A Toolkit for Practice-Based Learning of Mechanisms in Industrial Design Education: An Application of a Method Combining Deductive and Inductive Learning

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Abstract
Industrial design education is focused on teaching a combination of various interdisciplinary competencies. One of these projected learning outcomes is to be able to design mechanisms in order to fulfil certain mechanical constraints in products. Studies show that theoretical knowledge supported by practice helps to teach industrial design students the mechanisms. In the current situation in Turkey, practice-based courses are designed with a similar purpose. However, graduates severely lack mechanical design skills. In this study, a two-staged toolkit of a holistic flow is introduced to prevent the deficiency mentioned above. In the toolkit, mechanisms are taught by combining deductive and inductive approaches, instead of a directly inductive conventional approach. The toolkit is applied to 36 sophomore year students. Assessments of the students and their self-evaluations are collected and analysed. Findings show that the toolkit can be beneficial for teaching of mechanisms to ID students through some revisions.

Key words
design education, learning methods, experiential learning, inductive learning, learning of mechanisms

Introduction: Motive of a Toolkit
Paradigms of industrial design (ID), which is a crafts-based discipline (Başar & Ülkebaş, 2011), is shifting, while communication and information technologies are developing (Overbeeke, Appleby, Reinen & Vinke, 2004). Universities offer diversely structured ID programs. Research or practice-based approaches are already separated (Friedman, 2002; Zeng, 2017). The profession of ID is branching out and graduates posess various competencies (Domermuth, 2009). The scope of these competencies (Siegel, 2000) and approaches for evaluation of these skills (Horváth, 2006) are discussed in studies. However, discrepancy of expectations of the students, universities and companies from various industries (Erkarslan, Kaya & Dilek, 2011; Domermuth, 2009) shows that a universal approach for developing certain competencies is not likely to be found.

The Interdisciplinary essence of this profession necessitates an education that is based both on theoretical knowledge and practice. However, educational approaches are controversial. For educators, a holistic view is regarded as innovative (Horváth, 2006). However, the focused qualifications that a reductionist approach provides are still valuable for employers (Erkarslan, et al., 2011; Kındı, 2007). Reductionism assumes that comprehending components is enough to understand complex systems (Horváth, 2006). Contrarily, a holistic approach considers the net of relations between individual elements of the system in order to determine them. Companies expect to hire designers with mechanical engineering based skills. However, they argue that graduates lack these competencies. (Erkarslan, et al., 2011; Domermuth, 2009; Yang, You & Chen, 2005; Kındı, 2007). The topic is controversial. While some of the studies criticize employers for misunderstanding the ID competencies (Erkarslan, et al., 2011), others denounce conventional educational models for lacking experiential learning contents (Roozenburg, Van Breemen & Mooy, 2008; Bingham, Southee & Page 2015; Yavuzcan & Şahin, 2017).

Engineering courses are limited in ID education compared to the engineering programs. Particularly in Turkey, conventional methods for teaching engineering knowledge to ID students are inefficient, often reductionist, and there is a need for optimizing the practice-based learning approaches (Yavuzcan & Şahin, 2017). Howard (1997) remarked that only a few institutions in the USA grant degrees in ID engineering while there are many design and ID departments. Very few of the programs offer engineering courses unless they include “engineering” in their titles or are established within an engineering program. Universities often focus on an interdisciplinary integration but none of them meet the ‘sweet spot’. Howard uses the term sweet spot to describe a presumptive ideal combination of disciplines in an ID program. However, the formula of an ideal curriculum is unknown, and it makes the sweet spot a utopian ideal. On the other hand, Howard’s criticism is likely to remain valid in Turkey. Manifestos of some of the most renowned Turkish ID programs lack or consciously avoid integrating engineering. Even when added, engineering content in their curricula is often theoretical.

What engineering knowledge is and how it is related to ID are other questions of debate. Engineering practice is a systematic problem defining and solving process which is fuelled by specialized knowledge and an ability to integrate that knowledge into the process (Sheppard, Colby, Macatangay & Sullivan, 2006). Current approaches focus on teaching engineers to conceive, design, implement and operate complex systems within a sustainable and responsible framework (Crawley, Malmqvist, Östlund & Brodeur, 2007). Defining the current state, the attributes and constraints and developing a means-end chain is how engineering practice works as a problem-solving process. There are infinite numbers of ways to solve a problem. Comprehending them is “knowing that”. Implementing the efficient one is “knowing how”. “Knowing how” is what makes engineering knowledge identifiably different from scientific knowledge. (Sheppard, et al., 2006). The nature of engineering is often perceived as finding an optimal solution. However, some of the researchers argue that the solution should only be satisfactory. Rather than looking for an ideal design, engineering should be holistic, iterative, communicating with other disciplines, affected by cultural norms, considering the needs of society and able to integrate scientific, mathematical and social values and theories (Pleasants & Olson, 2018). The nature of engineering and definitions of ID overlap in these terms. However, engineering education is currently focused on teaching “knowing how” in a holistic manner, whereas engineering in ID education is limited to theories of mechanical engineering, materials and manufacturing.

The ID department of Gazi University is an exemplary case for Turkish ID education, as it is one of the few state universities which has include an ID program for around a decade and applies a generic curriculum. Several years ago, the second year design studio of this program was following a common approach. This common approach is focused on practice-based inductive learning. Inductive learning is a specific-to-general learning method, the opposite of deductive learning, and it is often hands-on learning (Prince & Felder, 2006). Lecturers observed that after completing heavily theoretical engineering lectures, attending a course based totally on inductive learning is compelling for the students. Besides, during the assignments of the design studio, the sophomore year students benefit only a little, if any, from the knowledge which theoretical courses aimed to teach them. The essential question of the study has originated from the criticism above: if the transition from one learning approach to the other is optimized to be more structured, would the education of engineering knowledge be more efficient for ID students?

A toolkit was developed regarding the mentioned discussion. It includes a two-stage guide for a project assignment: a semi-deductive pre-assignment and a subsequent semi-inductive design assignment. After taking a few theoretical deductive learning style courses in engineering, students were given the toolkit assignments. The study is focused on observing the participants during the application and receiving post-evaluations from them. 36 students and 5 instructors participated in the research. For the pre-assignment, students researched and presented the fundamental functions of the mechanisms. They were asked to design a system of mechanisms, free of sense-making purpose. After practising the mechanisms conceptually, students designed household tools and gardening equipment, considering the constraints of realizing some of the fundamental functions of mechanisms.

