and you’re part of aiding a makerspace, it's skills that you can use in any domain.” Some of the current students who are looking to enter the job market after graduating, asserted that managing the Red Room is a good prepartion for future professional environments, where they would have to “consult with other employees, with the manager, with the actual clients…" (Participant 18) similarly to how they operated in the Red Room. Another participant described the experience "like a job or an internship" where "the students are like your custozmers, there's teamwork skills when we all talk together like" (Participant 16). On the other hand, one participant reported that his decision to pursue a Master's degree in "additive manufacturing and design in engineering" (Participant 4) was heavily influenced by the Red Room, which was also the reason they had an internship in a commercial makerspace that specializes in 3D printing in the previous summer.

Alumni participants shared their the imprint of the Red Room on their lived experiences after graduating. One particant continued in research anddesign (R&D) in the biomedical field before going into graduate studies in this field; while biomedical engineering is broad and interdiscplinary, this particpant described themselves to be "more in the design" branch, and has benefitted greatly from the Red Room 3D printing experience in their later job (Participant 7). Design, prototyping, and 3D printing skills were also mentioned by other participants, who used these skills in interships, jobs, or even student club activities in their next universities; one of them, currently in their Master's program, is considering a thesis topic in additive manufacturing, following their experience as a JEDI. Beyond particular technical or even personal skills, participants shared that the opportunity of student work at the Red Room was a an enlightening exposure to what working in a professional environment would be like; for example, Participant 14 said that they "don't see much of a difference between the Red Room and the workspace" after being employed for a few months, while Participant 18 insightfully expressed their view that "life can both be like about like, work and being

productive, and having fun, like, working doesn't have to mean like suffering"
(Participant 18).

CHAPTER 5

DISCUSSION

In the previous section, results of the qualitative data from focus group discussions and interviews with JEDIs were coded and reported under two main themes, with each theme focusing on one aspect of the JEDI's role and responsibilities in the Red Room. The first theme, 'proficient makers', describes the JEDIs as members of a community of makers that design and prototype together and learn with and from each other through hands-on activities. The second theme, "facilitatators and educators", describes the JEDIs' role as managers of the Red Room who support and educate others and monitor all activities within the makerspace through their unique role as student-staff.

The discussion sections 4.1 and 4.2 will provide a deeper analysis of these two themes in response to each research questions of this study, respectively:

RQ1: What is the impact of makerspace membership on engineering students' experience as learners?
RQ2: What are the perceptions of engineering students regarding their skill development in the makerspace?

The data will be interpreted analatically through the theories presented in Chapter 2, and findings will be linked to previous research conducted in university makerspaces. In section 4.3, the two themes will intersect, manifesting the study's conceptual framework as a whole.

5.1. Proficient Makers: A Community at the Service of Learning

The results of this study echo some of Bouwma-Gearhart's (2021) findings pertaining to the affordances of university makerspaces; in particular, three affordances are identifiable in the present study's data: the "physical features" of the makerspace (affordance 1), users' "engagemeent in the process of design" (affordance 2), and the "welcoming and supportive climate for participation" (affordance 3) (Bouwma-Gearhart et al., 2021, p.15). The present findings also position the Red Room community as a community of practice, fulfilling the three components of such a community: the domain (component 1), the community (component 2), and the practice (component 3).

In all discussions with current and previous JEDIs, a prominent aspect of participating in the Red Room was hands-on learning. Members of the makerspace engage in technical activities as part of their work in the Red Room, but also through their own, self-driven tinkering and exploration with the "material and tools that you can mess around with and do whatever you want with them and just learn" (Participant 8). This finding reflects Bouwma-Gearhart et al.'s (2021) description of the physical features of the makerspaces (affordance 1), which suggests that the opportunity for hands-on learning is made possible by the physical features comprised within them. Similarly to respondents in the cited study, participants in the present research reflected that experiences like completing difficult 3D prints or repairing furniture in the Red Room enabled them to acquire technical skills of making that are complementary to their engineering knowledge; one of the oldest JEDIs in this study stated that "just using your hands, as an engineer, [is] quite important" (Participant 7). This process of learning-by-doing in the context of the Red Room is undoubtedly a constructionist one, as constructionism is a well-established pillar of educational and non-educational makerspaces alike (Halverson and Sheridan, 2014). Constructionist learning in makerspaces implies tinkering and experimentation, which in turn involves frequent errors and failures. A successful educational makerspace is one that tolerates and even encourages failure in order to stimulate “big ideas” (Kurti et al., 2014, p. 10). In the Red Room JEDIs experience failure routinely.

