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Makerspace: Innovation in Mechanical Engineering Education

Makerspace: Makina Mühendisliği Eğitiminde İnovasyon

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ABSTRACT

The complexity of industrial developments requires engineering students to have hands on experience as well as theoretical engineering knowledge. There is a need for a change of classical engineering curriculums. Makerspaces can be a crucial part of this change. They are introduced as physical locations where engineering student's curiosity is fed and solutions to problems are found through teamwork. Their use in higher education can also provide an opportunity for students to engage in experiential learning. They can develop a large range of soft skills that traditional undergraduate curriculum is unable to provide, such as planning, teamwork, critical thinking and communication. There are still limited studies about the full effect and impact of these spaces in teaching and learning, from the pedagogical perspective. The aim of this study is to determine students' experiences with such spaces and examine how makerspaces are contributing to their learning. The results of this study showed that students want more than theoretical knowledge from their engineering education. They want to be able to gain hands on experience while they are learning theory. While designing a makerspace for that purpose, the sustainability and the functioning of these spaces should be taken into consideration. The findings of this study can provide guidance for the institutions that are planning to build a makerspace in their campuses.

Keywords: Makerspace, Higher education, Engineering education, Innovation, Hands-on learning

ÖZ

Gelişen endüstrinin karmaşıklığı, mühendislik öğrencilerinin teorik mühendislik bilgilerinin yanı sıra deneyime de sahip olmalarını gerektirir. Klasik mühendislik müfredatlarının değiştirilmesine ihtiyaç vardır. Makerspace bu değişikliğin önemli bir parçası olabilir. Bu alanlar, mühendislik öğrencilerinin merakının beslendiği ve ekip çalışması yoluyla sorunlara çözümlerin bulunduğu fiziksel yerler olarak tanımlanmaktadır. Yükseköğretimde kullanımları, öğrencilerin deneyimsel öğrenmeye katılımları için bir fırsat sağlamaktadır. Geleneksel lisans müfredatının veremediği planlama, ekip çalışması, eleştirel düşünme ve iletişim gibi beceriler bu şekilde geliştirebilirler. Pedagojik perspektiften bakıldığında ise, bu alanların öğretim ve öğrenmedeki önemi ve etkileri hakkında hâlen sınırlı sayıda çalışma bulunmaktadır. Bu çalışmanın amacı öğrencilerin bu tür alanlardaki deneyimlerini belirlemek ve bu alanların öğrenmelerine nasıl katkıda bulunduğunu incelemektir. Sonuçlar, öğrencilerin mühendislik eğitimlerinden teorik bilgilerden fazlasını istediğini göstermiştir. Teori öğrenirken aynı zamanda tecrübe de kazanmak istemektedirler. Bu amaçla bir makerspace tasarlanırken, bu alanların sürdürülebilirliği ve işleyişi de dikkate alınmalıdır. Bu çalışmanın bulguları, kampüslerinde bir makerspace kurmayı planlayan kurumlara rehberlik edebilir.

Anahtar Sözcükler: Makerspace, Yükseköğretim, Mühendislik eğitimi, İnovasyon, Yaparak öğrenme

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INTRODUCTION

The concept of a makerspace is not a new concept, but it is a newly derived term and is based on the "maker" movement (Hatch, 2014). However, the use of these spaces in engineering education is new and has been creating a new era in education. In education, a makerspace is defined as a space where students and professionals come together to think, explore, and create something by using tools and materials (Stager, 2014; Burke, 2015; Roffey, Sverko & Therien, 2016). It provides students an experiential learning environment through tools and activities such as design, prototyping, 3D printing, manufacturing and/or programming. The space provides students with the opportunity to develop and demonstrate 21st century skills such as creativity, innovation, independence, collaboration, communication, teamwork, critical thinking and problem-solving (Dede, 2009; Barak, 2013; Wong & Partridge, 2016; Lanci et al., 2018) that are essential to the profession of engineering (Saorin et al., 2017 & Lanci et al., 2018). Constructivist education has been using makerspaces as a vehicle to develop students' creativity (Hilton et al., 2020; Saorin et al., 2017), self-efficiency (Hilton et al., 2020) and self-learning skills (Stager, 2014) that can be beneficial for students when they need to reskill themselves for the labor market.