Approaches in Design and Design Education

Even though the graduate and the postgraduate education of ID is slightly more than a century old, designing objects or structures can be traced back to the beginning of humankind (Friedman, 2000; Heskett, 2005). The simplest description of designing can be depicting or planning (Tarelko, 2006). Considering that any human-made object can be planned, the scope of design is immense, and limits of its extension are undefined. Behind every artefact there is a set of conscious and unconscious decisions made by designers (Walsh, 1996; Vial, 2015). While sources of knowledge are democratizing, anyone can design, yet what anyone designs is not always good design (Papanek, 1985; Atkinson, 2006; Vial, 2015). Even though being formally educated makes a designer competent (Gorb & Dumas, 1987), skills which an educated designer should have is a question of debate.

Origins of Industrial Design

A discussion about the scope of these skills can be made by comprehending what ID is. Natures of engineering and design show similarities. However, art is what separated ID from engineering in its origins (Findeli & Benton, 1991). ID is a profession originated from artisanship (Başar & Ülkebaş, 2011). It was pioneered by the Arts and Crafts movement (Weingarden, 1985), which objected to machines for taking the spirit out of crafts (Weingarden, 1985). However, the art centered and bohemian early stance of the Bauhaus was changed to a conventional educational approach towards the mid-20th Century. The apprenticeship orientated basis of ID programs has transformed into a more standardized university curricula. Since then, art has been losing priority in the pedagogical approach.

(Findeli & Benton, 1991). However, the priority has not shifted to engineering discipline. Besides, art should not be perceived as an opponent of engineering. Art in ID should be regarded as practising engineering aesthetically. Aesthetics is often assumed only as a visual issue, yet it refers to any kind of sense perception (Faste, 1995), being attractive or beautiful (Photiadis & Souleles, 2015; Filonik & Dominikus, 2009). When art lost its priority, engineering in ID education became more theoretical, less practice based (Weingarden, 1985), briefly not aesthetic, less beautiful.

Design Methodology

Along with their overlapping natures, engineering and ID are also related to each other in recent history. This can be observed in the history of the “design methodology movement”. According to Cross (1993), the 1962-1970 era of design methodology is the first generation, mostly based on heavily rational methods. The second generation changed the omnipotent behaviour of the designer, popularized user-centred methods such as participatory design, experimental design, usability, accessibility and universal design (Kreuzbauer & Malter, 2005; Kensing & Blomberg, 1998; Iwarsson & Ståhl, 2003). In the 1980s engineering-based design methodology rose andengineering and architectural design methods began to diverge (Cross, 1993). Due to the rise of engineering-based design methods, ID is becoming a more transitional profession by benefiting from architectural approaches as well as scientific engineering methods. According to Grant (1979), there is an opinion among designers that designing is not and will never become a scientific activity. However, some studies show that design can be investigated as a science and science can be within design (Cross, 1993; Andreasen, 1991). The tension is half a century old, yet it remains evident today (Kimbell, 2011). Even though the debate of art and science or engineering was stronger in the first generation, until and during the second generation, researchers started using terms such as scientific design, design science and the science of design. Cross (1993), shared an opinion that the divergence is likely to end in the upcoming third generation. In the 2000s and 2010s, design literature has been introduced to other approaches such as value sensitive design, (Miller, Friedman, Jancke, & Gill, 2007), sustainable design (Blizzard & Klotz, 2012) co-design (Thamrin, Wardani, Sitindjak & Natadjaja, 2018) or the C-K theory (Hatchuel & Weil, 2003). These user-centred theories and methods are based on scientific approaches, thus they validate the expectations of Cross about the controversy of science and design is likely to end. Concluding this section, approaches are classified. Hubka and Eder (1987), describe design science in four fundamental elements: theory of technical systems (1), theory of design processes (2), applied knowledge (3) and theory of design methodology (4). Considering their classification, it is comprehended that design methodology is focused only on theory and practice of design. Thus, design education methodology was researched prior to developing a toolkit based on this classification.

Design Education Methodology

Even though contemporary design practice and education are more complex than they had been in the 1900s, design knowledge still relies mostly on experience. Transfer of knowledge created by experience has shaped a certain teaching approach: apprenticeship (Düzenli, Alpak, Çiğdem & Tarakçı Eren, 2018). ID education has three periods in history, in all of which apprenticeship is fundamental: guild system (1), pre-Bauhaus schools (2), Bauhaus and post-Bauhaus schools (3). As one of the key elements of the present ID education, studio courses of the Bauhaus involve semi-structured experiential learning and hands-on learning methods which are applied under a master-apprentice relation (Düzenli, et al., 2018; Belgin Dikmen, 2011). Today, particularly in Turkey, studio courses remain in the apprenticeship model. Learning methods benefited in these courses are explained below.

Experiential Learning

There is a series of learning styles in psychology. A pyramid of learning is a summary of these styles (Wood, 2004). Efficiency of lectures is evaluated as only 5% in the pyramid yet practice by doing or making is 75%. Wood (2004) explains the difference simply: the more active subjects are during learning, the more they learn.

Until the mid-nineteenth century, before the experiential learning movement, education, in general, was formal and abstract, in which teachers present and students hopefully apply knowledge (Lewis & Williams, 1994). However, due to the craftsmanship origins, design programs already preferred experiential learning. Consequently, designers have two types of knowledge: conscious and experiential (Leader, 2010). Conscious knowledge is taught verbally or written, commonly and extensively, however experiential learning is individually unique. It is sensorial information, subjective and often implicit (Groth & Mäkelä, 2014).

Learning is a process of creating knowledge according to Kolb and Kolb (2005), sharing similarity with the transition of validated concepts to knowledge in the C-K theory (Hatchuel & Weil, 2003). Learning is relearning in substance (Kolb & Kolb, 2005). Thus, experiential learning is relearning of previously met theoretical knowledge. Designers still need the consciously learned theoretical knowledge, so they can relearn it by doing.

Deductive and Inductive Learning

Experiential learning methods diversify based on their relation to the experience. Learning is deductive or inductive. According to Prince and Felder (2006), deductive learning is conventional and was common once in engineering education. Deductive learning is theory first, experience next, from general-to-specific. Contrary to this, inductive learning begins with observation, experience and case studies, then proceeds to theories. Inductive learning is more likely to be correlated with Kolb's learning cycle: an infinite circular loop of reflective observation (1) to abstract conceptualization (2), active experimentation (3) and concrete experience (4) in order (Kolb & Wolfe, 1981; Kolb, 1984).

Hands-on Learning

The experience of a designer is generally sensorial. He or she must discover a tactile experience with actual materials (Leader, 2010). Touching is the basis of understanding materiality (Sonneveld & Schifferstein, 2009). It is a source of experiential knowledge which can be gained through the making of artefacts (Mäkelä, 2007). The term hands-on is often used as a synonym to experiential, yet in the ID literature it refers to building something physical. Even though hands-on learning is nothing new in ID education, particularly in studio courses, handling materials is often addressed as an idea generation tool (Viswanathan & Linsey, 2010). However, hands-on learning has a further potential: When hands-on learning comes forward in studio courses in ID education, students tend to learn engineering-based knowledge more efficiently (Yavuzcan & Şahin, 2017). Tactile experience is both a self-expression tool and a learning style.

