Evaluating Adopt-ability of Open Source Tools for Problem Solving in Specific Design Tasks in Industrial Design Education

Onder Erkarslan, Izmir Institute of Technology, Turkey

Zeynep Aykul, Izmir Institute of Technology, Turkey

Abstract

The purpose of the study was to evaluate the adoptability of Open Source Tools (OST) as a learning strategy in undergraduate Industrial Design (ID) education. OST has the potential for students to overcome certain difficulties in specific tasks, such as design presentation, design research, design decision, concept generation and design documentation. In this study, both quantitative and qualitative methodologies are used to develop the research. As the first step of the research, quantitative methodology is employed, using a survey method to collect data from students. The survey investigates industrial product design students' perceptions of difficult tasks and their reasons, as well as their awareness of OST. In the second phase of the study, qualitative methodology is followed to acquire feedback on the proposal regarding Open Source (OS) use in an ID studio course using case studies. The simulation follows qualitative methodology, using primarily observations and obtaining verbal feedback. The results indicated that students were willing to adopt OST as an effective design tool and to overcome difficulties in the design process.

Keywords

educational technology; open source tools; adoptability; problem solving; industrial design education

Introduction

The basis of openness is accessibility which means people can access to view, modify and use something. The Internet gave momentum to Open Design (OD) and its other elements like Open Innovation (OI), Open Source (OS) hardware, software, etc. because it made sharing possible from anywhere and also made it easier for students to access proprietary software, applications and the tools. Open Source Culture is the creative practice of appropriation and free sharing of found and created content including collage, found footage film, music, and appropriation art. In OS, the main function is collaborative effort, where people can use, improve and distribute software within the community. Anyone can contribute to a source with his or her knowledge and experience. Each of OI, OS, and OD refer to one of the steps of accessibility which are: to view, modify, and use (Avital, 2011).

"OD is a catchall term for various on- and off-line design and making activities. It can be used to describe a type of design process that allows for (is open to) the participation of anybody (novice or professional) in the collaborative development of something". (Tooze, Baurley, Phillips, Smith, Foote & Silve, 2014, p. 538).

Open Source Tools (OST) are software tools that are freely available without a commercial license. Many different kinds of OST allow developers and others to do certain things in programming, as well as maintain technologies or other types of technology tasks. OST offer an easy, cheap, and practical way to express design ideas. In addition to ID contribution to OST and the evolution of these tools in favour of ID, OST can assist with design processes in terms of easiness, low cost, and practicality. OST are valuable tools for both the design education community and the OD practitioner community because of their multidisciplinary nature. Previous practices in ID were mostly concerned with making the products given to designers look and function better. ID as a field has stopped approaching design as the act of making objects and reinterpreted the responsibility of the designer to fulfil the needs of people (Sanders & Stappers, 2011).

ID education involves a combination of the visual arts disciplines and technology, utilizing problem-solving and communication skills (NASAD, 2008). Specific NASAD standards and guidelines for ID programs in the United States comprise 30-35% of the total program; supportive course in design, related technologies, and the visual arts, 25- 30%; studies in art and design history, 10-15%; and general studies and electives, 25-30% (NASAD, 2011-2012). Students learn to sketch, model, design, and visually communicate in studio courses taught by ID faculty and industry experts. The courses aim to help ID students gain specific skills in design presentation, design decision, design research, concept generation and design documentation (Chen, 2015). In OS usage, users are also developers, so the technology evolves by and for those that use it. There are many tools and platforms that are based on the OS philosophy. Besides, the more industrial designers use OS the more they improve the tools to make them more convenient for their own needs. Furthermore, the issues of today's world are more complex than can be solved by only designing the form and function of a product. Programming, interaction, and human cognition are skills that industrial designers need as much as they need drawing, forming or moulding skills (Norman, 2010). In the example of Virginia Tech, Norwegian University of Science, Technology and Eindhoven University of Technology and Delft University of Technology, ID students use Arduino to move their design from sketches through to their real functions of wearable and pervasive computing products. (Alsos, 2015; Martin, Kim, Forsyth, McNair, Coupey & Dorsa, 2013). ID students can use OS both for their immediate and future problems since these tools help them in education as well as in industry.

OD and practices have been largely investigated in the literature: *Co-creation* (Galvagno & Dalli, 2014; Mobbs & Hawkridge; 2010; Vargo & Lusch, 2008); *Co-design* (Steen, Manschot & De Koning, 2011; Sanders & Stappers, 2008); *Open innovation* (Hossain, Islam, Sayeed, 2016; Torres & Ibarra, 2015); *Open design solution* (Tooze & Baurley et al., 2014); *Open design contribution* (Tooze et al., 2014; Mari, 2002; Kadushin, 2012; Smith, 2008); *Open Innovation practices* (Mobbs & Hawkridge; 2010); and *Open design process* (Tooze et al., 2014). The education of today is not suitable to create the multidisciplinary environment necessary to solve current complex problems. New skills are needed instead of disciplinary skills (Alsos, 2015; Martin et al., 2013; Yeh, Lo, Huang, & Fan, 2007; Auer, Juntunen & Ojala, 2011). OST can be used not only for software development but also in many areas, such as mechanical, electrical engineering, business, forensic, space studies, etc., and they are used in engineering education since they offer reliability, customization, innovation, collaboration and low cost (Scholz, Juang, 2015; Armesto et al., 2015; Benavides, 2011; Austin, 2007). OD can operate in the commercial sphere and generate economic value. Young designers are indeed pursuing OD activities, using open software and contributing to building OD communities (Menichinelli & Bianchini et al., 2017).

Reasons for using OST in many areas of education include preventing the limitations caused by the high cost of educational software and products and avoiding closed source tools that prohibit modifying them to follow technological and innovative changes in the area. OST can be used as an effective tool to eliminate design obstacles in the ID studio, but its efficacy has not yet been fully evaluated. Our objectives were as follows: 1) to introduce the OS concept to ID students and make them use these tools in their design processes, 2) to make students contribute to open culture and engage students with the OS Community, and 3) to evaluate the effectiveness of OST during the students' design process compared to the re-designing their previous projects in a traditional ID studio course.

To attain the objectives and solve the defined problems, following research questions were posed:

1 How and why should ID students be introduced to OS ideas?
2 Which stage of the design process can be supported by OST?
3 What was the students' approach to using OST in their design process?
4 How and why can design students engage with OST and the community?
5 What were the results of OST experienced by ID students in their design process?

Methods and findings

ID departments in Turkey receive undergraduate students according to the national university placement exam, which is held by the Student Selection and Placement Centre. In a three-stage sampling research process, three ID schools were selected according to their entrance exam results, accessibility and student number. Based on admission scores, the first three universities in the 2016-2017 term were the Middle East Technical University (METU), Istanbul Technical University (ITU), and TOBB University of Economics and Technology (TOBB). However, TOBB was excluded from sampling since only one student was registered in the design studio there in that year. Instead, Izmir University of Economics (IEU), the fourth university on the list, was included in a face to face survey. Questionnaires were sent to ITU and METU via mail and were also conducted directly (Table 1).

	First Questionnaire							Second Questionnaire						
Universities	Number of participants	Student year				Gender %		Number of participants	Student year				Gender	
		1st	2nd	3rd	4th	Female	Male		1st	2nd	3rd	4th	Female	Male
METU	44	-	-	37	7	62	48	47	-	-	27	20	66	44
ITU	32	-	8	15	9	74	26	65	-	28	26	11	76	24
IEU	71	-	19	34	18	80	20	61	-	18	27	16	79	21
	Age Average		20.2	21.8	22.4					20.3	21.6	22.6		
SUB-TOTAL	140	-	27	86	34	72	28	173	-	46	80	47	77	23

Table 1. Sample characteristics.

