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How Electronics Knowledge Relates to Industrial Design Education

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Abstract

This study has two purposes: To clarify how industrial design relates to electronics knowledge and to determine whether industrial design education is sufficient for teaching it. As digital product design is frequently focused on the design of virtual interfaces until recently, less attention was paid to the design of physical interactions and electronic interfaces. There is increasing interest in electronics education in industrial design, yet electronics is still a bottleneck for many industrial designers. What electronics knowledge industrial designers should have and whether they know it is debatable. Therefore, the study presents a literature review and thematically analyzed interviews to determine its scope. Then, a survey is planned based on the concepts which interviewees remark on. The survey aims to determine whether senior-grade and fresh-graduate industrial designers use correct reasoning in design cases based on electronics. Findings remark that two-thirds of the participants failed in the critical electronics domains and their reasoning scores are distributed equally depending on whether they took electronics courses. Therefore, it is discussed that there is a need for developing a common understanding of the role of electronics in design education. And it is recommended that the approach may focus more on a hands-on terminology education.

Keywords

Industrial design education, product design education, design engineering, design curriculum.

Introduction

The consensus in the literature is that the education and practice of industrial design are multidisciplinary or interdisciplinary (Li-Jun et al., 2016). However, the diversity and extensity of these disciplines, particularly engineering, are debatable. Although the connection between industrial design and engineering is widely acknowledged, it is debatable whether branches other than mechanical engineering are related to traditional industrial design education. This research focuses on one of the *other* branches: electronics engineering. Considering that digitalization is the new *megatrend* of the economy (Stein, 2015), the research discusses that, whether knowledge about electronics should be one of the major focuses of industrial design education.

Semantic Approach

Industrial design is often explained as a discipline closely related to mechanical engineering (Tavrou, et al., 2011; Akbulut, 2015). Because *industry* often implies mass production and manufacturing machines (Kemp, 2013), being *industrial* semantically refers to automated manufacturing. However, numerous industrial designers work as user experience or interface designers nowadays, and fewer designers are employed in physical product design (World Design Organization, 2020; Gill, 2003; Howell, et al., 2016; Vial, 2015; Trathen & Varadarjan, 2017). Therefore, entitling the profession industrial design was reasonable when manufacturing industries were emerging (Vial, 2015). However, arguably the industrial design title is inadequate to clarify the present scope of the profession.

Industrial design and *product design* are often used interchangeably. Confusingly, both titles deal with producible design (Nazarenko & Kazachkova, 2019; Kim & Lee, 2016). Therefore, the term *product* also affects what industrial design means. Whether it has a mass, any object, environment, or activity produced by humans is a *product* (Junginger, 2008; Margolin, 1995). However, semantically, *product* in economics and colloquial speech often refers to physical goods produced by the manufacturing industries (Durmaz, 2009; Lager, 2000). Accordingly, *industrial* designers may be responsible for designing *non-industrial* things.

On the other hand, as discussed below, there is a gap between *industrial* and *virtual.* Due to the growing popularity of e-service design (Funk, 2007), interface design is overgeneralized to design an internet or application-based medium (Benyon, 2019). *Digital* is often mistaken for what is graphical and intangible, and for software (Rask, 2005; Hui & Chau, 2002). Yet, hardware is digitalized as well (Page, 2016). Some researchers argue that *digital product design* is designing an object that includes a display and/or its software interface (Oygür İlhan & Karapars, 2019). However, technically, what distinguishes digitalized products is the binary logic (Stein, 2015; Ligthart, Porokuokka, & Keränen, 2016). Plenty of digital components exist other than displays. However, *digital product* in industrial design does not imply a technical basis. Therefore some studies criticize the usability literature for often focusing on software and underline that any physical part of a product that users interact with is a user interface (Dumas & Redish, 1999; Norman, 2013).