Reductionism and Holism

Independent of the preferred style, learning is the source of knowledge and knowledge of an individual is currently classified and measured by competencies. Schilling and Koetting (2010) mention that a competency-based approach is the fourth educational movement: Vocationalism (1), essentialism (2), social efficiency (3) and competency-based education (4). Competency is an interrelated set of attitudes, skills and knowledge (Government of Alberta, 2011), and a competency-based approach is the most up-to-date movement (Schilling & Koetting, 2010). Horváth's (2006) approach divides the competencies into two: Conventional reductionist (1) and innovative holistic (2). In reductionism, comprehending isolated elements is enough to analyse complex systems (Schilling & Koetting, 2010). Holism is the opposite. A system is a whole and elements should be examined by considering their relation to each other (Horváth, 2006). In ID, these elements are knowledge of mechanisms, materials, manufacturing, drawing, etcetera (Siegel, 2000). Horváth (2006), criticizes reductionism as being inefficient, while others accuse it of being epistemologically weak, educationally and philosophically inadequate and inappropriate (Brundrett, 2000). Even though reductionism is often not received well, measurability still helps it remain valid. Nonetheless, in the 2010s another stage of educational approach has begun. Despite being introduced in 1990 (Maurya & Ammoun, 2018), engineering design education benefited in the last decade from an approach known as CDIO. It stands for Conceive, Design, Implement and Operate. It is an active learning tool for the theory of technical systems and the theory of design methodology, besides being a holistic competency model (Bao, Liu, Lu, Xiang & Chen, 2014). In respect of its experiential and holistic structure, CDIO is assumedly what fits best to education of the theory of technical systems in ID programs. Nevertheless, best results can only be obtained by a complete or an extensive curriculum integration (Norinpel, Gonchigsumlaa, Tungalag & Purevdorj, 2018). This is already being implemented in some of the ID departments in the UK. However, as far as is known, there is no existing CDIO implementation in Turkey, in ID programs.

An Overall Criticism

Integration of technological development into design education is needed, and some universities have revised their curricula and their expected learning outcomes (Overbeeke, et al., 2004). However, the rest, and particularly in Turkey, maintain their conventional approaches.

Designers fail to use a common interdisciplinary language (Persson & Warell, 2003), particularly with engineers, which employers demand. The skill sets graduates have and what companies search for often do not match (Erkarslan, et al., 2011; Domermuth, 2009; Yang, et al., 2005; Kındı, 2007). Even though computer aided design skills and knowledge of mechanisms and manufacturing are vital, they disappointingly rise above all the vocational skills (Erkarslan, et al., 2011; Yang, et al., 2005; Siegel, 2000; Süel, 2006). Despite design education methodologists discrediting a reductionist approach, employers show strong resistance by preferring it. Besides, the mentioned skills of graduates are under the level which companies desire (Domermuth, 2009).

On the other hand, ID students often solve mechanical problems poorly (Bingham, et al., 2015) and ID graduates emphasize visually aesthetic innovation over any other creative solutions (Liu, Lee & Tsing, 2013). The conventional theoretical focus of engineering lectures is regarded as the reason for this tendency (Roozenburg, et al., 2008; Yavuzcan & Şahin, 2017).

Modern ID programs differ from the pedagogy of early Bauhaus. If not research-centred (Friedman, 2002), universities generally design a moderate curriculum, containing less hands-on learning sessions than the Bauhaus era. (Yang, et al., 2005; Zeng, 2017; Gropius, 1923). Innovative perspectives for hands-on learning in studio courses are suggested and applied by some researchers (Roozenburg, et al., 2008; Yavuzcan & Şahin, 2017; Bingham, et al., 2015). In Turkey, it is often discussed whether lecturers have comprehensive practical experience, and a lack of it is a great hindrance in experiential learning. Universities and researchers in the Far East put much emphasis on this issue (Bai & Sun, 2018; Zeng, 2017). On the other hand, universities, often lack modern facilities and equipment for offering an up-to-date experiential learning process (Zeng, 2017). According to Zeng, students' access to manufacturing tools and machinery supported by practical experience of lecturers increases the efficiency of ID education.

Supposedly, considering the curricula of the ID departments in Turkey, Turkish ID education appears to include inductive learning to support deductive learning conventionally. However, according to an unstructured observation in a previous assignment, a gap is suspected to exist between deductive and inductive learning. When students omit or ignore analysing mechanisms holistically, they propose superficial and failing designs. In this research, the ability of students to design mechanisms is focused on and a toolkit is designed hereby. However, the criticism can be broadened to all of the engineering-based courses in further studies.

Toolkit and Methodology of the Research

The toolkit is best described in comparison with existing practice. Contemporary ID education in Turkey is explained in Figure 1. The existing curriculum is nearly identical to Hubka and Eder's (1987) classification of design science. Thus, a version of it is used in the toolkit.

