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# The Role of the Maker Movement in Engineering Education: Student Views on Key Issues of Makerspace Environment*

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Makerspaces are becoming increasingly important as a new approach to enable individuals to experience new technology applications and increase creativity in universities and other educational institutions. Such learning implementations offer many advantages like learning-by-doing and applying theoretical knowledge in engineering education into practical skills in an interdisciplinary environment. Despite the advantages, makerspaces still lack integration into the curriculum of engineering schools. For a quality engineering education, establishing maker workshops where students can experiment, design and practice as well as feel encouraged to open-ended development projects are required in addition to standard theoretical and laboratory applications. In this study, we present student views on the learning opportunities, challenges and contributions of the makerspace environment. In this context, IHA Makerspace established within the Faculty of Technology, Marmara University, Turkey, aims to provide high-level engineering experience to students by designing and prototyping effectively in a multidisciplinary development environment.

**Keywords:** Makerspace; learning environment; engineering education; student views

## 1. Introduction

The core of engineering education is to train qualified engineers who are well-equipped and has strong critical thinking skills. Together with innovation and emerging technologies, educating practical engineers who can integrate science and technology plays an important role in fostering engineering excellence. Similarly, there are topics such as designing, executing, analysing and interpreting data, adapting to changing conditions, ability to work in an interdisciplinary group in the Engineering Criteria prepared by the Accreditation Board for Engineering and Technology (ABET) [1]. There are also studies showing that engineering graduates need the essential skills of problem-solving, communication, data analysis, and teamwork in their professional lives [2].

Constructivist learning, which provides students with the ability to control their own learning process and the permanence of learning in teaching activities, stands out more than other learning theories. In this theory of learning, the different aspects and dimensions of knowledge should be emphasised. It has been reported that the information is not passively transmitted to the mind of the individual; inversely, it is effectively structured in the mind [3–5].

In this respect, makerspaces are a growing movement that will enable students to become creative, innovative, independent and technologically literate through the applied-constructivist education [6]. This makes makerspaces not an "alternative" way to learn, but a modern learning tool that needs to be given more attention. Despite the advantages, it is not entirely clear what factors, especially based on student experiences, to take into account in designing makerspaces. The aim of this study is to introduce a makerspace that is established in a way to make a high-level contribution to engineering education and present student views of this learning environment.

## 2. Makerspace in Engineering

Makerspaces are community-based engineering and craft workshops that emerged in Europe and expanded in the United States in the late 2000s. In these spaces, it is possible to make applications that focus on rapid prototyping (e.g., 3D printers and laser cutters) or more conventional manufacturing (e.g., lathes, mills and hand tools). Activities include workshops covering various topics (e.g., circuit design, sewing and beekeeping) and hackathons where members compete to achieve a goal in a limited time. Makerspaces operate independently, but interact with others through visits, online meet-

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ings and worldwide events such as Maker Faire [7, 8].

In engineering education, employers and universities have long recognised the need for practical experience in addition to mathematics and science. For this reason, laboratory studies or project-based courses are frequently offered to incorporate hands-on experience in engineering education. However, limited access to the laboratory and students' lack of preparation and readiness may prevent the practice sessions from fulfilling their real purpose. Additional functional difficulties such as complying with the course curriculum and implementing them in crowded groups may be encountered in project-based courses as well. Consequently, some universities have internship opportunities where students work at a company for a semester [7]. In a typical internship, students work on a predefined task and do not have much control over the nature of the work [9]. At the end of the internship, employers evaluate students through various criteria such as the ability to identify and solve engineering problems, trying new approaches to complete tasks and using new methods with minimum supervision. Although these features are as important as technical engineering skills, it is difficult to teach and evaluate in the classroom [7].

The maker movement, which is a combination of the technology and culture of "Do-It-Yourself" and "Do-It-With-Others", provides an environment where students can develop these skills. It encourages the sharing of experiences and knowledge with others. This makes the movement even more effective. The individual involved in the makerspace environment becomes one who plans, designs and manufactures actively using his/her own thinking, perspective and handicraft [10, 11].