Being digital and being technological are interconnected phenomena. Although *technology* refers to the knowledge of any type of production (Fomunyam, 2019), being technological is about the complexity and novelty of the problem solved (Soltanzadeh, 2015). Therefore, society perceives technology as synonymous with the Internet and computers (Lachapelle, Cunningham, & Oh, 2018). However, plenty of other objects also benefit from complex digital technologies. Many simple devices, a remote controller, for instance, compute many choice axioms. Nevertheless, many would probably not regard it as digital. The discussion above points out that if a product does not contain a display and/or resolve a complex problem, it is often regarded as non-digital. However, designing digital hardware interactions and experiences is still essential (King & Chang, 2016).

Pedagogical Approach

The perceived quality of any sensory experience is aesthetics (Shusterman, 2011). Aesthetics is a branch of philosophy that deals with beauty (Walton, 2007). Industrial designers focus on the aesthetics of everyday objects (Akner-Koler, 2007). They design satisfactory experiences (Norman, 2013). Unlike the society considers, neither design nor aesthetics is focused only on visual beauty (Borja de Mozota, 2006; Faste, 1995). Therefore, if a design interacts with humans, but is designed to satisfy all sensory perceptions, it is a *good design*. And it is the expertise of an industrial designer (Moody, 1980; Vial, 2015). Contrarily, there is a concept titled *silent design.* It refers to the designs of someone who is not formally educated to design a product considering aesthetics (Gorb & Dumas, 1987). However, it is controversial whether formal education of industrial designers provides them with enough skills to design aesthetic elements other than visuals.

In early industrial design education, schools implemented specialized workshops, where students experientially learned tactile, auditory, and olfactory experiences of materials and finishing while designing (Lee, 2006; Birringer, 2013; Moholy-Nagy, 1939). However, the emphasis on experiential learning did not last long. Schools reduced the variety of workshops due to economic and political reasons (Weingarden, 1985; Betts, 1998; Findeli & Benton, 1991). Later in the 1950s and 1960s, a theoretical approach towards materials, production, and aesthetics emerged (Rhi, 2019), which forms the basis of the common approach in the present industrial design education. Since then, it is arguable that students lack in prototyping real materials or components. Therefore, they learn less about designing tactile, auditory, and olfactory features of an object and some visual aspects such as the brightness of an indicator. Consequently, industrial designers paid less attention to user experience than visual aesthetics until the previous decade (Norman, 2013). Therefore, the reason why industrial design is often considered as designing visual aesthetics (Borja de Mozota, 2006) may be the lack of experiencing in education. Ironically, industrial designers who fail to design all experiences of the objects, are the cause of *silent design* (Gorb & Dumas, 1987).

Epistemological Approach

Experiential learning is one of the most efficient learning styles. One learns more when one gets involved in the activity rather than listening or observing only (Wood, 2004). Moreover, some knowledge cannot be learned without experiencing. One cannot learn driving until one experiences driving, despite one is told what pedals are used for. Therefore, experiencing is often hands-on, sensorial, subjective, implicit, and sometimes unconscious (Groth & Mäkelä, 2014). Vice versa, theoretical knowledge is objective, explicit, common, taught verbally or written, and learned consciously.

Except for being theoretical or experiential, part of the knowledge in industrial design is also often mentioned as *technical*. *Technical* and *technological* terms are used interchangeably. Therefore, part of an industrial designer’s knowledge is based on engineering, as engineering is the source of technological knowledge by applying scientific theories into practice (Günay, 2018). And presently, engineering education is focused on learning and experiencing through *Conceive, Design, Implement and Operate* (CDIO) approach (Mauryo & Ammoun, 2018). Therefore, technical knowledge is not necessarily theoretical in engineering education. Instead, it becomes more experiential. Nevertheless, technical knowledge in industrial design education is criticized for being overly theoretical and focusing on the manufacturing economy and mechanical domain (Yenilmez & Bağlı, 2020; Varekamp, Keller, & Geraedts, 2014).