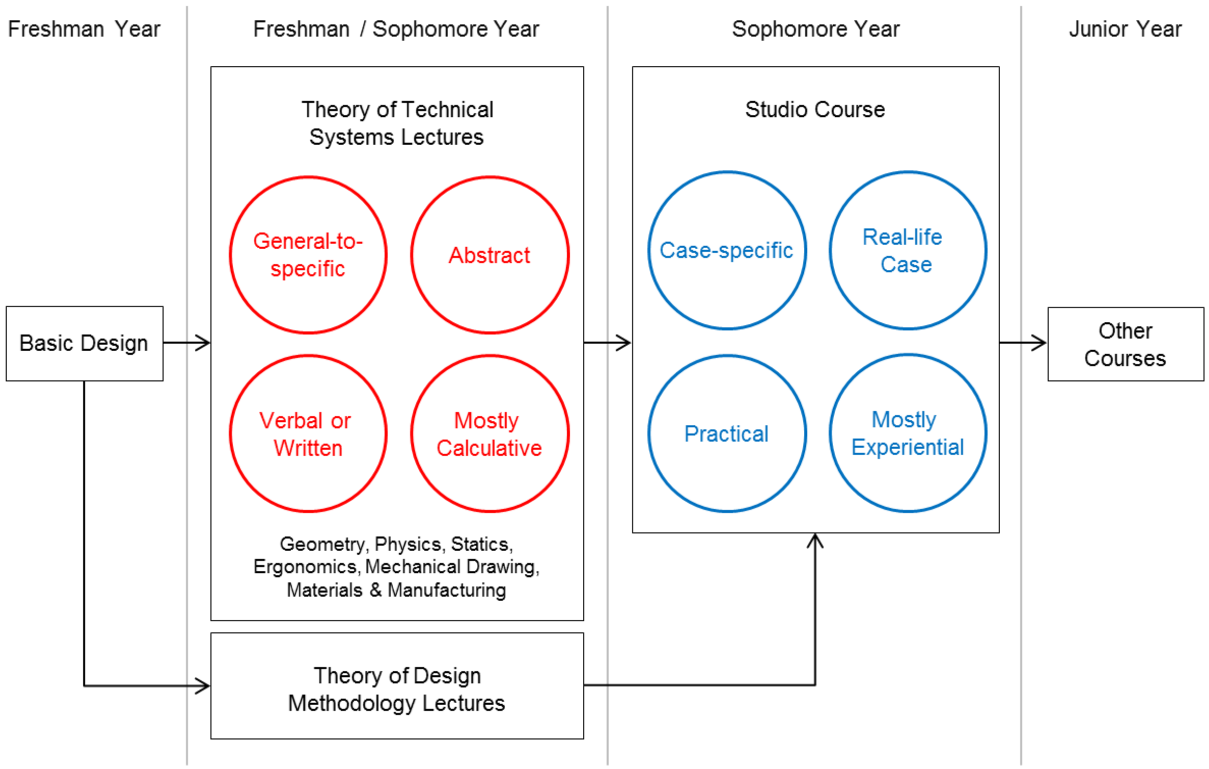

Figure 1. Contemporary ID education in Turkey

A freshman year in ID education is usually focused on basic design. However, students take lectures about the theory of technical systems and the theory of design methodology simultaneously. These lectures are usually general-to-specific, abstract, verbal or written, calculative and focused on reductionism. In the sophomore year students continue to participate in these lectures, beside studio courses. Studio courses are almost completely experiential, active, hands-on and require a totally holistic approach. Lectures on theory of technical systems are nearly the total opposite of the studio courses. The flow of theory to experiential learning is a typical two-staged deductive learning style.

The toolkit adds two phases between theory and experiential learning. Learning in the first stage is semi-deductive and experiential, but it needs a calculative approach. There is a case, yet it is abstract. Students are mostly active; however, they learn in a general-to-specific pattern. The second stage is semi-inductive. Unlike the first stage, an assignment is a real-life case and learning is in a specific-to-general pattern, while still holding a calculative design approach (Figure 2).

The toolkit benefits from a simplified classification of mechanisms: speed reduction (1), vector manipulation (2), timing (3) and reversing (4). In the first stage students research, design and prototype an abstract mechanical system. Designed objects should have only a little sense-making purpose and designs must be driven only by hand-power. In this way, students are not distracted from the engineering focus. In the second stage, students are asked to develop and present their designs about a certain product definition. Requirements of the assignment are including at least two of the mechanisms studied and electronic drives and sensors are not allowed.

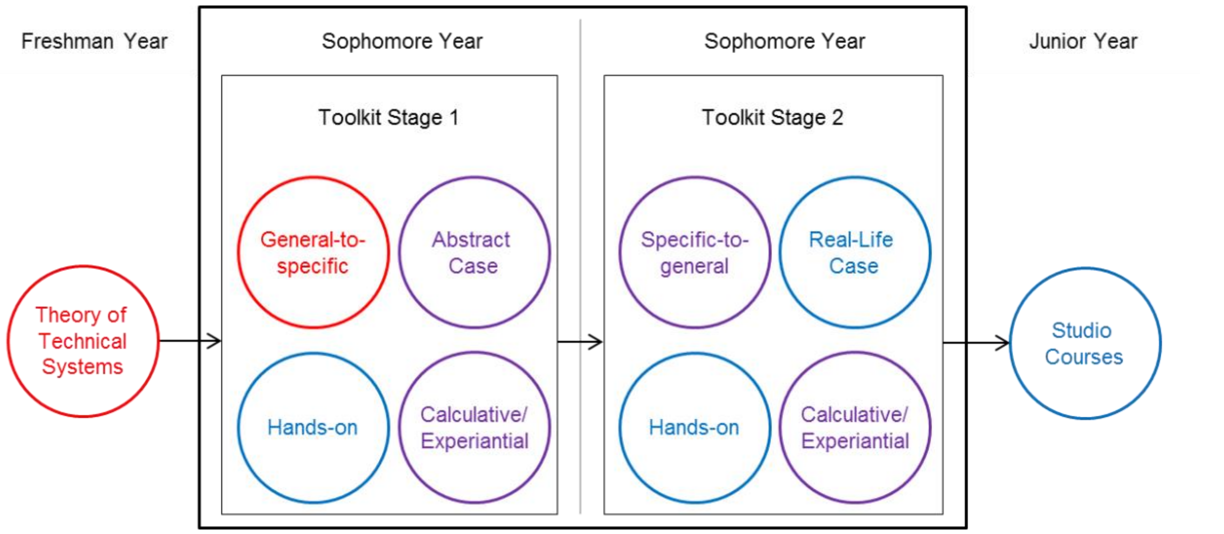

Figure 2. The toolkit

The purpose of the toolkit is to help students relearn theoretically gained engineering knowledge in the lectures on the theory of technical systems with an experiential and hands-on learning approach. The toolkit put emphasis on evaluating the competencies of the students holistically. Assessment of the students should be made considering this purpose; therefore, the toolkit includes the slightly modifiable assessment guide below, which is answered by each instructor via a 5-points Likert scale:

1. Does the design meet the required mechanical functions?
2. Are the functions of the mechanisms consistently designed?
3. Does the student have comprehending knowledge of mechanisms?
4. Does the prototype fully operate?
5. Is the material selection adequate?
6. Is the structure appropriately designed?
7. Are the joints and beddings properly designed?
8. Is it ergonomic?
9. Is the design original?
10. Is the purpose of the design clear?

The toolkit suggests evaluating the students at the end of both phases through the above-mentioned guide. Final evaluation is an overall score while differences between the assessments show the efficiency of the toolkit.

Research Methodology

The aim of the research is to present a toolkit to increase learning efficiency of the theory of technical systems for ID students in Turkey, intending to provide a controlled transition from theoretical to experiential learning. The research question is, "does the toolkit make contribution to the teaching of theory of technical systems for the ID sophomore year students?".

The toolkit was applied to 36 students of the ID department of [anon] University. While it is non-probability sampling, the sample represents itself. One of the students left during course, thus, 35 participants were evaluated by the assessment guide of the toolkit. A paired-samples t test was preferred for statistical analysis of the assessments. In a paired-samples t test, measures repeat on the same subjects over a period and minimum of 30 samples are required (Zimmerman, 1997).