Phases of Research Methodology

The questionnaires aim to determine whether OST can help ID students with any tasks in the design studio course and to measure ID students' knowledge and practice level for OS. Data were collected from ID students through the 1st questionnaire (Appendix 1), and difficulties in the design process, according to the data gathered, were analysed. Data analysis of the questionnaire was performed, and a same brief lecture was designed to introduce the open philosophy and its tools to ID students by Zeynep Aykul. According to data gathered in the feedback session through the 2nd questionnaire (Appendix 2), two pilot studies were performed to determine the best environment in which to observe students' use of OST. Simulation of Open Source Community (OSC) was performed in the Introduction to Design Thinking Course in the ID Department at ITU in the fall semester of 2016-2017. Assignments were evaluated through a SWOT analysis and questionnaire of the evaluation of the simulation of OSC. Student presentations on all aspects of their experience with the OSC and adoption of OST were evaluated through observation and an Evaluation Form for Simulation of OSC (Appendix 3). In the final week of the open source session, students presented all their experience with the open source community and tools in the jury. Students were willing to use OST in their ID studio projects, and their general opinion is that they would be useful (Aykul, 2016, p. 111-146).

Preliminary Research

1st questionnaire for evaluation of ID students

The questionnaire has four sections: personal information, tasks in the ID studio course and difficulty level, reasons for difficulty, and awareness of open source. In the first section, three questions ask for information on name and surname, e-mail address, school, year. Tasks in ID studio course and the difficulty level form another section, with a question that contains 20 items on a 5-degree Likert scale. These items are named T1 to T20 (Table 2).

Code	Task	Activity in Open source web platform
T1	Data collection and analysis	Source
T2	Presentation of data (how they can be used in design)	Indirect
T3	Understanding theme of project	Indirect
T4	Understanding requirements of projects	Indirect
T5	Generating sufficient ideas	Source
T6	Changing and developing ideas	Sharing, Source
T7	Expressing the concept quickly and correctly	Contribution, Source
T8	Finding inspiration	Source
T9	Generating form and style according to user's need	Source
T10	Finding reference knowledge	Source
T11	Decision skills	Sharing
T12	Evaluation criteria	Indirect
T13	Meeting lecturer's expectations	Indirect
T14	Digital modelling	Source
T15	Physical Modelling	Source
T16	Preparing presentation poster	Indirect
T17	Organization of presentation	Indirect
T18	Affording presentation budget	Source
T19	Delivering project in due time	Source, Contribution
T20	Affording overall budget for project	Source

Table 2. Tasks in ID Studio Course and Their Codes.

Students should accomplish several tasks when creating a design. The tasks are design research, concept generation, design decision, design presentation, and design documentation. These five categories comprise 34 sub-tasks. In the questionnaire 20 of the 34 sub tasks are chosen, for the purpose of eliminating possible misinterpretations by students through excluding similar subtasks. The next section also includes one question that aims to learn the reasons for students' difficulties in these tasks. Reasons can be classified as experience; technical knowledge, such as ergonomics, material, etc.; budget; time; technical support, such as help in the workshop, equipment, etc.; relevant courses; lecturer; and classmates. There were 16 reasons under three categories to examine in Chen's study: The first was personal problems included *capability, thinking, techniques and skills, experiences, personality, aesthetic, knowledge, and other issues*. The second was resource problems; *money (cost), time, technical support, equipment and tools, and related courses*. The third was interaction and communication problems occurred with *instructor and peers* (Chen, 2015). However, in this research, students were asked about only 8 of them. The personal category was excluded for it did not serve the purpose of evaluating the adoptability of OST to overcome certain difficulties in the specific task in ID studio course, but rather it was used to explore learning problems. The reasons are named R1 to R8 in a list to be found in Table 3.

Code	*Reasons for Difficulties*
R1	Experience
R2	Technical Knowledge
R3	Budget
R4	Time
R5	Technical Support
R6	Relevant Courses
R7	Lecturer
R8	Classmates

Table 3. Codes and reasons for difficulties.

The following section measures the awareness of ID students about open source. There are 3 questions that ask whether the respondent has ever heard the term 'open source'; about knowledge regarding specific OST, including Arduino, Raspberry Pi, Rasbian, OpenIoT, BugLabs, Makemagazine, RepRap, Lasersaur, GrabCAD, Thingiverse, Blender, Freecad, Inkspace, Gimp, and Scribus; and, lastly, if they used one of these tools or another OST in their design studio course project, as well as whether they think such tools are useful.

Data collection and analysis of questionnaires

For the 1st questionnaire, there were five different difficulty ratings: 'It is not difficult', 'A little difficult', 'Somewhat difficult', 'Difficult' and 'Very difficult'. Each rate was assigned a score from 1 to 5, respectively, to determine their total difficulty rate for each task in the design studio course. Then, the analysis of questionnaire focused on tasks that had total rates higher than the average ratio to analyse the reasons for this difficulty. DR(Tx) difficulty rate for each task from T1 to T20. 140 students answered the first questionnaire, so each student's rating for each task summed up and is showed in the graph.

$$\sum_{1}^{140} DR\,/ = DR(T1)$$

To find the average difficulty rate, each task's difficulty rate was summed up and divided into 20.

$$\left(\sum_{T1}^{T20} DR\right)/ = Average\ (T1)$$

As seen in Figure 1, some tasks were above the average difficulty rate of 382,55 such as meeting lecturer's expectations (T13), affording budget (T18, T20), time management (T19), expressing concepts correctly and quickly (T7), finding inspiration (T8), decision skills (T11), and generating sufficient ideas (T5), with the task of meeting lecturer's expectation supported indirectly by OST. For instance, OST made a contribution to Data Collection with source, so this made an impact on Data Presentation indirectly. As the element of OST, the open source tools could support T5, T8 T18, and T20. By sharing their designs, ID students could overcome difficulties in T11. T7 and T19 could be overcome by both contribution and source of OST (Figure 1).

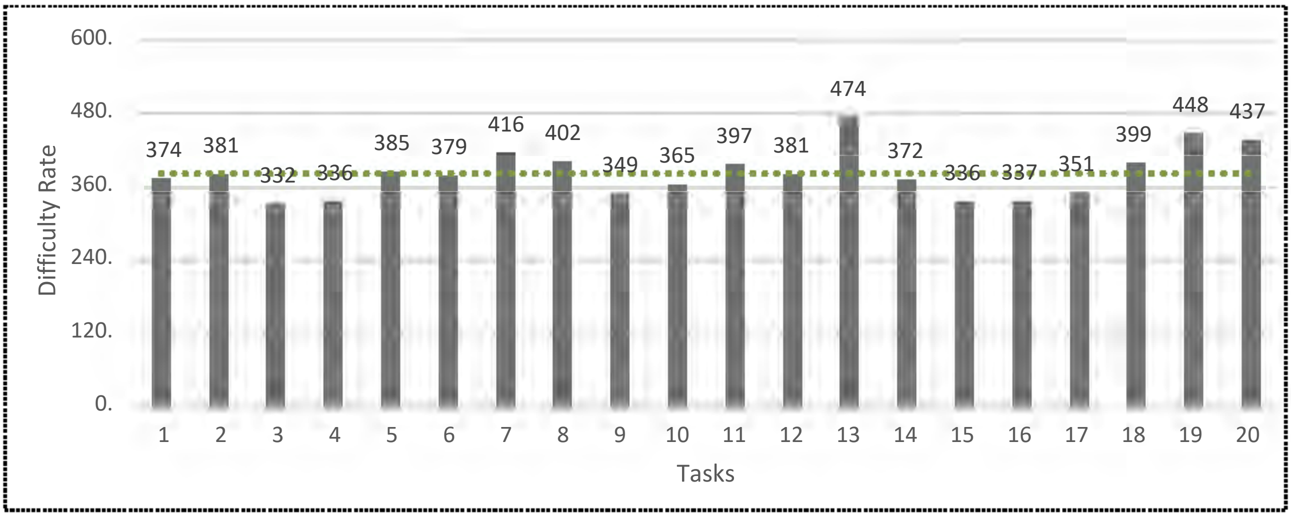

Figure 1. Difficulty rates and task analysis of question 1.