Engagemenet in the process of design (affordance 2) is demonstrated by members of the Red Room sharing stories of conducting engineering design, a process in which which hands-on technical implementations were but a part of the process of devising a project, building it, testing it, and improving it. Prototyping itself is more than simply shaping and connecting physical parts, but a critical process in which one constantly evaluates and iterates on their design; for example, Participant 21 and Participant 20 printed multiple miniatures of their final year project before constructing it in full scale. This “practice of design skills”, supported by the physical environment of the makerspace, also constitutes the domain (component 1) of a community of practice in a university makerspace (Galaleddine and Anis, 2017, p. 8). According to communities of practice theorist Etienne Wenger (2021), the domain of a CoP consists of a field of interest that members share a competence in and commitment to. Indeed, the domain in a university makerspace such as the Red Room consists of making and engineering design.

The welcoming and supportive climate for participation (affordance 3) is visible through the community aspect of the Red Room and how valued it is by the JEDIs, who reported a strong sense of belonging to the Red Room, echoing findings by Andrews et al. (2021). Like many of their colleagues, Participant 18 mentioned that the JEDIs “had this cute friendship, so it was like a family”. This comforting culture is, for many JEDIs, the reason they started frequenting the makerspace, even before becoming a member of it, which is similar to Galaleddine and Anis’ (2017) observation that the makerspace they studied grew through people inviting their friends to use it. In their case just as in the Red Room, the student-led nature of the makerspace is what allows the community to grow with participants with different skills and interest and a "shared passion for making" (Galaleddine and Anis', 2017); and just as the makerspace in these authors' study, the coming together of these participants composes the community (component 2) at the heart of the Red Room's community of practice; these individuals, the relationships between them, and their joint activities are typical of Wenger's (2009) definition of the community component of a CoP.

The practice (component 3) of a CoP is marked by the repertoire of resources shared by the community (Wenger, 2009). In Galaleddine and Anis' (2017) studied makerspace, a mentorship process underlies the sharing of knowledge between makers. The case of the Red Room is no different; oftentimes, friends of JEDIs begin to learn just by hanging out in Red Room and being exposed to its environment; whether they joined under the influence of their friends or out of curiosity and interest in new skills, new members of the makerspace start their journey as informal apprentices learning from their seniors. What makes this apprenticeship conform to Wenger's (2009) definition of the practice (component 3) is that the knowledge being transmitted is not limited to a static list of things to know but evolves dynamically through the experiences of each individual JEDI, the situations they face, and the problems they solve while operating the makerspace. One participant described the growth of knowledge in the Red Room as a "snowball" (Participant 1), while another explained that when teaching something to a new JEDI, they end up "using a lot of the anecdotes or like the examples that [they] never faced [them]self, but that people before [them] faced" (Participant 15).

According to the participants in this study, it would take a semester or less for the new JEDI to master the basics of all the tools in the Red Room, during which they rapidly become more independent and less reliant on their peers; they are directly involved in operating the Red Room through a “no blame and full trust culture” (Participant 22) and the same level of responsibility as their seniors. When they are so empowered by their colleagues to learn from everyday activities, newly joined JEDIs may be considered as legitimate peripheral participants (Lave and Wenger, 1991) of the Red Room, slowly progressing into full participation as their expertise increases, to eventually become, in some cases, mentors themselves.

5.2. Facilitators and Educators: A Professional Engineering Experience

Red Room JEDIs play an educational role in the faculty. Firstly, they assist students in making components for their projects: “there are some people that need to use the tools and they either ask us to use it for them or they want to learn how to use it” (Participant 3). Beyond discrete hands-on skills, JEDIs are willing “to provide any help anyone needs” (Participant 20), covering the whole process of engineering design from ideation to prototyping. Such activities are akin to the “just-in-time” learning identified by Gershenfeld (2005) in his first Fab Lab at MIT and are distinct from the pre-planned learning opportunities such as independent workshops, workshops for particular courses, outreach events, and individual training sessions that the JEDIs mentioned. The existence of both the spontaneous and the structured types of learning is reminiscent of Sheridan et al.’s (2014) observation that educational makerspace encompass a blend of community driven learning and formal pedagogical structures.