Statement of the Problem

The literature review shows that mechanical engineering education is transforming and the main aspects of these changes can be categorized as;

1) Engineering problems are becoming more interdisciplinary and engineering students need to learn the basic concepts of other fields. Thus, students can work more efficiently and create projects together with students from other engineering disciplines (Myers, 2015; Kececi, 2017; Saorin et al., 2017).

2) Students need a learning environment that sparks their creativity and reasons to apply what they have learned (Barak, 2013; Beanland & Hadgraft, 2014; Saorin et al., 2017).

3) Instead of a classical and disciplinary oriented engineering curriculum, students also need an interdisciplinary and constructivist-based curriculum that will help them to develop and demonstrate so-called 21st century skills (Shay, 2012; Lanci et al., 2018; Hilton et al., 2020).

4) The global employment crisis and future work emphasize the urgency of upskilling and reskilling to prepare students for the 21st century labor market (Lanci et al., 2018; Hilton et al., 2020; Bengu et al. 2020).

When Shay (2012) mentioned "the curriculum of the future" in his study, he affirms the need for disciplines to transcend theory. In this way, graduates will be able to "shift from conceptual learning to learning through inquiry" (Sheffield et al., 2017) where they will gain critical competence and ability to produce solutions. Innovative institutions aiming to train people with skills for today's multi-dimensional career settings should incorporate constructivism, a learning approach, into their curricula. The main purpose of constructivism is to create new information while interacting with the physical objects that the learners create (Roffey et al., 2015). This new curriculum calls for a space where students and professionals come together to think, explore, and create something by using the tools and materials provided in their fields. This mechanism is defined as makerspace (Stager, 2014; Burke, 2015; Roffey et al., 2016) and it originates from the "maker" movement (Hatch, 2014).

In 2017, Blackley et al. conducted a case study on a makerspace after a call for action to strengthen STEM in Australia. In their study, they used a makerspace as a pedagogical tool for integrated STEM education and investigated the impact of the place on students' learning. They found out that as female students participate in projects, these spaces provide opportunities for them to engage in a creative way and also inspire all of the participants to plan, research, design, build and apply their theoretical knowledge to hands-on activities (Sheffield et al., 2017).

In order to make engineering education interdisciplinary and practical, approximately 44 universities in the US, more than 5 universities in Europe and 15 universities in Australia have formed makerspaces under different names (Idea Lab, Hackerspace, Think Lab, FabLab or Make Studio) (Kececi, 2017). As stated in the field research, institutions that want to include makerspaces on university campuses are increasing day by day. As Wilczynski (2015) pointed out in his study, the institutions offering engineering education went beyond theory and started embedded project-based courses to create the atmosphere and conditions that students will encounter in their professional life. They began to include practices involving "design-test-build" activities. These activities differentiate makerspaces from classical laboratories or workshops that existed in the classical engineering education.

In Turkey, there are so far 11 makerspaces but not all of them are working under academia. Some of the prominent ones include Arcelik, a private company that has established one for its employees and for marketing purposes. Atolye LLC., in Istanbul, has one that works for profit. Yasar University, located in Izmir, has one for architecture students. The makerspace at Abdullah Gul University (AGU), called "The AGU Make," is the first one in its category since it is non-profit and the first one to be established at a state university. Moreover, it is used with the mechanical engineering curriculum to allow the students to gain much-needed skills as well as practical knowledge. Furthermore, it is built to serve all disciplines of engineering in the university.

Purpose of the Study

The aim of the research presented in this study is to determine:

a. The contribution of a makerspace to engineering students' learning experience,

b. Makerspaces' effect on students' motivation and

c. A need of common study space for interdisciplinary studies.

The Make, which is located at a public university, was used to collect the data. The data was collected from the instructor that was established the space, undergraduate students and graduate assistants that have been using the space. Based on the definitions in the field, in this study the makerspace is defined as a space where students and faculty members from different disciplines get together to work on a small or big scale engineering project.

AGU Make

The institution, AGU*,* where the Make is located is a small, public research institution that was established in 2013. The university emphasizes education, research and the utilization of knowledge by applying innovative teaching methods, such as active learning, hands on experience, experiential learning and mentored research to its academic courses (Bengu & Sebnem, 2018).