An increasing number of higher education institutions have already created these spaces for students. Particularly US universities such as Princeton University, Stanford University and Harvard University have makerspaces that help students realise their full potential [12]. The use of these environments at university level started in MIT in 2001 [13]. It has been reported that, since 2006, the number of makerspaces has increased 14 times worldwide [14]. According to the US News and World Report's Best Undergraduate Engineering Programmes Rankings in 2014, 40 out of the 127 top undergraduate institutions had makerspaces [15].

Makerspaces have the capacity to make a drastic change in the existing education system by providing an extracurricular tool for students to participate in more hands-on projects and to develop a variety of professional skills. These spaces are free environments that go beyond traditional undergraduate workshops, especially for engineering students where they can interact with each other, share knowledge, design and prototype [16].

## 3. Overview and Design

It is a vital necessity to create working spaces where students with similar interests can work in harmony with one another. In an undergraduate-level engineering education setting, laboratories are often the places where the knowledge learned in theoretical courses is put into practice. In laboratories, students generally follow the procedural steps to implement a given application on an experiment kit within a certain time frame. Makerspaces offer a more collegial environment in which students can explore their creativity [16]. In these areas, students can create their own designs using development cards, 3D printers, cutting and soldering tools. Makerspaces enable students to enhance their curiosity, knowledge and skills in line with the willingness to take initiative by eliminating the dependence on an experiment kit and time constraints. For this reason, Marmara University Unmanned Aerial Vehicle Student Club (IHA Marmara; IHA means UAV in English) was established as a makerspace workshop in March 2016. In addition to providing the most needed engineering skills, maker areas have the potential to create a quality environment for students to develop their design self-efficacy, innovation ability and creativity [16, 17].

When establishing IHA Makerspace, the most frequently used equipment such as screwdriver sets, measuring instruments (oscilloscope, multi-meter and compass), power supplies and consumables were placed on shelves and drawer cabinets so that students could use the equipment safely and comfortably. In addition to these, Raspberry Pi mini-computers, Pixhawk control cards, Arduino based micro-controllers and computers are available in the workshop. These hardware were provided by the Faculty of Technology, private companies, and the Scientific and Technological Research Council of Turkey (TUBITAK).

An area of approximately 60 square meters has been allocated for the workshop in order to provide a comfortable working environment. Special air ventilation system was established in order to effectively remove polluted air (solder fumes and any kind of dust) and supply fresh air. Some tools like 2D laser engraver, 3D CNC milling engraver (PCB prototyping) and Hot-wire foam cutter, which are necessary during manufacturing process, were developed by students. Students from different departments such as Mechatronics Engineering, Electrical-Electronics Engineering and Computer Engineering have come together with a tendency towards interdisciplinary team work. Different types of UAVs are designed to perform different tasks at the IHA Makerspace. Students are able to apply the theoretical concepts they studied in the courses such as image processing, communication systems, control systems, computer programming and computer-aided drawing into practice in this learning space.

At the makerspace, students can work on their own individual projects as well as prepare in teams for competitions such as TUBITAK International UAV Competitions, which is organised as part of the Aerospace and Technology Festival (Teknofest).[1] The makerspace supervisor is responsible for planning the activities in this environment, especially in national and international competitions, tournaments and events. Weekly and monthly meetings are held to monitor and document the status of teams, their duties and the tasks within the team. The first author of this study is a full-time faculty member as well as the supervisor of IHA Makerspace.

## 4. Methods

### *4.1 Research Design*

In this study, we follow phenomenological research methods to determine the purview of students from their individual experiences through a holistic approach. We use face-to-face semi-structured individual meeting (interview) method as a data collection technique. The most important benefit of the semi-structured interview is that the interview is conducted in accordance with the pre-set interview protocol and thus provides more systematic understanding. Moreover, we chose qualitative interviewing as a methodology because it provides greater depth and a better understanding of the participants' experiences [18].