Students participated in a 5-point Likert scaled questionnaire. As well as that, they answered a 3-point semi closed-ended question. 31 students returned the questionnaire. Researchers used participant observation to triangulate the findings.

Findings of the Toolkit

The findings regarding the toolkit are presented in terms of participant observations, student questionnaire results and lecturers' assessments, respectively. Images of the selected prototypes are given in the following order: first stage outputs in the left, second in the right.

Participant Observations

In the first stage, P5 (participant 5) could build a merely working abstract toy. However, in the second stage P5 designed and prototyped a fully operating leaf sweeper, driven by its wheels while the product is being pushed. Considering that belts, pulleys, bedding and shafts are designed appropriately, P5 improved notably in the second stage (Figure 3).

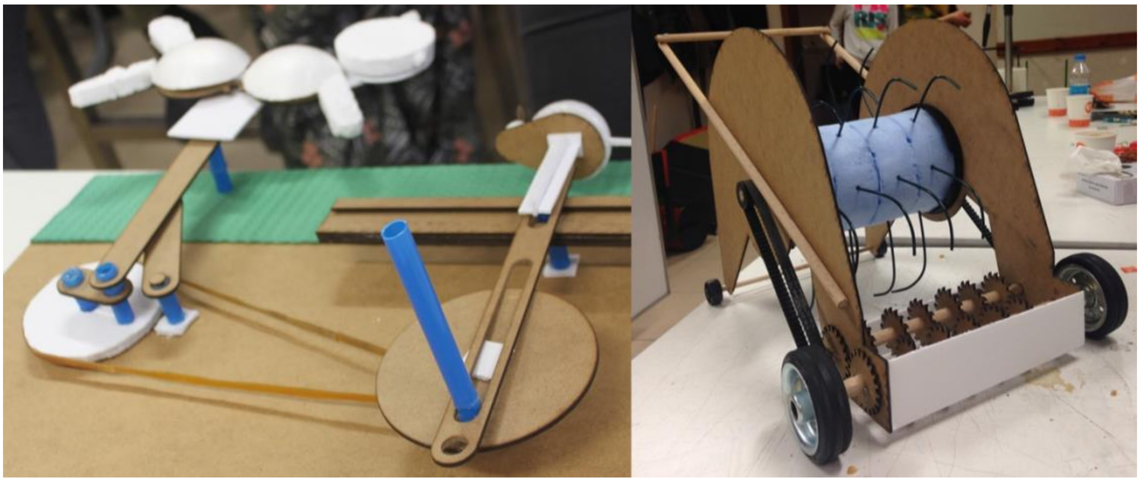

Figure 3. Toy and leaf sweeper (P5)

The first prototype of P8, a stamp tool, tended to tip over due to the weak design of joints. The chassis design and steel usage in the second design, a shredder, shows that the structural design approach of P8 is eminently changed (Figure 4).

Figure 4. Stamp tool and shredder (P8)

In Figure 5, P17's olive oil extractor design, on the right, is structurally more consistent compared to her first stage design, an abstract crane. And in Figure 6, P19's sowing machine design, on the right, is designed clearly in a more holistic approach, regarding the joints and bedding of the structural and the moving elements are designed more appropriately compared to her first stage design, a toy with a turning table. The mixer design of P27 (Figure 7), on the right, uses a planet gear which is fully operating. However, in the first stage, P27 designed a merely working, moving diorama. Thin and yielded shafts are visible on the left.

Figure 5. Crain and olive oil extractor (P17)

Figure 6. Toy and sowing machine (P19)

Figure 7. Moving diorama and mixer (P27)

In Figure 8, welded steel chassis, steel shafts and bearings are visible in P30’s second stage design, a dust cleaner. However, the student lost her control over visual output due to outsourcing most of the elements.

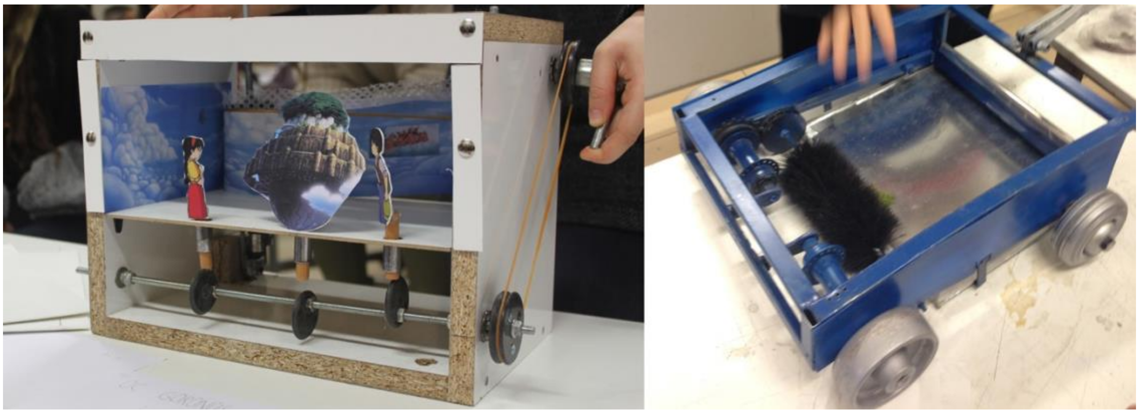

Figure 8. Moving diorama and dust cleaner (P30)

P36, produced a fully operating and reasonable prototype in the first stage, a short movie toy, (Figure 9). In the second stage, P36 designed a four-bar connection with customizable bar and pendulum lengths, which let the user to draw variety of patterns on walls. The second stage output of P36 was succeeded by seeking a function driven novelty, as well as designing proper details for manufacturing. The output can be shown as a good example in terms of the results of the toolkit.

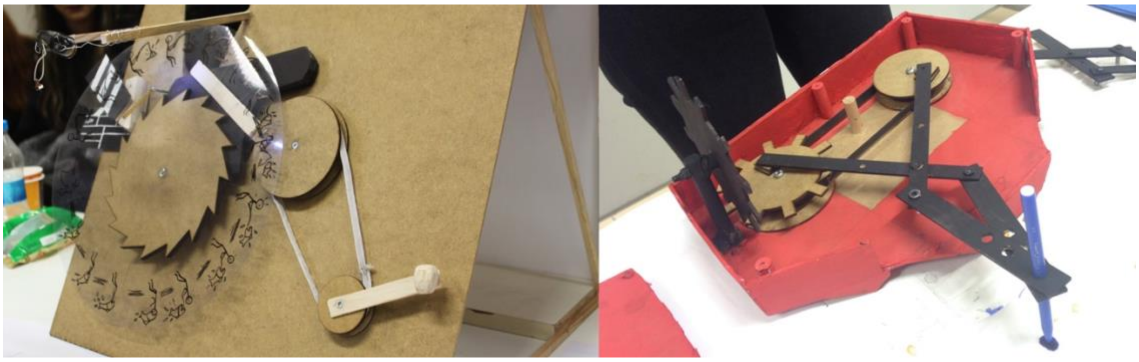

Figure 9. Short movie toy and drawing tool (P36)

Findings of the participant observation support that the toolkit can be useful to improve the cognition of the students of how mechanisms work and how they should be included. A notable number of students explored mechanical configurations as a tool for seeking novelty. However, most of the students were criticized during the juries about ill-designed ergonomics and visual aesthetics.