In the following portion of the questionnaire (Appendix 1), reasons for these difficulties were analysed. These reasons were experience, technical knowledge, budget, time, technical support, relevant courses, lecturer, and classmates (Chen, 2015). According to the collected data, a lack of experience, technical knowledge, and technical support were the most common reasons behind the difficulties in design processes. As seen in Figure 2, total of 141 students answered Question 6 (Appendix 1). 106 of students knew the term "Open Source" and 35 of them did not. There was an obvious difference between these two groups when the data were examined in total. However, 4th-year students from METU and 2nd- and 3rd-year students from ITU participated in the research as small groups, so their data did not provide information that could be correctly generalized. Nevertheless, there was approximately the same ratio of 75%

to 25% in nearly every data group, except those with limited participation and the 2nd-year students from IUE.

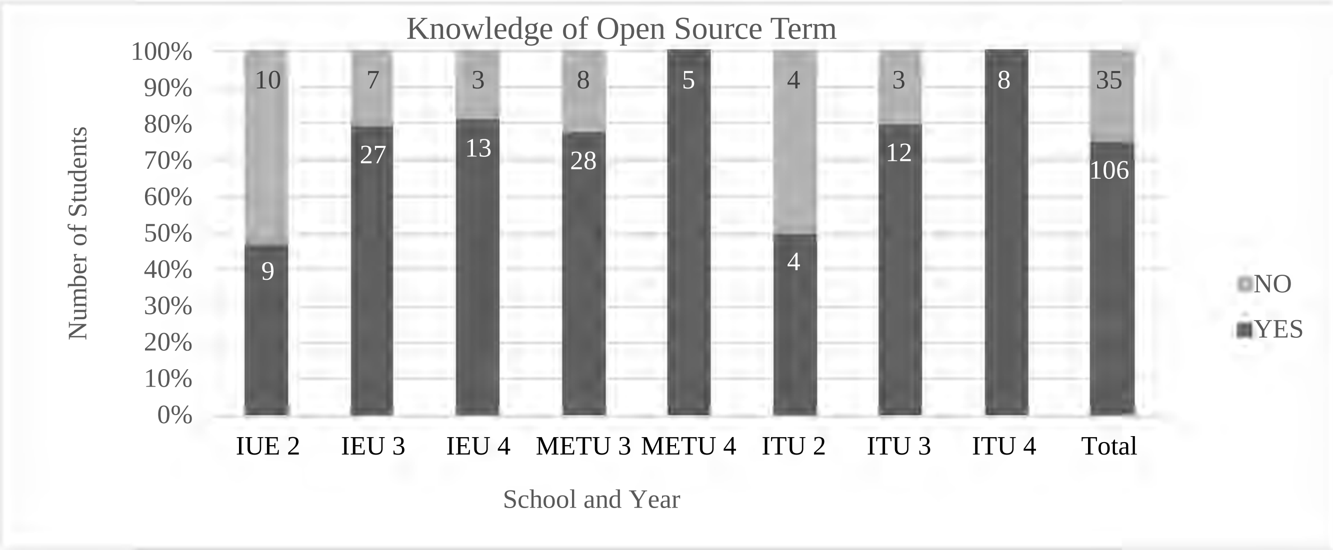

Figure 2. Students' knowledge level of "Open Source" term.

There were two more popular tools for ID students, which were Grabcad and Arduino. Grabcad is easy to use and offers free CAD models which were compatible with many CAD software (Figure 3).

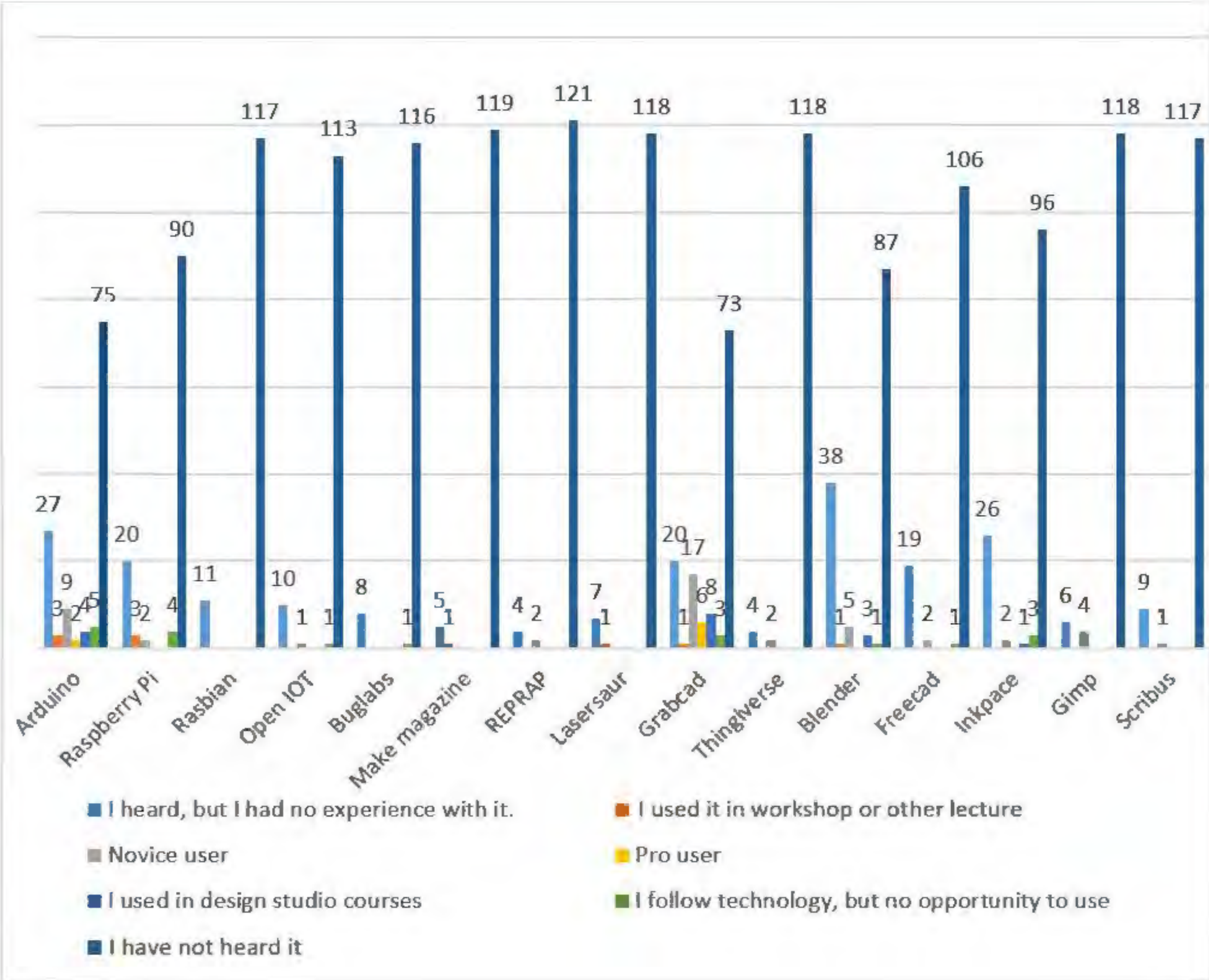

Figure 3. ID students' knowledge and practice level about OST.