On the other hand, experiential learning is relearning previously met knowledge (Yavuzcan & Gür, 2020). One must be told what the pedals are used for, before or during one experiences driving for the first time. Accordingly, theoretical knowledge is still essential and beneficial, as long as it is not too intense and learned to provide a basis for experiencing. There are a few studies that emphasize that teaching electronics over-theoretical does not fit the perception of industrial designers (Molwane, Sheikh, & Ruele, 2017). Instead, it is suggested that they would learn better by tearing objects down and prototyping electronics which is a typical CDIO approach (Romero et al., 2012). And it is argued that if a prototype of a design is to be made, it is necessary to prototype electronics as well (Seetsen et al., 2019). For now, prototyping is the only common option for designers to experience the sensorial features of what they are designing. Therefore, theoretical knowledge of electronics is argued as necessary for industrial designers, yet necessitated knowledge is not that extensive (Seetsen et al., 2019). Industrial designers do not design or prototype printed circuit boards. Instead, they build simple circuits often through physical programming with ready-made kits, Arduino in particular (Page, 2016). However, theoretical knowledge is not only beneficial while prototyping. Industrial designers may never design circuits themselves, yet fundamental electronics knowledge will still be beneficial in practice for transdisciplinary communication (Romero et al., 2012).

Although formerly graduated industrial designers are often not trained in electronics, many of them designed electronic appliances (Varekamp et al., 2014). They experienced situations where electronics knowledge is necessary. And they usually consulted experts. However, researchers point out that industrial designers communicated in *designerly* ways. They benefited only a little from technical terminology. And what they designed is often unfeasible. Researchers underline that courses on electronics were marginal in the early 2010s (de Vere et al., 2010; Pedgley, 2010; Moalosi & Molokwane, 2008; Varekamp et al., 2014). Therefore, nearly a decade ago, lacking these courses resulted in industrial designers suffering from deficient terminology.

Electronics in the Curriculum

Presently, interest in electronics-based technology education increased. Numerous design departments and polytechnics offer courses on electronics or mechatronics. TU Delft in the Netherlands, Loughborough and Brunel in the United Kingdom, University of Aegean in Greece, MSFAU and METU in Turkey, Monash in Australia, and NUS in Singapore are some of the many. Nevertheless, in Turkey, such courses are still few in number. However, some lecturers state that they initiatively modify the contents of courses such as *materials, manufacturing,* or *ergonomics* to include electronics. Arguably, a common ground has not yet been reached due to the types of design programs being diversified worldwide. The programs are classified into these types except for the unique ones:

1. Design
2. Industrial design
3. Product design
4. Industrial design engineering
5. Product design engineering

A typical example of the classification above, Loughborough (2023) offers 4 types of design-related undergraduate programs: design, industrial design, product design & technology and product design engineering. The programs contain technical courses, from less to more, in the above-mentioned order. And their emphasis on prototyping and designing for manufacturing increases in the same order. The engineering program offers numerous technical courses on various technical domains, including electronics. However, programs other than engineering benefit more from common social sciences based courses. Nevertheless, product design and technology program still gives more credit to designing for manufacture. And the program includes a compulsory course titled Electronics, Programming, and Interfacing.

On the other hand, some of the engineering programs have more in common with the design programs. TU Delft (2023) offers *industrial design engineering* as the only undergraduate program. It includes numerous compulsory and elective courses based on both social sciences and technical knowledge. The program emphasizes producible design, yet it still includes typical design courses. These electives directly focus on electronics: *Electronics for Product Designers* (TU Delft, 2022) and *Interaction and Electronics* (TU Delft, 2022). During these courses, by designing, analyzing, and prototyping via Arduino and programming tools, students are taught the fundamental concepts and components: circuits, energy sources, what sensors, actuators, and controllers are, and differences in analog and digital electronics. For further research, readers may visit the course browser of TU Delft: studiegids.tudelft.nl.

Furthermore, some industrial design programs differ from others in their approach to electronics. MSFAU (2022) offers two electives, despite it originally is a fine arts university. *Product Electromechanics* focuses on basic principles of electrics, circuits, micro components and elements of digital electronics, Arduino and coding. *Smart Industrial Products* is based on graphics based programming. METU offers two electives. One is *Interactive Prototyping for Designers* (METU, 2022). As a former lecturer mentioned, the course emphasizes teaching a basic understanding of electricity, circuitry, sensors, and actuators through hands-on experiential learning through building circuits and coding.