Students were not restricted to process specific materials when prototyping. However, they frequently outsourced laser cut medium density fibreboards. Because of the ID department having only a few machines, laser cutting of these boards can be outsourced from nearby facilities. Some of the students outsourced sheet metal cutting, bending and welding or milling of steel and aluminium. Only a few students benefited from 3d printing because of the long printing times needed to print numerous parts. Considering that it is more expensive and time-consuming to process metals and to 3d print, students may fail to revise and optimize their prototypes due to lack of time and financing. Most of the students tried to use simple tools to form cardboard and foam in the early stages. However, they have experienced that building a mechanical system requires higher precision than hand crafting can offer. Thus, lecturers agreed that laser cutting of fibreboards is more beneficial where applicable. Thus, some of the students were advised to benefit from laser cutting accordingly.

Student Questionnaire

In the first two questions, students evaluated their progress of vocational knowledge in the theory of technical systems and theory of design methodology. Three-fourths of the students agreed or strongly agreed that the project helped them learn skills in both contexts. While 7% did not agree, 16% were neutral. The mean of the answers is 4,06 (Q1) and 4,00 (Q2).

In Q3, students were asked if the design project helped them develop design concepts. While 36% were neutral, 29% agreed and 19% strongly agreed to the statement. Almost half of the students answered positively, and the mean of the answers is 3,48.

In Q4, students were asked if the design project guided them through their novelty seeking. 74% of the students agreed or strongly agreed to the statement. 19% answered neutral and 7% did not agree. The mean of answers is 3,94.

Q5 aimed to evaluate the opinion of the students about the effect of a project having no mechanical restrictions on their innovative thinking. Findings show that 42% of the students strongly agreed to the statement. Agreed and strongly agreed answers analysed together, 81% of the students believed that constraints suppressed their novelty seeking. The mean of the answers is 4,16.

In Q6, the aim was to understand if the students were motivated by the toolkit. Findings are remarkable: 36% of the students agreed, 29% did not agree and 25% preferred neutral. The mean of the answers is 3,26. One-third of the students who were negatively affected should be taken into consideration.

In Q7, students were given a few optional statements and asked to choose which fit their opinion. Accordingly, prototyping and making it fully operating, ideating and drawing mechanisms are the most frequent problems that students faced. However, 84~88% of the participants believe that they strove to succeed (Figure 10). Only two students chose the open-ended option, and both believed that they strove to succeed while they faced with the below mentioned problems:

(1) “To understand what a mechanism is and what is the definition of it”
(2) “To understand the problem-solving technique”

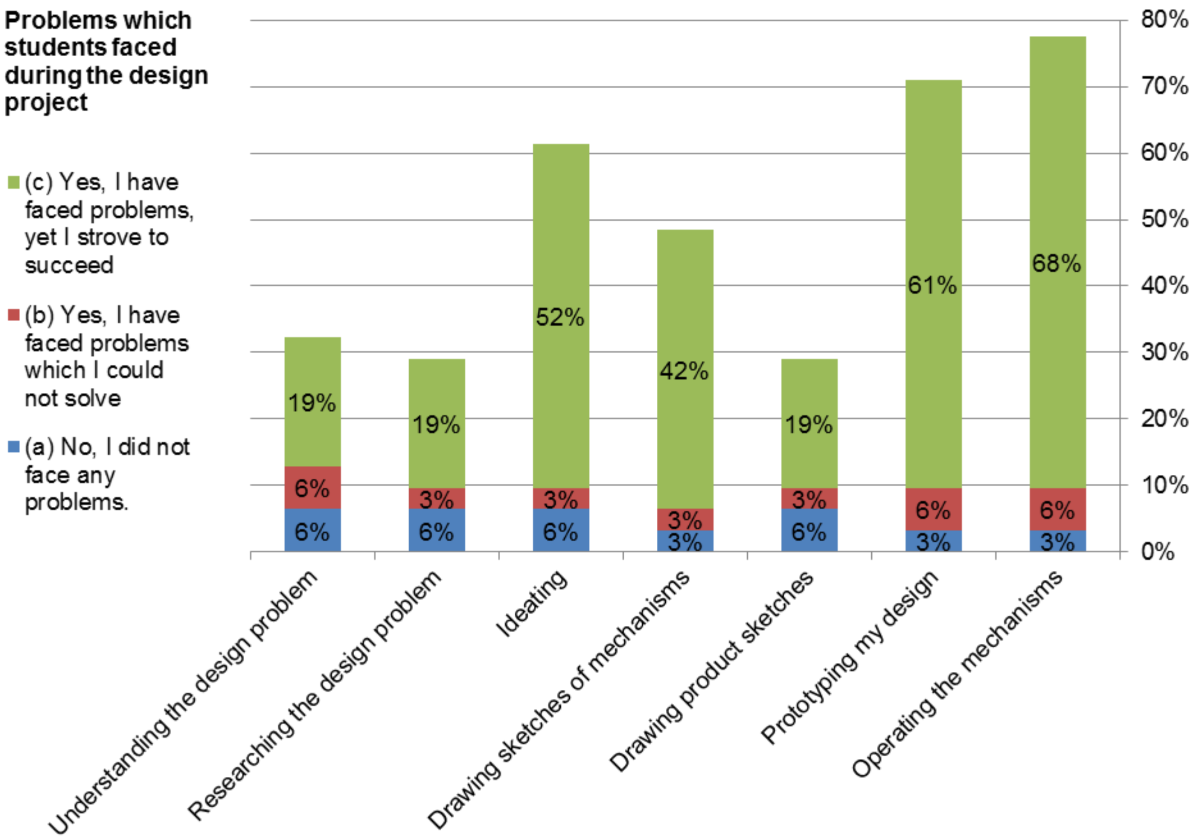

Figure 10. Results of Q7 in the student's questionnaire

In Q8 students were asked if the project helped them learn manufacturing knowledge. 55% of the students agreed, 23% answered neutral and 16% did not agree. Two of the students strongly agreed to the statement. The mean of the answers is 3,51. While some of the students processed steel, aluminium and wood which are common yet hard to process industrial materials, the rest of them used medium density fibreboard, cardboard and foam which are also common, yet easy to process by hand or to outsource, providing less learning opportunity.