One issue with the data was that 75% of students said that they knew the definition of OST, but they also answered "I heard it for the first time" for tools. This answer indicated that students had some experience or knowledge about the tools, or they had heard the definition due to the popularity of software, but they did not know how to integrate it in design projects.

2nd questionnaire for feedback session about OST for ID students

In the feedback session, the 2nd questionnaire was answered by students at ITU, METU and IUE. The 2nd questionnaire had two parts: pre-presentation and during the presentation. In the pre-presentation section, there are two questions which asked about the year of the student and if students know about OS. Questions were answered in parallel with a presentation by students. There are six questions in this section. The 3rd question aimed to learn the students' definition of the OS term and whether or not they clearly understood how OST worked. In the 4th and 5th questions, students' opinions analysing their difficulties in design tasks and their reasons were solicited. The 6th question asked about OST and students' relationship with each tool. The 7th question was asked to find out about any tool that could be helpful if students had learned about it before the project. In the last question, students were asked to provide any other ideas or opinions.

Data Analysis of Feedback Session

After presenting each tool, students answered the question with 7 options (Appendix 1). Students indicated that they had heard of KAA, Thingiverse, and Raspberry Pi for the first time in the presentation. Arduino, Instructables, and Grabcad were the most well-known and commonly used OST by most ID students. All found the advice about Arduino, Grabcad, and Thingiverse useful for their design process. On the other hand, a few were sceptical that Raspberry Pi, KAA, and Arduino would be a good choice for design studio courses. All participants emphasized that any tool could be helpful if they learned it before the project. Despite their limited knowledge, students built a connection with OST as a useful design tool to clear up difficulties in specific tasks.

Simulation of OS Community

After the case study session in three different universities, a workshop session was designed to understand the usability of OST in ID studio projects. According to the feedback session, students had positive opinions about using OST in their design process.

Pilot study 1: redesigning previous design studio projects with OST
In OS, people can modify the source and share because its design publicly accessible so the modification capability is the main characteristic of the source. Re-designing one of their previous studio projects with OST aimed to determine the differences with or without use of OST in the design process. According to the first questionnaire's results, R1 showed some difficulty in T1, T12, T13, T19 and CT20. R2 has some problems with more than five tasks in design studio projects, and the reasons were similar to R1's. R3, R4 and R5 reflect difficulties in digital modelling, budget, time and idea generation. A need to design Pilot study 2 emerged due to the unsatisfactory design process in Pilot study 1.

Pilot study 2: using OST in a design studio project
Students did not redesign their previous project. Thirteen students volunteered at the beginning to participate in this research. They are from six different universities: five students from Isik University, two from Anadolu University, three from Kadir Has University, one from ITU, one from METU and one from Ozyegin University. Three students are from the 2nd year, seven from the 3rd year and three from the 4th year. The result of pilot studies showed that students are not willing to learn new tools during the ID studio course or when redesigning their previous projects. Most of the OST were new for the students. Thus, they needed to practice before using them in design studio courses. Also, offering them only tools with specific ways of use was not an effective and permanent solution to develop the students' habit of open source use. Students should learn how an OS community was working with all the elements: developer, source, sharing activity and contributors. For this purpose, a simulation of OS culture was designed to see what kind of behaviours and activities ID students perform and what the impacts of simulation are for students. The simulation aimed to create an effective environment offering an experience of open source tools with all the elements such as source, sharing, contribution and community. A session was run parallel with

the semester, and students were followed through the entire design process, week by week, for their first project in the fall semester of 2016-2017.

Primary Research: Simulation of OS Community

The simulation was performed in the *Introduction to Design Thinking Course* in the ID Department at ITU in the fall semester of 2016-2017. Reasons explaining the need for the OSC simulation in this course were explained by the lecturer as the following: design thinking includes empathy, prototyping, co-design and co-working in the scope of the course. It is similar to OST regarding these aspects. Design thinking is partially applied as a design research step in the ID studio courses. Students' term project was a cup designed for a persona and considering the brand. Persona is accepted as the common point of design thinking and OS. Persona is a representation of the needs, thoughts and goals of the target user. In an OST, persona would be transformed into the contributor. The contributor is everyone who has contributed something back to the project. The simulation took a total of five weeks; after the 5^{th} week, students began to create their OST.

Week 1: The content of the simulation and Instructables were introduced to students. Instructables is a website specializing in user-created and uploaded do-it-yourself projects, that lets you explore, document, and share your creations. Students were then given a first-week assignment of creating an Instructables profile, uploading their design, persona and brand studies to their page, then examining each other and commenting on one another's projects. The first-week assignment was for students to share their design for the week on Instructables. Nine students shared their design on Instructables. Students were identified with a number and abbreviation of a keyword that was related to their project.

Week 2: Each student presented their work and Instructables experience, and then a short lecture about OST and a contribution session was held. As an assignment, students were to have continued developing their projects according to the outcomes of the contribution session. A SWOT analysis was performed as a structured co-working session. Each student mentioned their concerns and additional ideas for the current product design, and then every student offered ideas about the strengths, weaknesses, opportunities and threats of the product. The reason for using SWOT is to offer a specific tool for students to use when contributing to each other's projects, instead of only demanding that everyone would contribute to each other's projects. In the SWOT analysis session, students used A3 paper and post-its. They divided the paper into four areas, offering ideas for strengths, weaknesses, opportunities and threats. Then, classmates wrote their ideas on post-its and stuck them to the related part of the paper. Thus, students could evaluate ideas more easily and clearly. As a 2^{nd} assignment, the student would continue to develop their ideas, update their Instructables, and contribute to each other's projects. Moreover, they had to consider SWOT analysis while developing their design.

Week 3: Arduino was introduced to students as OS hardware, and they created simple Arduino circuits and learned its basics. For this purpose, Arduino, breadboards, jump wires and

LEDs were supplied for students by Inno FabLab. The given example could be the easiest one to build with Arduino, but the aim was making and exploring on one's own or with friends, not with an expert on the subject. After a few attempts to connect wires and LEDs and run codes, each student succeeded in making their LED blink (Figure 4). Then, students had to work on an interactive version of their cup design with Arduino. Although they did not have the required hardware, such as sensors or modules, some basic modules such as temperature or pressure were supplied for them so that they could present their ideas, findings from OS research, and circuit design using some online tools such as Fritzing or circuits, as well as their concept of interaction. After that, an interactive design process was requested in the rest of the project duration.