### *4.2 Data Collection*

The study sample consisted of nine students, seven undergraduate and two graduate students, participating in the IHA Makerspace activities between 2017–2018 spring and 2018–2019 fall semesters. Eight of the students are male and one is female. Each member of the study sample was approached individually by one of the instructors to conduct a face-to-face interview via appointment. Participants were informed of the subject of the interview in advance. Interviews typically lasted around 40 minutes. All the interviews were conducted in Turkish. Each interview was voice recorded and later transcribed for further analysis. For anonymity, each participant was assigned a label such as S1, S2, etc. During the interview, the participants were encouraged to speak openly about their experiences and positive and negative aspects of their involvement in makerspace.

A semi-structured interview form was used as a data collection tool in this study. Based on literature review, the form was prepared as a result of preliminary interviews with the makerspace consultant as well as two students using the makerspace. In the light of the expert opinions obtained from one academic and one field expert, the interview form was examined in terms of the clarity, suitability and adequacy of the questions.

### *4.3 Data Analysis*

In the evaluation of the interview, we apply content analysis and frequency to understand and determine the nature of the words and sentences in the answers. This approach, that is the conceptualization of the collected data according to the theme, allows the generation of categories (classification) from the data [19]. The open-ended interview questions created for this purpose are as follows:

- How does this makerspace play a role in deciding your potential career path?
- Have there been any technical issues or experiences regarding engineering design?
- What are the benefits of working collaboratively at this space?

From the analysis of the interviews, three main themes were identified: Benefit, Difficulty and Success criteria. Data were evaluated and coded separately by two researchers. The consistency between the codes was calculated as 0.8. Consistency higher than 0.7 shows that the analysis provides internal reliability [20]. While reporting the results of the research, frequency values of the themes/subthemes as well as direct interview quotes were presented.

## 5. Findings

In this section, we included direct interview citations as well as the theme reports of the research results. Three main themes were determined within the framework of the interview questions. Table 1 highlights these themes and their sub-themes which are ranked by order of frequency of students' response.

### *5.1 Benefit*

Students strongly specify that the makerspace provides the opportunity to work in teams and a comfortable working environment in the ***Benefit*** theme. This is followed, respectively, by easy access to laboratory equipment, finding solutions

[1] Shortly after the creation of the IHA Makerspace, the team from Marmara University received honourable mention and a monetary award at the 2018 Teknofest Istanbul competition.

**Table 1.** Thematic categories and their sub-themes derived from interviews

| Theme category | Sub-themes | Freq. of response |
|---|---|---|
| Benefit | Working in a team | 7 |
| | Comfortable working environment | 7 |
| | Easy access to equipment | 6 |
| | Finding solutions to technical problems | 6 |
| | Working interdisciplinary | 5 |
| | Creative thinking | 5 |
| | Self-confidence | 4 |
| | Peer learning, brainstorming | 4 |
| | Technical reporting | 3 |
| | Activating the sense of curiosity | 3 |
| | Developing responsibility | 3 |
| | Exchanging ideas | 2 |
| | Leadership experience | 2 |
| Difficulty | Documentation problems | 7 |
| | Problems due to lack of technical knowledge | 5 |
| | Financial problems | 4 |
| | Problems related to planning | 4 |
| | Lack of staff | 3 |
| | Working hours | 3 |
| Success criteria | Implementation and test success | 5 |
| | Learning new things | 4 |
| | Achievements from competitions | 4 |
| | Knowledge transfer | 3 |
| | Solving a technical problem | 3 |

to technical problems, developing interdisciplinary working skills, developing self-confidence, peer learning, developing technical reporting skills, stimulating curiosity, developing task responsibilities and brainstorming with peers. Some of the student views on the sub-themes are as follows:

### *5.1.1 Working in a Team*

Seven students commented on the first sub-theme of working in a team. They pointed out that although there are many practical lessons in their curriculum, it is not possible to work in teams. They also stated that makerspace allowed them to learn through group work.

> "I learned to work efficiently by sharing the workload with my teammates." (S1) "This environment has allowed me to find committed and friendly people to work with." (S6)

### *5.1.2 Comfortable Working Environment*

As regards this sub-theme, students found the makerspace environment peaceful, relaxing and sufficient (in terms of office supplies, tools and equipment).