AGU Make was established with funding from the Engineering School of the Abdullah Gul University in 2017 to be operated by student staff after examining the existing ones in the USA. During the operation of "the Maker," 4 different expenses were occurred: consumables, machine costs, lost tools and service and fixing cost. The biggest consumable spending was the filaments for the 3D printers. The aim was to observe the operation of the space and increase the number of machines and manufacturing capabilities according to the needs of the projects and students. With this vision, a laser cutting machine, a CNC milling and a CNC lathe machines were purchased. In the meantime, some of the small hand tools either were damaged or got lost. The Department of Mechanical Engineering needed to allocate special funds to purchase these kinds of tools every year. The service and fixing costs for the 3D printers, which have been used by almost 200 students and around 10 faculty and staff were substantial.

The current rector of the university was aware of the importance of hands-on experience in Mechanical Engineering education and with his vision all the expenses of the Maker were paid from the School of Engineering budget. Şahin & Tosun's (2018) descriptive research, emphasized the need for such state support to build these spaces.

AGU Make is primarily intended for engineering and interdisciplinary projects. There is no fee to use the Make at this point and it is open to all university members. The Department of Mechanical Engineering redesigned its curriculum and courses to enable students to use this space. The space has all kinds of hand tools, lathes, milling machines, all kinds of power tools, carpenter machines for wood processing, 28 different 3D printers in 5 different brands and models. 3D printers followed by the laser cutter are the most commonly stated pieces of equipment in the studies from U.S. and Australia. According to the experiment conducted by Saorin et al. in 2017, computers with 3D software, 3D printers and 3D scanners that are used in a learning environment can boost the creativity of students.

AGU Make was designed as a place to provide students with practical experience by teaching technical knowledge and theoretical understanding. In order to improve student's learning experience, the department implements design projects into their curriculum where students are active, learning by themselves and through peer-learning.

At the time this study was conducted, the Make was open two hours a day, one hour in the morning and one hour in the afternoon, outside class hours. Priority in machinery use is given to students conducting final-year projects, a practice learned from the University of Texas, Austin and Rice. Training is offered by students and is published through a website established by the students. The aim is to provide a peer-to-peer learning environment by providing interaction between students in upper and lower classes. The Make is not open for those outside the university at this point. However, in the future, it may be open to work with a partner in industry that comes with inclusive projects for their students.

New curriculum

In the mechanical engineering department, the students take a total of 50 courses. Some of these courses are common courses such as GLB (global initiative) and history courses. Departmental courses are basic courses that almost every university offers, such as mechanics, fluid mechanics and manufacturing. The difference and the success of a program lies in the way these courses are taught. A makerspace can be a crucial learning tool at this point, since it can provide a mechanism for students to experiment hands-on and learn outside the classroom (Burke, 2015) and build 21st century competencies, such as critical thinking and teamwork.

The fundamental addition at this institution is the newly designed curriculum (Table 1) to provide students an environment to learn by doing. There are 16 courses in pairs where students learn a basic theory and then apply it to a project in the following term to understand the application of theoretical knowledge. They are encouraged to work in teams and expected to create prototypes of their designs. These courses are shown in Table 2.

METHODOLOGY

Exploratory case study was chosen as a methodology to understand participants' engagement with the space and their reflections on how a makerspace changed their learning experiences. The focus was to establish an understanding of how best to proceed for later investigation in a future study project and whether the methodology was effective in regards to data collection. To assess students' engagement, researchers chose a qualitative perspective. The project was started in Fall 2017 and ended in the middle of the 2019 Fall semester.