In Q9, students were asked if the design project helped them learn mechanisms. The majority (84%) of the participants agreed or strongly agreed. The mean of the answers is 4,03. Considering the findings, the toolkit is evidently efficient in teaching mechanisms.

In Q10, students were asked if the design project helped them experience designing a real-world product. 52% of the students agreed or strongly agreed and 36% preferred neutral. The mean of the answers is 3,45.

In the final question Q11, the aim was to understand if the method helped students analyse and optimize their design proposals. 81% of the participants agreed or strongly agreed. Only one student disagreed and 16% preferred neutral. The mean of the answers is 4,10. The summary of all answers except Q7 is shown in Figure 11.

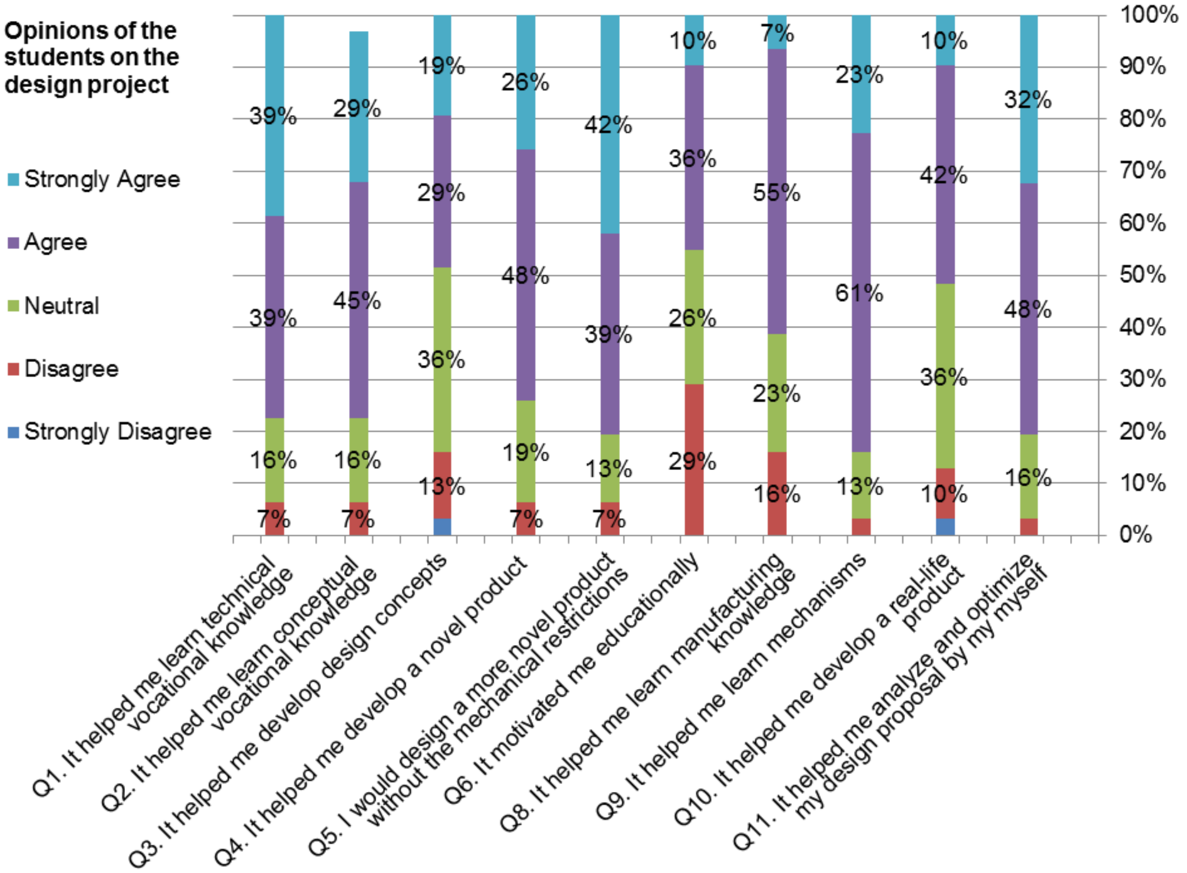

Figure 11. Results of the student's questionnaire

Assessments of the Lecturers

5 lecturers evaluated 35 students individually over 10 assessment criteria for each of the 2 mentioned stages. In total, 3,498 valid and 2 missing answers were analysed. In the second stage, the average of the student scores in each criterion increased between 8,5-20,8% when compared with the first stage. Students built structures (A6), bedding and joints (A7) with over 20% improvement. Students showed less than 10% progress between the two stages in meeting functional requirements (A1), obtaining comprehending knowledge of mechanisms (A3) and building fully operating prototypes (A4). Considering that students progressed at least 8,5% in all the criteria, the toolkit has been useful in the education of the theory of technical systems (Figure 12). 74% of the students progressed in the second stage, at least in half of the 10 criteria. On average, each student progressed in 7 assessment criteria. Notably 34% progressed in all the criteria, and only 9% showed no progress at all. For each assessment, 20~37% of the students got equal or worse scores with respect to the first stage. The average progress of assessments is 71%.