> "I am able to produce creative ideas by thinking freely. The boundaries of other laboratory courses in the university are very specific and therefore not suitable for creative thinking." (S3) "I do not even have the chance to make mistakes in other laboratory classes, but I am free in this space and can learn from my mistakes." (S4)

### *5.1.3 Easy Access to Equipment*

Students reported that they could use devices that were not available in other laboratories. In addition, they were not subject to rules such as inspection, access control and authorization.

> "Many tools and materials are available at the IHA Makerspace, so it is possible to proceed quickly." (S5)

### *5.1.4 Finding Solutions to Technical Problems*

Students were positive about the experience of dealing with technical problems that occur in the makerspace. They felt involved in every stage of an engineering process such as analysis, design, implementation and testing.

> "We encountered the Ground Effect problem in our UAV and made a new design from scratch to cope with this problem. It was a very interesting experience for

me." (S2) "The task in one of the competitions was the autonomous landing of a UAV on a certain platform. We tried to do this using image processing techniques, and this taught me a lot." (S5)

### *5.1.5 Working Interdisciplinary*

We observed that five students expressed their opinions about this sub-theme. They found it exciting that members studying in different engineering departments such as computer, mechatronics and electrical-electronics work together on the same product.

"We required a mechanical design to make a lighter UAV. With the help of the Department of Textile Engineering, we built a durable and lightweight body using a carbon fibre material." (S2)

### *5.1.6 Creative Thinking*

With reference to this sub-theme, students stated that this environment encourages lateral thinking skills and its application to practical engineering problems.

"For UAV competitions, we made a very different design by using a net to carry objects. It was not entirely successful because of the wind but it got us an honourable mention prize." (S3)

### *5.1.7 Self-confidence*

In this sub-theme, students expressed an increase in self-confidence when completing a task, helping a friend and participating in a competition as a team.

"I feel more confident in my field now and want to work in the field of aviation and defence industry." (S8)

### *5.1.8 Peer Learning, Brainstorming*

Students stated that they learned a lot from each other and had the opportunity to share their ideas through brainstorming in teams. They believed that this environment contributed to their desire for learning.

"When a problem arises in design, we first evaluate the situation among our friends and learn a lot from the clashing ideas." (S9)

### *5.1.9 Technical Reporting*

According to the students, the analysis, design and implementation reports required for UAV competitions gave them a good engineering experience.

"Thanks to the reports we prepared while participating in competitions, we learned the documentation process in accordance with engineering regulations and standards." (S6)

### *5.1.10 Activating a Sense of Curiosity*

Three students commented on this sub-theme. They reported that they had the opportunity to use a measuring instrument they were curious about and to experiment with the results of different designs.

"We can easily experiment with our equipment on any subject we have in mind." (S5)

### *5.1.11 Developing Responsibility*

Students stated that they took responsibility for both the projects developed in the makerspace, as well as the cleaning and organization of this area.

"In this environment, all responsibility belongs to the students who use it. We are dealing with issues such as collecting and cleaning the clutter in this environment as well, and our sense of responsibility has increased." (S1)

### *5.1.12 Leadership Experience*

Concerning this sub-theme, students expressed that, for different tasks, they elected group leaders who took more initiative and responsibility in a particular division.

"Since I am in charge of mechanical design, I can lead issues relating to this subject. For example, if there is a problem in mechanical design due to electronic boards, I can ask my friends to fix it." (S2)

## *5.2 Difficulty*

Students stated that documentation of the activities and procedures is the biggest ***Difficulty***. This is followed by the issues arising from the lack of knowledge, which can be named as technical difficulty. According to the interview results, students prefer doing research online; from forum sites, YouTube videos and open source platforms such as GitHub. There are also financial difficulties such as lack of equipment, failure to deliver the materials in time and general problems such as planning team tasks, lack of personnel and workshop access hours. Student views are as follows:

### *5.2.1 Documentation Problems*

Seven students gave opinions on this sub-theme. They reported that because they work on reporting at the end of their tasks, there are problems in the event of joining and leaving the teams.