Participants

The first set of data was collected through one-on-one meetings with 5 undergraduate students from Mechanical Engineering and 3 graduate assistants from Mechanical Engineering who had been using the space. These participants were interviewed to evaluate their perception of the space. Following that, the researcher interviewed a faculty member from Mechanical

Table 1: The Mechanical Engineering Course Program

AGU Mechanical Engineering Program								
1	**Fall**	ME 101 Technical Drawing	ME 103 Engineering Math I	SCI Elective I	SCI Elective II	GLB 101	ENG 101	
	Spring	ME 102 Engineering Innovation and Programming	ME 104 Engineering Math II	ME 106 Mechanics I	ME 108 Materials Sciences	GLB 102	ENG 102	
2	**Fall**	ME 205 Mech. Eng. Labs.	ME 207 Fluid Dynamics	ME 209 Materials Design	SCI Elective III	GLB 201	TURK 101 Turkish I	
	Spring	ME 202 Fluid System Design	ME 204 Strength	ME 206 Mechanics II	SCI Elective IV	GLB 202	HIST 101 History I	
3	**Fall**	ME 301 Machine Elements I	ME 303 Manufacturing	ME 305 System Dynamics and Controls	ME 307 Thermodynamics and Heat Transfer	GLB 301	TURK 101 Turkish II	ME 311 Internship I
	Spring	ME 302 Machine Elements II	ME 304 Mechatronics and Measurements	ME 306 Machine Theory	ME 308 Thermo-fluid Design	GLB 302	HIST 101 History II	
4	**Fall**	ME 401 Capstone Design I	ME 403 Prototyping	ME 405 Mechanism Design	ME/Free Elective - Independent Research	ME/Free Elective - Independent Research	OHS 401 Occup. Health and Safety I	ME 411 Internship II
	Spring	ME 402 Capstone Design II	ME 404 Machine Design	ME/Free Elective - Independent Research	ME/Free Elective - Independent Research	ME/Free Elective - Independent Research	OHS 402 Occup. Health and Safety II	

Table 2: The Theoretical and Corresponding Applied Course

	Theoretical and Corresponding applied course	
	Theoretical	**Applied**
1	ME 101 Technical Drawing	ME 102 Engineering Innovation and Programming
2	ME 108 Materials Sciences	ME 209 Materials Design
3	ME 207 Fluid Dynamics	ME 202 Fluid System Design
4	ME 301 Machine Elements I	ME 302 Machine Elements II
5	ME 305 System Dynamics and Controls	ME 304 Mechatronics and Measurements
6	ME 307 Thermodynamics and Heat Transfer	ME 308 Thermo-fluid Design
7	ME 306 Machine Theory	ME 405 Mechanism Design
8	ME 403 Prototyping	ME 404 Machine Design

Engineering who established the Make. The interviews lasted approximately 30 minutes. The new curriculum was also examined since it was redesigned to encourage students to experiment and learn outside the classroom (Burke, 2015). The results were compiled using the details to create a final conclusion. In order to increase the reliability of the findings, an online questionnaire was applied to approximately 50 mechanical engineering students using the comparison method.

Data Collection Tool

Two sets of interview forms were prepared by the researcher to determine:

a. The students' experiences with the Make and how this space had contributed to their learning.

b. The department of Mechanical Engineering's experience with the space and how it had affected their teaching.

At the same time, the researchers' aim was to reveal the potential of the AGU Make as a space for interdisciplinary studies and a model for the other universities that wish to establish a makerspace.

Data Analysis

For this aim, the courses which are included in the curriculum of Mechanical Engineering and the ones that used design-based projects were examined. Since the study follows a qualitative weighted method, the form of the study was interpreted and edited in the light of the data obtained in the process. The researchers used a trained assistant to type the conversations. Interview notes were coded by the researcher and the assistant independently. Four categories were formed: a) the effect of makerspace on the competencies, b) its effect on soft skills, c) the sustainability of a makerspace and d) the need for adequate training. Direct quotations from the interviewees were used to emphasize their opinions.

FINDINGS

The Effects of Makerspace on Field Competencies

In the online survey, 80% of the students stated that they use the Make outside of their courses and expressed their desire to continue their learning with the Make. They stated that the space provided them an environment to apply the theory for better learning. Although the students are satisfied with the independently-run projects that they have been working on so far, they have expressed their desire to work on projects that are embedded in the course work and offer different perspectives in the content knowledge. They also express their desire to use tools other than 3D printers in their projects.

The Effect of Makerspace on Soft Skill

The interviewed students expressed their desire to work on projects that increase their creativity and support their critical thinking. When they were asked to share at least 3 of the competencies that they are expected to acquire when they graduate, 90% of mechanical engineering students mentioned creativity and teamwork, 70% of them mentioned analytical thinking and the ability to initiate, and 50% of them mentioned being a self-learner and the ability to write a project. As one student expressed:

The main one … is creativity, which assists the graduate to find alternative solutions for current problems... [although the third one] may sound like creativity, it is still different. I believe … being able to produce the best quality with the least [effort] and this requires analytical thinking.