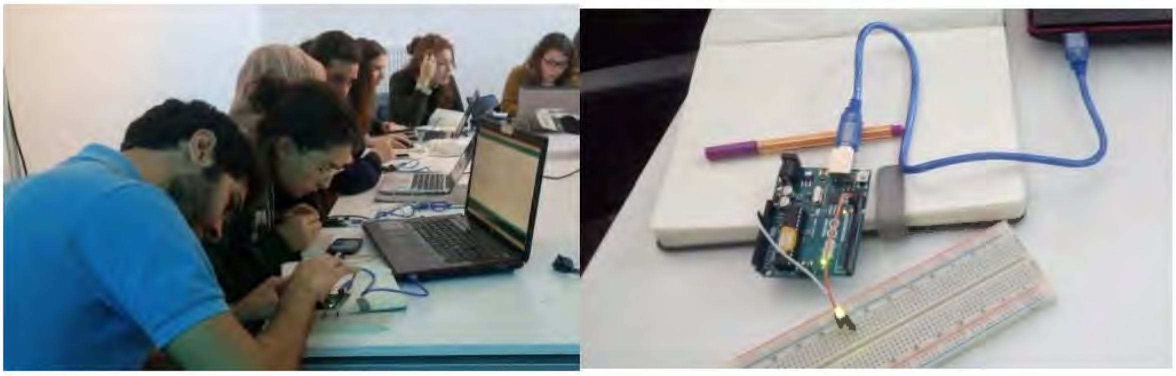

Figure 4: Students built their circuits to blink LED & blinking LED circuit with Arduino

Week 4: Students continued working on their design and using OST in co-working sessions, and they asked about Arduino and sensors based on their needs.

Week 5: According to lecturer and teaching assistant opinion for this session, Arduino was the most tangible expression of OS practice for ID students, because they were used to dealing with products, but considering sharing as a movement and reflecting it in their design process were insufficient to fully understand OS. However, the students could use OS as both hardware and software with Arduino. Moreover, this usage affected their design process, and some of the students wanted to continue with this side of exploration. Furthermore, their lack of knowledge about coding made it necessary for them to use OS.

OSC session through selected students' cases

In this section, the aim was exploring students' projects before and during the open source community session in the course, and then evaluating implications of open source tools usage in their design process. The evaluation of the implications was based on basics of open source such as source, sharing, and contribution. During this section, three cases were-S1Grab, S4Fshp, S8Cmp- selected, because they fulfilled all the requirements asked throughout the whole process. The cases were evaluated to understand adoption level of open source tools in student' design process, and which element of open source is more effective for students.

Code	*Age*	*Gender*	*Initial Design*	*Theme/Aim*	*Final Design*	*Changes*
S1Grab	21	F		Natural and warm feeling		Rather than combining two materials in production level, giving people customized pieces
S2Geo	21	F		Eco-friendly and geometric patterns		Using cups already on the market and adding some details based on theme
S3Cont	20	F		Contrast and practical		Focusing on user need in function level
S4Fshp	21	F		Friendship		SWOT analysis showed that using form to give the sense of togetherness is hard to store and not functional, creating wearable pieces with both function and technology.
S5Cpfy	21	F		Spotify and mood		Using a cup already in coffee houses and adding details with a qr code to create its effect

S6Mlt	20	F		Healthy lifestyle		Focusing on what her persona is already using and designing customizable and printable parts
S7Meas	21	F		Measuring things and controlling habits, LEGO		Giving effect of adding parts to each other with inspiration of LEGO
S8Cmp	21	F		Compact		Rather than changing cup at the production level, a flexible part that can be used with any drink and snack or additive combination, 3D-printable based on needs and cups' dimension
S9Heat	20	F		Safety		Rather than using many layers to create high-level isolation, a do-it-yourself (DIY) holding surface and colour-changing alert for any cup
S10Fld	20	M	He attended class later	-		He did not have any initial design

S11X	21	M	Shared his design in class only, not on Instructables	-	-	-
S12Y	22	M	Did not share any design in class or on Instructables	-	-	-

Table 4. Students' initial and final designs with themes and modifications during the OS session.

S1Grab used the form and some patterns in her first concept before brand analysis, then she decided to change her choice of materials to create a warm feeling. She aimed to capture a sense of belonging through the compact design of cup and spoon. After sharing her concepts on Instructables, she took feedback from her classmates. At this point, she had created a source and shared it. With the feedback of her classmates, OS community was built around the S1Grab's product design. Having taken feedback on Instructables, she added more wood surface to improve the design project and used two materials to make her product larger. The product had a regular form from outside, but it had a convex form inside. The SWOT analysis indicated that she needed to pay attention to manufacturing method, joining details and hygiene. Due to the hygiene problem and challenging manufacturing process of the previous version, she decided to use a detachable cork part instead of wood. However, the feedback indicated that this form was not easy to create. In the OS hardware session, only basics of Arduino and how to find and run the source was taught, so during the rest of the session they did research to work Arduino circuit.

S1Grab designed a DIY product instead of mass production, as the final design, she prepared a guide to show how people can produce her design. S1Grab used felt cloth instead of wood or cork, so the problems of manufacturing and hygiene were eliminated. Her guide which was shared on Instructables was easy to understand. Moreover, the presentation of her design on Instructables showed a designer touch; she considered not only the users and the production process, but also users' experience with this product. In the final step, she offered customization. This shows that her product developed step by step with the consideration of each feedback. She also designed an interactive version of "Relish" in the scope of OS hardware session in the class. She aimed to design a reminder for people who forget their hot beverage which results in it becoming cold. She decided to use Lilypad which is sewable Arduino for wearable technologies, temperature sensor, coin battery holder, LEDs, conductive thread and thin fabric which enabled light transfer. Moreover, she added customizability features into an interactive version of "Relish". During the five weeks, S1Grab reflected sharing activity and interaction with feedback as open source's elements. She integrated each piece of feedback into her concept step by step, such as changing the material of the product.

S4Fshp focused on friendship theme with inspiration from friendship bracelet. She shared her paper cup mock-up and wanted feedback on her Instructables profile and then, she decided to share the story behind her design with persona analysis. She defined her persona and the cup design as:

"The persona likes simplicity and comfort, care about memories and friendships, wants to remember always. Regarding product, the persona prefers light, coherence, endurance, and eco-friendly. The cardboard cup is designed as friendship cups. Every unit should be part of one thing. It is aimed that while they are using the product, it will remind "the part of one (friendship)." For that reason, units are designed like puzzle parts. They make a holistic image. There are some alternatives for both units and the total image. This effect will be made with applying of colours and form."

After sharing the design on Instructables, she took feedback such as trying different forms to create modularity, storage together, trying a different material combination to embrace product family. S4Fshp decided to use different materials. During the SWOT analysis, she took similar feedback. As a result of the SWOT analysis, she focused on form to make manufacturing easier. Her new design had cup sleeves instead of cup itself. These sleeves were set with three combinations, so when a group of friends want to buy a cup of coffee or another drink with these sleeves, then they can keep them and use as a bracelet. After that, she looked for basics of Arduino, while she did her research, she focused on wearable technologies mostly. After the OS hardware session with Arduino, she designed interactive and communicative friendship sleeve bracelet. The interactive version aimed that when one of the friends used a bracelet or sleeve again, then it sends a message to other's mobile phone or other's sleeve which blinks LED. She also used Lilypad, because it is flexible and easy to sew. In the final presentation, she showed her interactive sleeve design and explained the instructions: Cut the patterned fabric and interlining according to template with the seam allowance. (a), Iron the fabric and interlining for joining. (c), Apply these steps for another face. (d), Lay out velcro parts to two edges. (e), Sew velcro on fabric. (f)

At the end, S4Fshp's design's last phase showed the advantages of co-working and taking feedback. At the stage of OS hardware, she made extensive research to compensate lack of experience in this area. She used source effectively as open source's components.