By providing both types of educational support, JEDIs acquire the teaching skills necessary to communicate information and advice to other students. Improved communication skills are an established effect of makerspace use on engineering students (Galaleddine et al., 2017; Choi et al., 2021); it is no different for JEDIs, who not are only users of the Red Room, but also teachers and facilitators for other students. Participants in this study agreed that "the thing about the Red Room is that it teaches people how to talk with people" (Participant 4); but this communication goes beyond instructional conversations when students come to the Red Room as a space to socialize. Socialization is an essential aspect of the Red Room's outreach: as Participant 22 explained, "it's important sometimes to have a social space, but not in the uncontrolled constant taken for granted matter that gives off an unprofessional image of the Red Room". It is then the responsibility of the JEDIs to maintain this balance, a task that necessitates people skills and a professional attitude.

Despite the Red Room being "for students and run by students" (Participant 3), it exhibits some of the boundary spaces identified by Choi et al. (2021) in a university makerspace, particularly, the "novice and expert users" and "students and staff" boundary spaces. According to the authors, the "novice and expert users" boundary space is illustrated by student staff's efforts of empowering students who are using the makerspace for the first time (Choi et al, 2021). Findings in the Red Room show that the dynamic between JEDIs and other students is no different; in fact, they are even more pronounced, as the JEDIs themselves are the only staff operating the Red Room. Though somewhat overlapping, the "students and staff" boundary space focuses more on the relationships between these two groups than on their levels of expertise; according to Choi et al. (2021), both professional and student staff of the makerspace provided students with a welcoming and comfortable environment that encouraged students to use the makerspace and allowed them to a comfortable relationship with the staff themselves. In the Red Room, this inviting environment comes naturally, as JEDIs are enthusiastic about spreading the maker culture among their peers, but also because they are students themselves and share a sense of community with most visitors to the makerspace. Contrarily to professional staff found in other university makerspaces, the task for JEDIs is to reinforce their relative authority over other students within to maintain order in the Red Room.

In short, both boundary spaces are "resources for learning" and for students' development as engineers (Choi et al, 2021, p. 15), not only for frequenters of the makerspace (as in the case in the cited research), but also for the JEDIs who guide and support them. The overlap of being students and members of the makerspace invokes essential communication skills for JEDIs interact with and teach other students, but there is also communication among the JEDIs themselves who "work together to make sure everything was running smoothly" (Participant 20). Managerial responsibilities such as scheduling 3D printing tasks, preparing presentations, and making orders of materials and supplies, all require JEDIs to coordinate and keep each other informed. Thus, members of the makerspace acquire organizational skills such as time and resource management, and teamwork skills in general. University makerspace have been shown to positively impact teamwork skills in students (Galaleldin et al, 2017; Morocz et al, 2014); the present research extends these findings to JEDIs as a particular group of makerspace users that is also directly responsible for its management.

The impact of the JEDI experience on such transferable skills is especially apparent with older participants who have graduated and taken up jobs or joined graduate programs in engineering, who cited improvements in communication and problem-solving skills, as well as “patience and creativity in general” (Participant 21), as valuable lessons they carried away from the Red Room. Additionally, leadership skills were emphasized by participants who worked in the Red Room for more than a year and achieved a high level of seniority; for example, Participant 22 mentioned leading a team of undergraduate students working on a prosthetic hand at his current university as an example of where the leadership skills he developed in the Red Room were beneficial. Such stories align with premise that makerspaces promote students' development into “well-rounded future engineers” (Choi et al.. 2021, p. 17) whose skills exceed technical book-based engineering knowledge and who are well-equipped to be creative problem-solvers to meet challenges of the 21st century (Choi et al.. 2021).