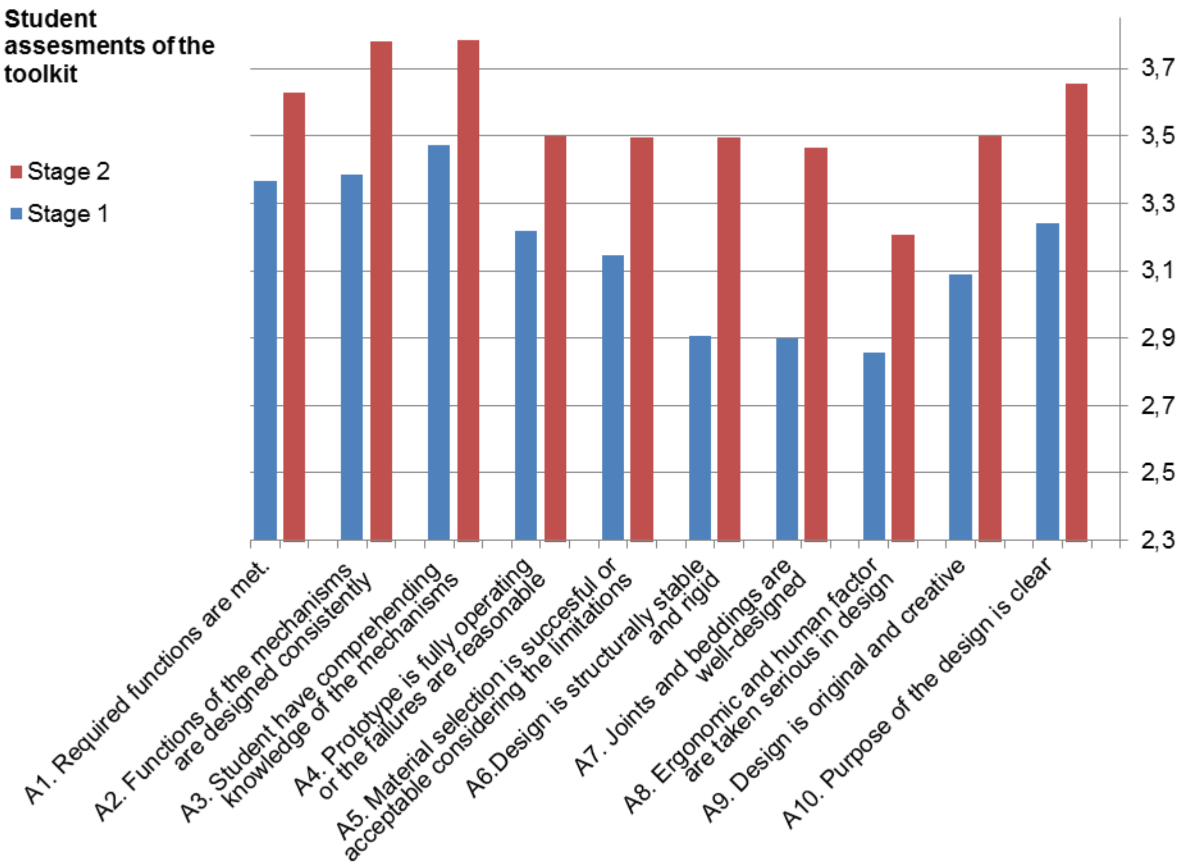

Figure 12. Lecturers' evaluation over 10 assessment criteria in both stages

The variation of each assessment criteria in both stages are validated in the 0,01 or 0,001 confidence intervals through a paired-samples t test (Table 1). However, sample size should be enhanced for providing a better idea about a larger population.

Table 1. Paired-samples t test results of the assessments

Paired-Samples t test			
Stage 1 compared to **Stage 2**	t	df	**Sig.-2 tailed (p)**
A1. Required functions are met.	-3,69	34	0,001
A2. Functions of the mechanisms are designed consistently.	-4,9	34	0,000
A3. Student have comprehending knowledge of the mechanisms.	-5,06	34	0,000
A4. Prototype is fully operating, or the failures are reasonable.	-3,14	34	0,003
A5. Material selection is successful or acceptable considering the limitations.	-3,31	34	0,002
A6. Design is structurally stable and rigid.	-5,09	34	0,000
A7. Joints and beddings are well-designed.	-6,03	34	0,000
A8. Ergonomic and human factor are taken serious in design.	-3,72	34	0,001

A9. Design is original and creative.	-3,52	34	0,001
A10. Purpose of the design is clear.	-3,84	34	0,001

Consequently, while the application of the toolkit shows significant signs of progress in learning of the theory of technical systems, it is also seen that some further revisions would stimulate an increase in the motivation of students.

Discussion: Validity of the Toolkit

It was considered by the staff that hands-on learning is influential when teaching the theory of technical systems. There has been obvious progress, yet designs were overwhelmingly focused on developing a fully operating prototype, often ignoring the visual aesthetics of designed products and, in some cases, the ergonomics. Although the criticism is substantial, the progress in learning of the theory of the technical systems is worthy. On the other hand, aesthetics in pedagogy should not be considered only for the visual quality of products. It is any kind of sense perception (Faste, 1995) during learning. In fact, even though art lost its priority in ID education (Findeli & Benton, 1991), aesthetic approaches are still implemented in ID pedagogy by benefiting hands-on and experiential learning methods (Düzenli, et al., 2018; Belgin Dikmen, 2011). However, it is a question of debate if these implementations are sufficient or conscious (Roozenburg, et al., 2008; Bingham, et al., 2015; Yavuzcan & Şahin, 2017). Consequently, it is understood that there is room for improvement. Implementation of the toolkit displays that teaching of mechanical engineering knowledge is one of the topics of this debate. Benefits of the toolkit are mostly significant on the learning of mechanisms and structures among all the subjects of the theory of technical systems. Neither observations nor student questionnaire indicates a conflict with the findings of the toolkit. Thus, considering the arguments of companies that graduates particularly lack the knowledge of mechanical systems (Domermuth, 2009), the proposed toolkit can be beneficial. On the other hand, students criticized the mechanical restrictions of the toolkit as an obstacle for seeking novelty. Nevertheless, in the overall review, they found the application helpful. Briefly, the method is useful for ideating in a structurally and mechanically reasonable way, embracing a “knowing how” motto (Sheppard, et al., 2006), yet restrictions may be limiting. While one-third of the students disagreed that the project motivated them educationally, another one-third agreed to the statement. Some students may not be interested in mechanical designs. Heterogeneity on interests is foreseeable, and lack of interest can demotivate the students. Considering that the toolkit is focused more on knowledge of the theory of technical systems and hands-on learning, it may be expected that some of the aspects of an ordinary design assignment will be missing. These missing aspects can be compensated by other assignments, while students’ lack of motivation is a matter of concern. Moreover, material restrictions are also necessary in the further applications for learning manufacturing knowledge more intensively, despite restrictions being demotivational. It can be assumed that the accessibility of tools and machinery is substantial (Zeng, 2017), as the toolkit benefits hands-on approaches.

Conclusion

A long-known debate exists behind teaching the theory of technical systems to ID students. Companies often request engineering-oriented knowledge from the graduates (Erkarslan, et al., 2011; Kındı, 2007), yet researchers heavily discredit the reductionism of the employers (Horváth, 2006). Nevertheless, considering that graduates severely lack engineering skills

(Domermuth, 2009), education of the theory of technical systems should be a matter of concern. Curricula of ID schools in Turkey already include both lectures on the theory of technical systems and theory of design methodology as well as experiential learning in studio courses that are based on inductive and deductive learning. Considering that these lectures are prior to studio courses in Turkey, teaching the related engineering knowledge to ID students is clearly a deductive learning approach.

The applied toolkit shows remarkable signs of progress in comprehending technical systems. Findings validate the research question: The toolkit contributes to the comprehension of the theory of technical systems through building a structured transition between theoretical and experiential approaches. Thus, the toolkit can be beneficial in CDIO approaches, considering that experiential learning and holism are the bases of CDIO. Further amendments of the toolkit should consider the criticism that restrictions may be demotivational, limiting the search of novelty and decreasing visual quality of the design proposals. Restrictions could be narrowed moderately; however it should be noted that they have a worthy role in the hands-on learning approach of the toolkit.

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