S8Cmp focused on a personalized cup design, she aimed to offer a new experience with drinks and a side compartment that could be integrated into the cup. The feature of the personalized cup was inspired by her persona and favourite object analysis as mentioned before.

Her first mock-up offered a compartment to serve tea in. According to the feedback on Instructables, she needed to work on the leaking problem, she needed a spoon or a detail which could work as a spoon, a compartment for bulk tea instead of a tea bag, and a cup or thermos as a function. After the feedback, S8Cmp divided her cup into two parts to keep utensils for the drink experience, but there were still leaking problem and complex manufacturing process. In the SWOT analysis, feedback showed that connecting between traditional experience and OS may provide more engagement. She decided to design a colourful and interactive coaster to offer customizable service for each customer. In this phase, she had the most detailed work with Arduino with the help of another user which reflected contribution as open source' elements. Their work showed the result of interdisciplinary co-working. In the end, her product used a 3D printer, so she did not have to deal with leaking problem. Through the use of OST components -source and contributions- her project was levelled up.

Other Implications with OST

In addition to selected cases, other students' design process had some stages that needed analysis. These stages show alternatives views about OST use in their design process. In the 3rd week, S5Cpfy shared her new findings and developed parts on her design. She wants to design an espresso cup which offers interaction with the customer through a Spotify music list. She found dynamic QR code to add to the design different from the ones in previous weeks.

With that, S1Grab and S6Mlt claimed that they learned dynamic QR code and offering interaction with it thanks to her Cupify project, so it may give inspiration to other people, too. This indicates that students accept sharing activity of OS for only complex production or very interesting ideas, but the point is sharing and taking feedback, then move the project one step further.

Another remarkable thought was expressed by S12No. He did not present any projects idea. According to his opinion, many posts on Instructables did not have a design or product value. He also expressed his opposition against sharing his own ideas with a group of professionals without obtaining an economic benefit. He believed that one should start a Kickstarter instead of posting on Instructables if the design idea was good enough.
S2Geo started with a recyclable material cup with geometric pattern, and she wanted to add some seeds on it for the secondary use of the cup. However, she did not find the direct way of doing it, instead, she designed the gift idea with seeds. Then, she designed a water level controller for plants. All steps of her design were not connected with each other through a cup design, but she still continued with the eco-friendly concept, and used sharing and sources as OS elements.

S9Heat designed a safer cup with stronger isolation at first then she decided to include a thermocolour (colour-change) feature to the design. In the interactive design, she also designed a coaster which integrated a tiny piezo buzzer and temperature sensor. When the temperature of the hot drink reaches to 65°C, the speaker functions.
In addition to the design process and OS session in the class, students used OST in their previous design. For example, S6Mlt had designed a cocktail glass in her previous design studio courses, and she decided to add interaction to her glasses for parties and cocktails. The aim of interaction was building communication with the waitress, when a customers' drink is finished. For this purpose, she decided to use a load cell in the cocktail desks which sense the weight of the drink; then it sends signals to waitress. Moreover, she shared on Instructables and wanted help from other Arduino users. Using OS outside the class and without any obligation shows that she may adopt it as a design element and usable in the design process.

Similar to S6Mlt, S4Fshp also shared her previous design on Instructables. She published instructions of her previous "Bookside" project. She did not need any support with her design. Furthermore, she said that she just wanted to share and see other people produce her design. This indicates that students adopt OS to interact with communities and become part of the communities.

Adoption of OST use into students' design process

According to questionnaire data (Appendix- I*)* students found the experience regarding, OST and communities useful. Eight students agreed on the session's positive contribution to their design

process, but three students claimed that this made their design process slower. Two students did not find OST effective or useful for their design process. The question of students' anxiety about sharing their design was asked, with responses rated on a 0-to-10 Likert scale, where 0 indicated students had no anxiety to share, 5 indicated students had some anxiety, but it did not prohibit sharing, and 10 indicated that students had anxiety and did not want to share. Only two of students felt anxiety about sharing and were somewhat limited in their willingness to share. Three students chose scale 5 to represent their anxiety, and the remaining students had less anxiety about sharing.

According to students' feedback about the effects of sharing their design on Instructables, almost every student agreed that comments had a positive effect on their design process. Some comments had helped students when they were stuck; some comments were stimulating for students and made their design process much easier. One of the students said that he found the critiques objective and helpful in his design. Another student's opinion was that comments had helped the transformation of her design from a raw to a more developed product. Students agreed on the positive effects of contributing to each other's projects. Only one student found the contribution to another project time-consuming. Two students said that contribution provided personal satisfaction in helping others' designs. The remaining students claimed that this activity supported their project and their personal development.

Moreover, two students gave an answer indicating that contributing to other projects had contributed to both their projects and themselves.

In the weekly classes and assignments, students had to do research and find OST to build their Arduino prototype. There was a question asking about how hard or easy the process of finding knowledge from an OS was. It was asked to evaluate their research process with OS. Only one student found it hard, five of them saw it as a normal process, and four of them agreed with its easiness. Students had some difficulties due to their lack of practice so far, but the majority thought positively about learning Arduino and gaining this experience for their further projects. Due to the course structure, all students used Instructables. Although a part of the course included Arduino, not all students used Arduino. To find a 3-D model for their design, students used GrabCad and Thingiverse. One student chose the option for another tool, but he did not specify which one. Students' opinion was that learning these tools would be helpful for further projects if they needed to design an interactive project. Students understood that Arduino, coding or electronics were not that difficult if they needed clear and OS to learn from.

Discussion and conclusion

Pilot study 1 showed that students need more time and practice to engage with OST. In the 2nd pilot study, students' feedback indicated that they needed more time, more practice and knowledge before using OST in studio course projects. Moreover, students had no motivation to work with OST and did not want to use anything without the lecturers' notice. Students had become used to designing for economic value, so sharing their design free of charge was not a usual situation for them. Thus, students needed to understand why people shared their design and other works for free. For this purpose, students could meet with those people and interview them to improve their understanding. The primary research included an OS session in the ongoing course, so students had some confusion about how they were to continue on their projects. Even in the 4th week, students were clear whether they had to include their previous work, such as persona or brand, or needed to design a do-it-yourself (DIY) product. Students' feedback in the evaluation session showed that they could not engage with the reasons for sharing their projects. Although students had limited knowledge they were able to overcome the obstacles generated by specific tasks via using OST as a useful design tool. This feedback supported the reasons of technical knowledge and technical support that were analysed as the result of the first questionnaire. However, according to their answers, students also took a positive approach to using OST in their design studio course projects. Follow-up studies were designed to find an effective way to encourage ID students to use OST in their projects. The last step of the research, OSC session showed that an effective way of creating engagement between students and tools was offering all elements of OS, such as hardware, software, community, and platforms. Without using it in their design, most students did not see OST as a design element. That there was a gap in the students' perception and experience of design culture today - between professional ID and increasing practices of OD - but they began to see the connections. Furthermore, with the co-working and contribution elements of OSC, students overcame the difficulties including decision skills, expressing concepts correctly and quickly, finding inspiration, generating sufficient ideas, changing and developing ideas. A great majority of students agreed with the positive effects of contribution to each other's projects. Students believed that learning these tools would be helpful for further projects if they needed to design an interactive project.