5.3. Self-Efficacy Development in the Red Room Community

The Red Room JEDIs form a community of practice in which all three components are clear. First, the domain of the Red Room CoP is making – the use of available tools and equipment to create artifacts through a process of engineering design. JEDI's assigned job is to help others make, but they also use the Red Room for their own academic projects as well as for self-driven exploration of the available technology. Second, the community itself is not limited to JEDIs alone, but also includes students that JEDIs interact with in the scope of their membership to the makerspace, whether these students are using the Red Room to work on projects, to learn directly from JEDIs, or simply to hang out. Finally, the practice of making in the Red Room is apparent through its continuity over the years; the model of legitimate peripheral participation by which new members learn from each other to eventually become leaders of the next generation, is underpinned by shared knowledge and resources that are continuously evolving.

The existence of a CoP across the Red Room is marked by a friendly, welcoming, and supportive environment that allows both JEDIs and members of the extended community to feel comfortable using the makerspace and to learn from each other. Previous research suggests that students with higher motivation for engineering design are more likely to use a university makerspace (Hilton et al., 2020) and that anxiety and low self-efficacy might deter students from using a university makerspace (Morocz et al. 2016); this is not found to be the case in the Red Room. The encouraging, failure-positive culture itself is sufficient to encourage newcomers to use the Red Room, no matter how limited their design and prototyping skills are. According to Hilton et al. (2020), this culture of support and collaboration in university makerspaces has the potential to increase students' self-efficacy in engineering design through social persuasion and should therefore be leveraged to reduce the barrier to participation. In the Red Room, this social persuasion is constantly in effect and is indeed successful at encouraging students to use the Red Room regardless of their initial self-efficacy levels.

According to Bandura's (1991) theory of self-efficacy, social persuasion is one of the sources of self-efficacy, along with vicarious experiences and performance accomplishments. Vicarious experiences are significant for newcomers when they see that peers from a similar academic background are entrusted with managing the Red Room. As legitimate peripheral participants progress into full participation, social persuasion and vicarious experiences become secondary to performance accomplishments; successful tasks and projects raise the JEDIs' design self-efficacy despite any setbacks encountered along the way, as “occasional failures that are later overcome by determined effort can strengthen self-motivated persistence” (Bandura, 1991).

The combination of constructionist learning and peer supported learning suggests that membership to the Red Room is in fact situated learning, or “learning that takes place in the same context in which it is applied, through participation in the life and activities of the maker community” (Forest et al., 2014). This situated learning is rooted in the sense of responsibility that JEDIs have towards the Red Room and its users. Furthermore, this situatedness further implies that the learning is not only technical, but also drives the previously identified non-technical skills such as leadership, communication and teamwork, organization and management, as well as “problem solving skills [and] this real sense of responsibility which a lot of a lot of recruiters like to see” (Participant 3), all of which are essential for 21st century engineering work and often underdeveloped in undergraduate engineering curricula (Barret, 2015). Carbonell et al. (2019) have shown that makerspace use positively influences students’ affect towards engineering design along with their self-efficacy; in the Red Room, this effect is noticeable, as for some JEDIs, working in the Red Room confirmed their interest in having a career in design, while for others, it provided them with an entirely new perspective they did not previously hold.

CHAPTER 6

CONCLUSION

6.1. The Academic and Professional Impacts of the Red Room

Managing a university makerspace is a unique extracurricular opportunity with a dual impact: academic and professional. Academically, working in the Red Room enriches undergraduate students' learning with hands-on applications that complement and enhance the scientific knowledge and technical know-how they acquire through coursework. Professionally, it teaches JEDIs responsibility and professionalism by entrusting them with a job where their work is consequential not only to themselves, like in course projects for example, but also to others, namely users of the Red Room that they support and assist.

JEDIs' activities in the Red Room can be summarized in three words that represent the pillars of all makerspaces: make, learn, and share.