"If we could create technical documentation of our UAV designs, it would be very useful for the students who later joined our teams." (S4) "I am leaving the documentation part to the end of the project; it would be better if it was done throughout the project." (S7)

### *5.2.2 Problems due to Lack of Technical Knowledge*

Regarding this sub-theme, students stated that curriculum activities were not sufficient for the task of creating a UAV. They reported a lack of information when deciding on the UAV design material, on how to evaluate mechanical and electronic design together, and on how to run image processing applications.

"I had difficulties installing image processing software on a drone. It was difficult to stay on schedule." (S5)

#### 5.2.3 Financial Problems

In this sub-theme, students stated that, because of limited equipment at the makerspace, UAVs did not have all the features they wanted. They also mentioned that the late purchase of the equipment delayed the project plan.

"Replenishing the material supply can be a real problem due to the lack of funding." (S1) "I can make better designs if I have a CNC machine. I have to think in a way that is simple and can be done with our tools." (S6) "When there is a lack of material or a need for design, the planned work process can be extended." (S8) "It is sometimes difficult to find the material I am looking for because our makerspace is brand-new and does not have enough cabinets." (S9)

#### 5.2.4 Problems Related to Planning

Students pointed out that, since they could not work according to the time plan prepared at the beginning of the semester, the tasks were intensified later, especially in the last weeks before the deadlines for competitions.

"We share the tasks in the UAV races we prepare, but generally have a very tight schedule and most of the tasks are completed at the last minute." (S1) "It would be better if we could increase the supervision and feel a little more responsible for the assigned tasks." (S5) "There are students who join in teams at the beginning of the semester, but some of those do not attend the makerspace afterwards." (S7)

#### 5.2.5 Lack of Staff

Students stated that the presence of more faculty members from different disciplines would be beneficial in encouraging and supporting students as well as monitoring activities.

"It would be better if there were more academic advisors in this space." (S2) "It may be useful to have someone in charge of monitoring the tasks. This way, we would feel a little more obligated." (S4) "It would be nice to have students from many various departments that we could work with." (S9)

#### 5.2.6 Working Hours

Students stated that, when the makerspace was first established, they could not stay on public holidays or at night, which is important because the completion of their tasks require long hours. However, this was resolved by obtaining the necessary permission.

"It is important to work at night when classes are over. We can stay at night with the special permission we have received. We did not have this when the makerspace was first established." (S2) "We wanted to stay in the makerspace at night, on the weekend and on public holidays. There were problems because we did not have permission. Permissions were given this year and now we can use it freely." (S4)

### 5.3 Success Criteria

Based on student views, the main ***Success criteria*** is to be able to participate in competitions. Any awards or prizes would provide additional motivation. Students also describe themselves as accomplished when the testing stage of the end product performed successfully. Furthermore, realising to learn something new, transferring their knowledge and experience to a friend and solving a technical issue would be seen as success as well. Selected student views on the success theme are as follows:

#### 5.3.1 Implementation and Test Success

In this sub-theme, students indicated that they felt successful, especially when they saw a UAV performing well.

"Aviation is an area that does not allow mistakes; I feel successful if the flight is successful. Our success expectation is simple but difficult to reach." (S2) "Building a drone can take a really long time. It is a huge success for me to see a fully functional product." (S8)

#### 5.3.2 Learning New Things

Regarding this sub-theme, students considered all new knowledge learned in the makerspace as an achievement.

"Learning new things and updating what I already know is my success criteria." (S6) "Everything I have learned in this environment is a success for me." (S9)

#### 5.3.3 Achievements from Competitions

Students attributed value to the attainment of results (awards, positions, prizes, etc.) in competitions.

"It makes me feel successful that our brand-new UAV designs are participating in international competitions." (S4) "It is a success for me to qualify to participate in the competitions and to observe other competitors." (S5)

#### 5.3.4 Knowledge Transfer

In this sub-theme, students stated that they felt successful when exchanging information with their peers, helping them on tasks, and contributing to their success.