In contrast to the offerings of OST for ID students, some students also expressed views about their occupation. They interpreted the definition of industrial designers as designing a product with economic value so the product could find a place in the market, thereby earning its company money. In this circumstance, students did not clearly understand why they shared their design with others. In consideration of this definition, they should not use OST, because these tools could not be used as commercially. However, as the opposite of this definition, some of the students mentioned personal satisfaction due to contributing to another project. This process was the driving force for OS users and people sharing projects. Students' knowledge about OS transformed from a basic definition to all elements and experience.

OST and community positively affected students' experience of their design process and made it more rapid. As seen in the examples from many disciplines, OS could be used in education to set new skills to students for preparing them to solve today's and future's problems. They could support their lifelong learning with OS, so teaching and adopting OST into ID education could contribute students' development not only prepare them as competent for the industry but also competent to solve any complex problems of future in a multidisciplinary environment. OST can be taught in class, and students can pick a project to develop themselves instead of being given a specific theme and obligation. Moreover, contacting any project owner from any OS platform and contributing to it can be required of students so that they can be part of a real community. The way to create engagement between ID students and OST is to build an environment with all OS elements. Within this environment, students experience the whole process, starting from source, sharing, and contribution to the community. Then, students begin to accept these elements as design tools. Moreover, they contribute to OS by doing things such as sharing their designs, developing them with the community and giving feedback to others, so they contribute their design perspective into OS as much as they learn from it.

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Statements on open data, ethics and conflict of interest

Data used in this study can be accessed via the following link: https://cloud.iyte.edu.tr/index.php/s/HzLi7lP8Md1d8T1

The study was conducted and approved under the ethical guidelines in place at the Izmir Institute of Technology for all graduate students. The participants volunteered to complete the survey in the present research. The students in the simulation phase were enrolled in the course *Introduction to Design Thinking Course* at ITU and graded in the fall semester of 2016-

2017. Besides, all figures, explanations and posted comments about ten students' projects were available on Instructables:

S1Grab http://www.instructables.com/id/Fundamentals-of-Design-Thinking-the-Development-of

http://www.instructables.com/id/Design-Thinking-the-Coffee-Cup-Part-I/

S2Geo http://www.instructables.com/id/Cardboard-Cup/
S3Cont http://www.instructables.com/id/Contrast-Cup/
S4Fshp http://www.instructables.com/id/Design-a-Cardboard-Cup-With-Design-Thinking-Method
S5Cpfy http://www.instructables.com/id/Cupify
S6Mlt http://www.instructables.com/id/ArduinoCupDesign/
http://www.instructables.com/id/Fundamentals-of-Design-ThinkingCup-Design/
S7Meas http://www.instructables.com/id/Design-Thinking-Cup/
S8Cmp http://www.instructables.com/preview/E5WL9U6IUKF06CN/
http://www.instructables.com/id/Fundamentals-of-Design-Thinking/
S9Heat http://www.instructables.com/id/Design-Thinking-Cup-Design/
S10Fld http://www.instructables.com/id/Collapsible-Cup

References

Arduino. (2016). Arduino Products. Retrieved from Arduino: https://www.arduino.cc/en/Main/Products

Alsos, O. A. (2015). Teaching product design students how to make everyday things interactive with Arduino. Make2Learn 2015 workshop at ICEC'15. 7-14, September 29, 2015, Trondheim, Norway.

Armesto, L., Fuentes-Durá, P., & Perry, D. (2015). Low-cost Printable Robots in Education. *Journal of Intelligent & Robotic Systems*. http://doi.org/10.1007/s10846-015-0199x

Auer, L., Juntunen, J., & Ojala, P. (2011). OS project as a pedagogical tool in higher education. *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments MindTrek '11*, 207. http://doi.org/10.1145/2181037.2181073

Austin, R. D. (2007). Digital Forensics on the Cheap: Teaching Forensics Using OST. Conference on Information Security Curriculum Development (InfoSecCD), (2006), 1–5. http://doi.org/10.1145/1409908.1409915

Avital, M. (2011). The generative bedrock of open design. In *Open Design Now* (p. 239). Retrieved from http://opendesignnow.org/index.php/article/the-generative-bedrock-of-open-design-michel-avital/

Aykul, Z. (2016). Evaluating adoption of open source tools in industrial design education.

Unpublished master's thesis, Izmir Institute of Technology, Izmir, Turkey.

Benavides, G., A., M. (2011). Integrating Free- OST as Teaching Resources for an Electronic Engineering Undergraduate Program. Integrando Herramientas Libres-Abiertas Como Recursos Para La Enseñanza En Un Pregrado de Ingeniería Electrónica., 5(2), 24–32. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db =fua&AN=7153 4653&lang=es&site=ehost-live

Chen, W. (2015). Exploring the learning problems and resource usage of undergraduate ID students in design studio courses. *International Journal of Technology and Design Education*. http://doi.org/10.1007/s10798-015-9315-2

Galvagno, M, Dalli, D. (2015), Theory of Value Co-creation. A Systematic Literature Review. *Managing Service Quality: An International Journal*, 24, 6, 643-683

Hossain, M., Islam, K. M. Z., Sayeed A., M. (2016). Comprehensive review of open innovation literature. *Journal of Science and Technology Policy Management,* 7, 1, 2-25.

Instructables. (2016). How to make anything. Retrieved from https://www.instructables.com/

Kadushin, R. (2012). Open Design Manifesto. Available at: http://www.ronen-kadushin.com/index.php/open-design/) [accessed 10 February 2013].

Mari, E. (2002). *Autoprogettazione*, 1st edn. Mantova: Corraini.

Martin, T., Kim, K., Forsyth, J., McNair, L., Coupey, E., & Dorsa, E. (2013). Discipline-based instruction to promote interdisciplinary design of wearable and pervasive computing products. *Personal and Ubiquitous Computing*, *17*, 3, 465–478. http://doi.org/10.1007/s00779-011-0492-z

Menichinelli, M., Bianchini, M., Carosi, A., & Maffei, S. (2017). 'Makers as a New Work Condition between Self-Employment and Community Peer-Production: Insights from a Survey on Makers in Italy'. *Journal of Peer Production*, 10.

Mobbs, R., & Hawkridge. D. (2010). Utilizing OST for online teaching and learning – By Lee Chao, *British Journal of Educational Technology*, 41(3), 59-60.

National Association of Schools of Art and Design (ed.) (2008). National association of schools and art design handbook. Reston, VA: NASAD.

National Association of Schools of Art and Design (ed.) (2011-2012). National association of schools and art design handbook. Reston, VA: NASAD.

Norman, D., 2010. Why design education must change. *Core*, 26. November, 2010.

Sanders, E., & Stappers, P. (2008). Co-creation and the new landscapes of design. *CoDesign* 4, 1, 5–18. Retrieved 07 20, 2015, from: http://www.maketools.com/articlespapers/CoCreation_Sanders_Stappers_08_preprint.pdf

Sanders, E., & Stappers, P. J. (2011). All People Are Creative: A primer on generative design research. Unpublished Book.

Scholz, A., & Juang, J., N. (2015). Toward OS CubeSat design. *Acta Astronautica*, 384-392 http://doi.org/10.1016/j.actaastro.2015.06.005

Smith, Z. (2008). Objects as software: The coming revolution. In Objects as Software: The Coming Revolution, 25th Chaos Communication Congress, Berlin. Open Design: Contributions, Solutions, Processes and Projects Available from: https://www.researchgate.net/publication/266622283_Open_Design_Contributions_Solutions_Processes_and_Projects [accessed Sep 17, 2017]

Steen, M., Manschot, M., & De Koning, K. (2011). Benefits of Co-design in Service Design Projects. *International Journal of Design*. 5, 2. Retreived 08 13, 2015, from http://www.ijdesign.org/ojs/index.php/IJDesign/article/viewFile/890/339

Tooze & Baurley et al. (2014). Open Design: Contributions, Solutions, Processes and Projects. *Design Journal*, 17, 4, 538-557-8.