Except for the specific courses on electronics, electronics knowledge is often an element of systems thinking. It is often included implicitly or explicitly in education. Systems thinking is a holistic approach which prefers to examine elements in the context of their relationships (Ghim, 2022). It regards the complete product experience as the coherent integration of a set of experiences. Since the product-service systems emerged, in which the objects and the services are integrated, it necessitates a systematic approach to product design (Greene, 2019). Following a systems-thinking approach, students design flow charts and schemes as well as the physical aspects. In this way, they develop a better understanding of complex interactive things. NUS Division of Industrial Design (2022) offers a specific course titled *systems-thinking*. And many others, the University of Cincinnati, for instance, integrate the approach into studio courses (Ghim, 2022).

As researched through the Turkish Higher Education Institution (2023) website, the majority of the undergraduate design programs in Turkey are titled *industrial design.* The few engineering programs offer courses on various technical domains, including electronics, fluid dynamics, thermodynamics, etcetera (Erciyes University, 2021). Therefore, it is argued that design engineering departments should not be considered as a version of industrial design due to their cross-discipline basis (Akbulut, 2015). The following question can be answered based on the above section. Do design programs include electronics, apart from design engineering? Yes, many do. Yet, many do not. Besides, any design program may offer electronics unless it puts too little emphasis on producible design.

Methodology: Rationale and Scope of Electronics Knowledge

Considering the conceptual framework given above, this study, which is based on an ongoing doctoral thesis, argues that, despite the increasing interest in electronics worldwide, there is no common approach. Except for a few, courses are often elective. Many programs still do not offer any, particularly in Turkey.

The study presents the recently completed phases of the research: Interviews and the survey. A conference proceeding has been published in Turkish (Gür & Yavuzcan, 2021). It presents the interview findings. The survey, published hereby for the first time, is designed based on the interviews. Therefore, the methodology and findings of the interviews are given in detail. Interviews and the survey together have two purposes and three research questions:

P1. To determine the details of electronics knowledge required in industrial design,
RQ1. What electronics knowledge do industrial designers need and why?
RQ2. What benefits and harms does electronics knowledge bring to industrial designers?
P2. To find out whether industrial designers have the necessary knowledge,
RQ3. What electronics knowledge do industrial designers currently have?

What these questions search for is implicit. Implicit knowledge is subjective and varies based on the experience of each subject (Leonard & Sensiper, 1998). Answers may depend on what problems participants face, what they need, and what is expected of them. Subjective opinions and beliefs are typical data in qualitative research (Creswell, 2007). Therefore, the research is qualitative. Moreover, because what participants may argue cannot be predicted in detail, closed-ended questionnaires are not reasonable. Consequently, interviewing is preferred in the first stage, as the non-response rate to the open-ended questions is much lower in interviews than in surveys (Reja et al., 2003; Manfreda et al., 2002). Semi-structured interviewing is the most appropriate, considering that structured interviewing is based on closed-ended questionnaires, and unstructured interviews could fail to stay focused on the subject (Stuckey, 2013; Carruthers, 1990). Semi-structured interviews are often based on open-ended questionnaires. They provide both unrestricted answering and comparability (While & Barriball, 1994).

Based on the recommendation that Varekamp, Keller, and Geraedts made for further studies (2014), it is considered valuable to get insights from electronic experts as well. Accordingly, six industrial designers and four electronics engineers attended interviews. The participants represent different backgrounds regarding their level of experience and expertise. Two of the industrial designers are lecturers in industrial design departments, two are employees, one is a student, and one is both a lecturer and a manager in a design studio. While employees have only two years of work experience each, those who are business owners have 19 and 12 years. The lecturers have 8 and 14 years of experience in studio courses. One of them used to give an elective on prototyping electronics and physical programming. Two of the attending electronics engineers are employees. One is a manager in an IoT start-up, and one is both a lecturer and manager of a research and development agency.