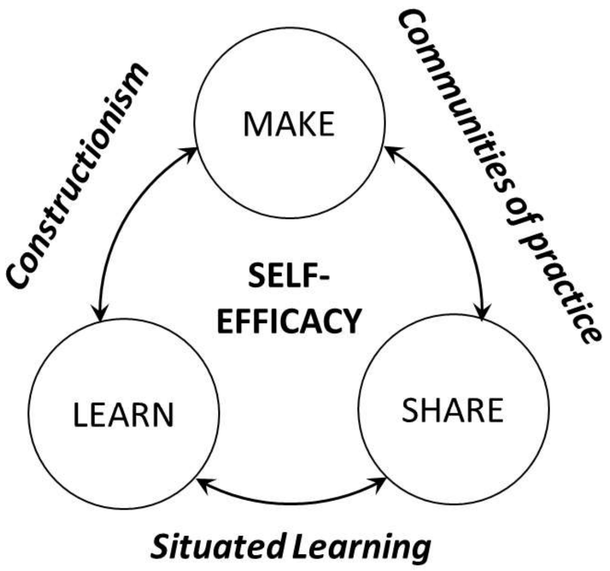

Figure 3 Theories of the Red Room's impact on JEDIs' self-efficacy

As shown in Figure 3, each pair of these pillars is connected by a theory of learning that, in practice, informs the JEDI's perceptions of their own skills, i.e., their self-efficacy beliefs. Making is connected to learning through constructionism, which reflects the hands-on, experimental nature of working with the physical tools and equipment available in the makerspace – whether they are experimenting and tinkering for the sake of learning, working on their own projects, or helping other students build their own ideas. The practical engineering skills at play here are prototyping and design, as well as creativity and problem solving.

On the other side, making and sharing are interlinked through the community of practice formed by the JEDIs and other frequenters of the Red Room, a friendly and welcoming community that promotes exploration and encourages positive failure in all its members. This culture is supported by the JEDIs' management of the social aspect of the Red Room; it also ensures the continuity and the growth of the community through the years.

Sharing of ideas, inventions, stories, and lessons strengthens the community by making the makerspace more attractive and accessible, but also by contributing to the learning of others, as well as oneself. Thus, learning is situated in the JEDIs' community of practice, particularly, in their interactions among each other and their coordination in operating and managing the Red Room. In addition to the engineering-specific skills previously mentioned, membership to the makerspace improves JEDIs self-efficacy in other more transferable skills, such as communication, collaboration, time and resource management, and leadership.

All in all, working in the Red Room not only improves not only JEDI's technical and personal skills, but also their outlook on engineering as well as their preparedness for employment or other leadership roles in the future. This was demonstrated from participants' own perceptions, as well as concrete examples of where and how they benefitted from this experience.

6.2. Implications for Theory and Practice

In his work on the theory of communities of practice, Wenger (2009) suggests that this theory can be transformative if leveraged in formal education, leaving open the following question: "how to organize educational experiences that ground school learning in practice through participation in communities around subject matters?" (Wenger, 2009, p. 4). The findings of this study provide one particular answer to this question, that proves the potential of immersing students in a CoP that is internal to academic institutions: a university makerspace. While university makerspaces have been shown to encompass communities of practice in past studies, such as Forest et al. (2014) and Galaleddine and Anis (2017), these studies targeted the population of makerspaces users as a whole, without making a distinction for student staff in particular.

The current work implies that giving students relative authority in leading a makerspace provides them with more ownership of their learning. While the impact of the Red Room on JEDIs' self-efficacy coincides largely with the proven impact of other university makerspaces on their students, some benefits are unique to the JEDIs, who have to achieve a comprehensive level of technical mastery in the Red Room to be able to adequately fulfill the role of the makerspace. Thus, the difference lies in JEDIs' accountability in the makerspace, and their autonomy in it.

In practice, the outcomes of this study invite universities with makerspace that are, at least in part, student-staffed, to pay a closer attention to the significance of this opportunity to these student staff themselves, and to evaluate the system by which this community sustains itself through peer learning, collaboration, and belonging.

6.2. Limitations of the Study

This study has limitations pertaining to both the data collection methods and the subjectivity of the author. Regarding data collection, one issue is that not all the JEDIs who have worked in the Red Room since its inception have been included in the study; however, the 22 students and alumni who did participate cover all the semesters from Spring 2018-29 until the present day (Spring 2022-23), and therefore provided a comprehensive view the Red Room community's evolution over the years. The hardest subgroup to reach were alumni who graduated in 2020 and 2021, and therefore few JEDIs from that period were included in the study; as such, the conclusions on the long-term impacts of membership to the Red Room, especially on employment, are limited, because most of the alumni respondents pursued further studies upon graduation from AUB. Additionally, this study was qualitative, and due to the nature of the research questions, no control group was considered. Interviewing non-JEDI users of the Red Room would not offer a genuine comparison, as a different discussion guide would be needed, thus leading to potential interpretation errors when the two groups are compared.