Torres L., T., R., & Ibarra E., R., B. (2015). Open Innovation Practices: A Literature Review of Case Studies. *Journal of Advanced Management Science*, (3)4, 362-367.

Vargo, S. L., & Lusch, R., F. (2008). Service-dominant logic: continuing the evolution, Journal of the Academy of Marketing Science, (36)1, 1-10.

Yeh, S.W., Lo, J. J., Huang, J. J., & Fan, Z. Y. (2007). A Synchronous Scaffolding Environment for Collaborative Technical Writing. Technologies for E-Learning and Digital Entertainment, 4469, 829–840. http://doi.org/10.1007/978-3-540-73011-8

APPENDIX 1

EVALUATION OF INDUSTRIAL DESIGN STUDENTS' DESIGN PROCESS TASK BY TASK AND THEIR AWARENESS ABOUT OPEN SOURCE

This questionnaire was applied for Zeynep Aykul's MSc Thesis in Industrial Design Department at IZTECH. In the first chapter, there are two parts which are difficulty rates design tasks and reasons design tasks. In the second chapter, knowledge of students about open source term and open source tools are asked.

1. Name and Surname

2.E-mail

3. School/Year

Tasks and Their Difficulty Rates

4.Please, mark your difficulty rate for each task in the design studio projects. *

	It is not difficult	A little difficult	Somehow difficult	Difficult	Very Difficult
Data collection and Analysis					
Data presentation					
Understanding project theme					
Understanding project needs					
Producing enough amount of ideas					
Developing and changing ideas					
Express the concept quickly and correctly					
Finding inspiration					
Generating form and style according to user's need					
Finding reference knowledge					
Decission ability					
Evaluation criteria					
Meeting expectation of lecturer					
Digital modelling					
Physical modelling					
Preparing presentation poster					
Preparing presentation organization					
Affording budget for presentation					
Delivering project on due date					
Affording budget for overall project					

Reasons of difficulty for design tasks

In this section, you will answer reasons of difficulties of tasks as the same as the previous question.

5. Please, mark your difficulty reason for each task in the design studio projects.

	Experience	Technical Knowledge	Budget	Time	Technical Support	Relevant Courses	Lecturer	Classmates
Data collection and Analysis								
Data presentation								
Understanding project theme								
Understanding project needs								
Producing enough amount of ideas								
Developing and changing ideas								
Express the concept quickly and correctly								
Finding inspiration								
Generating form and style according to user's need								
Finding reference knowledge								
Decission ability								
Evaluation criteria								
Meeting expectation of lecturer								
Digital modelling								
Physical modelling								
Preparing presentation poster								
Preparing presentation organization								
Affording budget for presentation								
Delivering project on due date								
Affording budget for overall project								

Measurement of Awareness about Open Source Term and Tools

In this section, your knowledge about open source will be measured.

6. Did you hear term of "open source" or "açık kaynak"?

- yes
- no

7. Mark your relationship about each open source tools

	I heard it, but did not use before	I participated its use in workshop etc.	novice user	pro user	I used it in design studio course project	I am following the tool, but no opportunity to use	I did not hear it
Arduino							
Raspberry Pi							
Rasbian							
Open IoT							
Buglabs							
Makezine							
Reprap							
Lasersaur							
Grabcad							
Thingiverse							
Blender							
Freecad							
Inkspace							
Gimp							
Scribus							

Additional

If you used any tools in your class, then please answer the question.

8. Did you use open source tools which you marked in previous question or another one in design courses? Please note your aim and experience. *

APPENDIX 2

FEEDBACK SESSION OF INTRODUCTORY PRESENTATION

Pre presentation Section

This survey aims to take feedback about my presentation. For further information on your questions, you can send me email to zeynep.aykul@gmail.com

1.Your School/Year (If you want to take information e-mail about open source and further studies, you can write your email)

____

2. Do you know term of "open source"?

Yes

No

During Presentation Section

You should answer these questions during the presentation.

3. Did you understand Open source terms and system?

- yes
- no
- not clear enough
- Diğer: ______________________________

4. Do you think that I analyzed challenging tasks of industrial product design students and reasons of them in studio courses?

absolutely true	true	there are some missing points	there are wrong analysis
⬭	⬭	⬭	⬭

5. If you think there is mistake or missing point in previous question, you can add here.

6. In this question, can you pick the best option for you in each project sample?

	I heard it for the first time	It was interesting tool	Advises are useful, I may use it in future project	Advises are not enough	Advises are useful, but they are not effective for studio project	I am already a user
No:1 GRABCAD	⬭	⬭	⬭	⬭	⬭	⬭
NO: 2 INSTRUCTABLES	⬭	⬭	⬭	⬭	⬭	⬭
NO 3: THINGIVERSE	⬭	⬭	⬭	⬭	⬭	⬭
NO 4: ARDUINO	⬭	⬭	⬭	⬭	⬭	⬭
NO 5: RASPBERRY PI	⬭	⬭	⬭	⬭	⬭	⬭
NO 6: KAA-PLATFORM	⬭	⬭	⬭	⬭	⬭	⬭

7. Did you think about any tool which could be helpful, if you learnt before the project?

8. If you have any additional opinion or idea, you can add this part. Thank you.

APPENDIX 3

Evaluation form for Simulation of Open Source Community

The aim of this form is evaluating 5 weeks process in the "Introduction to Design Thinking" course. the study is run by Zeynep Aykul as master thesis study.

1. Name-class

____

2. What is mean of open source for you?

____

3. What is open source community? Please answer based on your experience in the class.

____

____

____

4. Do you think open source tool contribute your design process?

Uygun olanların tümünü işaretleyin.

- ☐ No contribution
- ☐ Limited contribution
- ☐ positive contribution, fast process
- ☐ positive contribution, but slower process
- ☐ negative effect, it was hard to focus on my project
- ☐ negative effect
- ☐ Diğer: ______________________________

5. Did you anxious about sharing your design? 5= I feel few anxiety, but it was not obstacle to share.

Yalnızca bir şıkkı işaretleyin.

	0	1	2	3	4	5	6	7	8	9	10	
no anxiety	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	very anxious, I did not want to share my design

6. How did comments on Instructables affect your design process?

____

____

____

____

7. What did you think about contributing others' projects?

____

____

____

____

8. Affects of contributing others' projects:

Uygun olanların tümünü işaretleyin.

- [ ] It was time consuming
- [ ] It made me hardly focus my own project.
- [ ] It also contributed my design process
- [ ] It provided personal satisfaction.
- [ ] It provide me to develop myself in different topics.
- [ ] Diğer: ______________________________

9. Reaching knowledge for open source tools was....... for me.

Yalnızca bir şıkkı işaretleyin.

	1	2	3	4	5	
very hard	◯	◯	◯	◯	◯	very easy

10. How do you evaluate your experience with Arduino?

____

11. **Which open source tools did you use in your project?**
Uygun olanların tümünü işaretleyin.

- [ ] Arduino
- [ ] Instructables
- [ ] Grabcad
- [ ] Thingiverse
- [ ] Diğer: ____________________

12. **Will you use your learning from this class in your future projects?**

____

____

____

____

13. **other...**

____

____

____