They are well aware that these are the skills that industry demands. Undergrad and graduate assistants stated that they benefit from the makerspace and the positive output on their soft skills, such as team work, time management and conflict resolution. However, students expressed their concerns about the operation and the sustainability of the space, which leads us to the third category.

The Sustainability of the Space

When the academician who set up the space was interviewed, he stated that the space was designed to be operated by Mechanical Engineering students and graduate assistants. Although the students stated that working with upper-class students had accelerated and enhanced their learning processes, they expressed the need for a specialist or a technician working full time in the space. For the sustainability of this specific makerspace there is an urgent need to have an experienced and equipped technician to run the space.

As one student expressed:

… there is a lack of [technician] [access to makerspace is limited] … the makerspace [should be] easier to access and [institutions should] encourage the multi-department-based projects.

Institutions that want to establish and operate a makerspace in their university campuses should also take into consideration the not-so-positive views of students in order to solve the problems that may arise in the future. The interviewed students stated that there should be strict rules regarding the use of the area. As one student expressed, "… students are not responsible. When we arrive in the morning, we see the pieces left on the table. Individual responsibility is required." Students also advised that if the student is to be employed, the log books should be used to keep track of work.

A Need for an Adequate Training

The students stressed the lack of training prior on using the space. 70% of the students stated that the support provided by the department was inadequate. They compensated by teaching themselves through YouTube videos and with the help of the upper-class students.

RESULTS, DISCUSSION and RECOMMENDATIONS

It can be said that students want more than theoretical knowledge from their engineering education. Therefore, it is essential to provide them with a place for them to be active, creative, engaged and apply what they have learned. As emphasized both in Saorin et al. (2017) and in Hilton et al. (2020), students who spent time in these venues have significantly higher level of confident, self-efficiency, motivation and creativity.

The sustainability and the functioning of these spaces should be taken into consideration when designing these areas. In a study that was conducted in the US, a combination of student support staff and specialized staff personnel was found to be the most common staffing model as opposed to the use of specialized staff personnel in Australian academic makerspaces. In this study, the users emphasized the need for specialized staff personnel. However, for institutions that have difficulty in recruiting staff, involving undergraduate and graduate students is of great importance. These students should be trained prior to use of the space and continuous orientation programs should be offered.

The Mechanical Engineering Department took an important step on behalf of engineering education by designing a new curriculum. However, our observations have shown that changing the curriculum from scratch may not increase the use of the space. There is a need for faculty development since not all of the faculty members will have the competency to use these kinds of learning spaces and they need experience to apply new teaching methods. Integrating the makerspace into courses through projects and providing support for faculty members specifically for interdisciplinary projects may provide positive results and will ensure their sustainability of the space.

As mentioned by the students, providing workshops to use the tools and machines is another necessary step that should be taken for the sustainability of the space. Student groups should be supported and asked to design workshops for the space to initiate peer-to-peer learning.

After the report from this study was shared with the administration, in mid 2019, a technician was appointed and the makerspace's hours of operation was expanded from 8am to 5pm every weekday. The space was moved to a bigger space in order to meet growing demand. It became an interdisciplinary study space for students from various disciplines (Mechanical, Electric Electronics, Material Science and Molecular Biology and Genetics, Computer Engineering).

There are several topics that could be further investigated which would bring different perspectives to the field. Such as,

- Assessing students' engagement with students from other disciplines.
- Assessing students' state of motivation while they are working on their makerspace projects.
- Assessing the engagement level according to the genders.

In Turkey, makerspaces are unlikely to be founded in academic libraries, unlike the models in the USA and Australia. On the other hand, "pop-up" or "mobile" makerspaces might be a good idea to be used in an exploratory stage to assess interest in makerspaces. The model of temporary makerspaces that are compact and inexpensive and easy to establish and take down might be a good sustainable alternative to "test the waters" before implementing a permanent like those adopted by University of Melbourne and Curtin University (Wong & Partridge, 2016).

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