Industrial designers are asked during interviews:

- How often and what electronic appliances they design,
- Which components they often benefit from and what for,
- Whether these components significantly affect the design,
- Whether they ever faced situations that they need electronics knowledge,
- Whether could they learn it and how,
- What components or concepts they had to learn,
- Whether they benefit from the knowledge in further projects,
- Whether they make recommendations regarding electronics,
- Whether what they recommend is considered feasible,

- Whether they feel more competent as they learn electronics more,
- How much should industrial designers know about electronics,
- Should it be taught during undergraduate education,

Electronic engineers are asked:

- Whether industrial designers which they cooperated make decisions regarding electronics,
- Whether they ever encounter situations that they need electronics knowledge,
- Whether and how they acquire the necessary information,
- What problems arise when they have incomplete or incorrect knowledge,
- Whether a list of topics on electronics concepts and theories concerns industrial design,

Analysis of semi-structured interview records can be carried out inductively or deductively (Marks & Yardley, 2004; Vaismoradi et al., 2013). The deductive approach requires predetermined keywords or themes. Although it is efficient, the rich content of the raw data obtained cannot be analyzed in-depth (Braun & Clarke, 2006). Besides, considering there are limited studies regarding the phenomenon, keywords and themes are undetermined. It is necessary to derive the keywords or themes from the interviews. That is an inductive method (Hsieh & Shannon, 2005).

Interviews are converted into raw texts. The texts are analyzed either through content analysis or thematic analysis (Vaismoradi et al., 2013). The content analysis measures the number of repetitions of an explicit keyword. Therefore, the data obtained is quantitative. The thematic analysis concerns the implicit meanings of the themes rather than repetition (Hsieh & Shannon, 2005; Marks & Yardley, 2004). As the phenomenon is not yet specific enough to generate explicit keywords, inductive thematic analysis is preferred. Exceptionally, theories and components are generated as keywords. Because the purpose of interviews is to explore the phenomenon and provide a basis for the survey by expert opinion, repetition of the codes or keywords is not a concern. No statistical analyses are conducted. Therefore, the first stage is a case study.

Interview Findings

Through the thematic analysis of the interviews, 15 thematic codes and 15 keywords are determined. Thematic codes are combined under seven themes and content keywords under two. Derived codes and themes are presented in Table 1. The common attitudes of the participants and their significant statements are given below the table.

Table 1. Thematic analysis findings based on thematic codes

Themes	Codes
T1. Industrial designers design many electronic objects during their education and in practice,	C1. To frequently design electronic objects
	C2. To design many electronic objects in studio courses
	C3. Relevance of the amount of data inputs and outputs to the number of components

T2. The more an object interacts with users and the environment, the more electronic components the industrial designer deals with.	C4. Relevance of intensity of user interactions to the number of components
T3. Both internal and external components that affect the volume, mass, structure, materials, and manufacturing methods interest industrial designers.	C5. Relevance of volume and mass of an object to the components
	C6. Relevance of materials and manufacturing to the requirements of components
	C7. Relevance of form and structure to the properties of components
	C8. Relevance of form and structure to the internal components
T4. Utilizing the electronics knowledge in creative thinking stages can lead to more creative ideas or block creativity.	C9. Likelihood of leading an industrial designer to design more creative user experiences
	C10. Likelihood of leading an industrial designer to develop ideas less creatively
T5. The more industrial designers have electronics knowledge, the more their ability to manage interdisciplinary projects increases.	C11. Being able to criticize the electronic components which engineers decided
	C12. Relevance of the amount of electronics knowledge to feeling competent
T6. The amount of electronics knowledge given in education should at least be adequate for datasheet reading.	C13. Datasheets and distributors as the sources of electronics knowledge
	C14. Need for electronics knowledge in education
T7. The electronics knowledge of industrial designers might be measured by evaluating their reasoning skills while solving case problems.	C15. Irrelevance of theoretical computational skills to the expected industrial designer competencies

Predictably, all industrial designers mentioned that the increasing necessity of electronics in education and practice is related to the amount of data inputs and outputs in the technological objects. However, it is noteworthy that the participants associate the *data* phenomenon with even the most basic interaction.