"It makes me feel very happy and successful to share what I know with another friend." (S3) "I feel like I have succeeded when a friend I helped completes a task." (S7)

#### 5.3.5 Solving a Technical Problem

Concerning this sub-theme, students defined success as solving a technical problem in the completion of a task.

> "We benefit from this makerspace by building a fully autonomous drone. I will feel successful when it is complete." (S3) "I feel successful when I focus on the technical aspects of drones to solve important issues such as extending the flight time or meeting a certain level of performance." (S8)

## 6. Implications

There are several implications of our findings that arise from the use of makerspace in engineering education:

- According to the students' views, as stated under the benefit theme, makerspaces allow students to discover, discuss and share new ideas in an active learning environment. Students transcend the limits of standard education and become aware of their social and academic potential. Creation and innovation skills can have a broad impact on students' lifelong learning and ultimately on education and society. This is consistent with Van Holm's finding that maker environments stimulate creative ideas [21] and Moilanen's finding that makerspace is the place where ideas and machines are shared [22]. Developing smart and effective solutions in technology is only possible with engineers that have creative thinking and innovation skills. In today's engineering education, however, there is a gap between creativity, innovation and engineering. Makerspaces offer important opportunities to overcome these disruptions [23].
- The relaxed and flexible learning environment of makerspace enables students to learn from peers (where they can accompany a friend as a teacher when necessary). Peer learning makes a significant contribution to engineering students' critical thinking, problem-solving skills, and self-learning skills [24]. Co-creation and learning by teaching have the potential to make a significant contribution to students' motivation and future professional experience. Moreover, peer learning helps engineering students to develop communication and teamwork skills, which are essential for a successful professional life [25].
- A sense of curiosity is key to success in engineering education [26]. We see that a hunger for knowledge, which is the foundation for the development of new concepts and theories, is gained through these environments.
- The new learning environment of makerspace brings a new teacher model. Unlike the classroom environment, in which the teacher directs students to learn through memorization and recitation techniques, the role of the teacher in this environment is guiding, leading, inspiring, providing support and communicating via multiple channels. This fits the teaching definition of Kurti et al. [27] as well.
- Despite their many advantages, these environments are only available to a limited number of students. Ensuring the security of these environments, recruiting personnel and providing funds and resources for their expenses are important problems. Determining the financial policies that will enable these environments to survive is a need that should be addressed.

Makerspaces provide a valuable contribution in terms of offering students the experience of solving many problems that they have not encountered before, as part of a team. The outcome of the proposed work is also in parallel with the study of Saorín et al. [28] which reported that makerspace areas contribute to the creative capabilities and the study by Forest et al. [16], which showed that makerspaces contribute to engineering skills as well as academic and professional collaboration. Paganelli et al. [29] pointed out that makerspace supervisors concluded that it contributed to the themes of learning, collaboration, confidence and creativity. Wilczynski and Adrezin [30] stated that makerspaces in higher education make an important contribution to the development of students' design and cooperative problem-solving skills. Similarly, in our study, we observed that the makerspace played an important role in the development of students' design skills and teamwork. In the research conducted by Harnett et al. [7], it was found that makerspaces encourage big ideas, help develop self-confidence and provide collaborative learning environments. These observations coincide with the findings obtained in this study as well.

## 7. Conclusions

The interview results showed that the established makerspace is accepted as an interdisciplinary work environment by students. We also observed that the students feel particularly successful when they complete the implementation and test procedures which are the fundamental steps of engineering. In addition, the students reported that the makerspace environment has a positive effect on the development of creative thinking skills and professional self-confidence.

Although students have problems related to documentation and lack of technical knowledge or skills, they develop vital problem-solving skills when tackling these challenges. This can be considered as a learning opportunity to realize the lack of knowledge or skills and receive support from the advisor or friends.

It is one of the essential requirements for engineering education to train engineers with problem-solving, innovative thinking and teamwork skills. We confirmed that makerspaces support meeting this requirement.

The current members of the IHA Makerspace are students with a certain level of knowledge about technical procedures and instruments. As future work, we aim to open this space to people who are interested in new technologies but have no prior experience. This will allow us to examine the impact of the makerspace environment on their development from beginning to end.

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