Other limitations of this study arise from the status of the author this thesis and her exposure to the Red Room and some of the current JEDIs before the start of the study, placing her as a participant-observer. In addition, the motivation for this study stems in part from anecdotal evidence of certain themes presented in this study, especially the community aspect, thus giving rise to possible biases both in the design of the research methods and in their analysis; the study is somewhat focused on positive outcomes and impacts of membership to the Red Room. While a few negative remarks were made by the participants and reported in the results, such themes were not sufficiently explored at the stage of data collection to allow for a nuanced analysis to be conducted. In order to minimize such biases, the coding of the data was predominantly semantic, meaning that verbatim quotes were taken at face value and sorted into themes according to spoken keywords and phrases and other explicit meanings. Additionally, the results underwent member checking with two different participants, and the analysis was reviewed by a member of the thesis committee from outside MSFEA who is unaffiliated with the Red Room and thus objectively external to the study and its participants.

6.3. Recommendations and Future Work

At the time of writing this thesis, two articles are also being prepared for publication using the data collected for this project. Beyond the topics discussed herein, the focus group discussions and interviews with JEDIs opened up multiple areas for recommendations for the Red Room. Future studies in the Red Room should focus on the broader impact of the makerspace locally at MSFEA, where themes such as academic performance, entrepreneurship and innovation, or women in engineering could be explored. And in order to amplify such impacts, the Red Room should be included more formally in engineering curricula. At the present, few courses are well-known to make use of the makerspace, such as engineering FYPs, mechanical engineering design courses, and architecture and graphic design studios. The Red Room is also incorporated in the mandatory first-semester course for all MSFEA students since Fall 2021-2022. Structures should also be put in place to encourage creativity outside classwork, especially for students interested in product design and entrepreneurship. Finally, monitoring activity in the Red Room and future research works would both benefit from a data collection system embedded into the operation of the makerspace, as well as large-scale longitudinal data collection among students in the faculty.

APPENDIX

AMERICAN UNIVERSITY OF BEIRUT

Institutional Review Board
لجنة الأخلاقيات

APPROVAL OF RESEARCH

April 4, 2023

Dr. Mohammad S. Harb
American University of Beirut
01-350000 Ext. 3423
mh243@aub.edu.lb

Dear Dr. Harb

On April 4, 2023, the IRB reviewed the following protocol:

Type of Review:	Initial, Exempt
Project Title:	Impact of Student-Run Maker Space on Engineering Student Community
Investigator:	Mohammad S. Harb
IRB ID:	SBS-2022-0251
Funding Agency:	None
Documents reviewed:	Received April 4, 2023: Amended IRB Application Amended Consent form- Current students Amended Consent form- Alumni Proposal, Invitation Script, Tools.

The IRB reviewed and approved your study from **April 4, 2023, to April 3, 2024,** inclusive.

Please find attached the IRB approved documents:

- IRB Application (received April 4, 2023),
- Consent form- Current students (received April 4, 2023),
- Consent form- Alumni (received April 4, 2023),
- Proposal (received April 4, 2023),
- Invitation Script (received April 4, 2023),
- Tools (received April 4, 2023).

Only these IRB approved consent forms and documents can be used for this research study.

Thank you.

The American University of Beirut and its Institutional Review Board, under the Institution's Federal Wide Assurance with OHRP, comply with the Department of Health and Human Services (DHHS) Code of Federal Regulations for the Protection of Human Subjects ("The Common Rule") 45CFR46, subparts A, B,

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Template Revision: April 4, 2023

C, and D, with 21CFR56; and operate in a manner consistent with the Belmont report, FDA guidance, Good Clinical Practices under the ICH guidelines, and applicable national/local regulations.

Sincerely,

Lina El-Onsi Daouk, MSc, CIM
IRB Administrator, Social & Behavioral Sciences

Cc:

Lara Nasreddine, PhD, LD
Professor of Human Nutrition,
Co-Chair, Institutional Review Board, Social & Behavioral Sciences

Rami Mahfouz, MD, MPH
Professor of Pathology and Laboratory Medicine
Chair Institutional Review Board

Ali K. Abu-Alfa, MD, FASN, FAHA
Professor of Medicine
Director, Human Research Protection Program
Director for Research Affairs (AUBMC)

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