> *P6 (industrial design student): Even the most basic lighting, or the charge indicator, requires electronic components. The objects that interact with the user include many electronic components because there is an input or a data reception.*

One of the lecturers assumed that nearly half of the projects given in the studio courses include basic or complex electronics. Considering that the program does not offer any courses on electronics, the assumption is notable for discussion. Remarkably, one of the electronics engineers acknowledged that interacting components concern industrial designers rather than engineers.

> *P9 (electronics engineer business owner): Deciding on a component that interacts with the user directly concerns industrial designers. Moreover, it has almost nothing to do with electronic engineers.*

Predictably, participants often mentioned interfaces and interactions. However, all industrial designers frequently marked that components affect the structure, volume, and mass. Thus, they affect the form and ergonomics. Moreover, engineers underlined that electronics affect the choice of materials and production methods. Based on the statements, electronics affect many non-electrical physical aspects of a product.

> *P5 (industrial design lecturer): Benefiting from the electronics knowledge, one might not decide to use a motor. One may prefer another approach. Then, the ergonomics and aesthetics of the object would drastically change.*
>
> *P8 (electronics engineer business employee): The volume and mass of the components matter. As some components overheat, they shall not be placed near plastics.*
>
> *P9 (electronics engineer business owner): Concepts such as electrical insulation are critical. Therefore, industrial designers severely need to know the electrical properties of materials.*

The participants shared their opinions on both benefits and harms of electronics knowledge on creativity. No generalizable consensus has emerged. Yet, their perspectives are noteworthy. What was agreed upon by all six industrial designers is that electronic knowledge is beneficial in interdisciplinary collaboration, time and cost saving, and feeling more competent.

> *P2 (industrial design employee): Industrial designers should be able to argue what is unsuitable and suggest alternatives. The electronics engineer should consider that the designer is competent in electronics at a basic level. However, electronics knowledge is not required in the early steps of design. The brainstorming phase should be free of any technical limitations. Yet, while shaping the outputs of brainstorming, the knowledge of electronics comes in.*
>
> *P3 (design studio owner): Once, my studio designed a medical device. The client requested to add a button that wakes the device up. Instead, we suggested placing a gyroscope inside to detect movement and wake the device up as the voltage increases. What we have suggested resulted in a more advanced experience, and it became much easier to design a waterproof body.*
>
> *P4 (industrial design lecturer): Students sometimes think ahead, yet other times behind the present technology. They are not aware of the existence of some types of sensors. Learning innovative technologies help them to design better products. Therefore, they get rid of unnecessary components and design smaller objects. They may benefit from sensors that suit the purpose better. However, comprehending that sensors work within certain limits may block them. Learning a lot may cause one's expertise to shift. Students may lack in thinking free if they get bogged down in the technical details.*

Remarkably, four industrial designers stated that the primary source of electronics knowledge is datasheets and websites or salespersons of distributors. They argue that industrial designers should at least be trained to read datasheets and to research and compare components. Moreover, participants criticize that their design decisions regarding electronics are often not a matter of evaluation during education.

> *P1 (industrial design employee): I often ask an expert when I need to learn something about electronics. However, I also frequently search for datasheets in Digikey. I watch YouTube videos. What I search for rarely requires advanced technical knowledge. I often compare the specifications of the existing components with the alternatives.*
>
> *P6 (industrial design student): Students often prefer to take the easy way out in the studio courses. They pick components only on whether they fit in the remaining space. Although I am often aware that a component is not applicable, I would argue that it is.*

Table 2. Thematic analysis findings based on contents

Themes	Keywords
T8. Designers should have the knowledge of components and theories which; Provide energy and movement to an object, Interact with users, objects, and the environment, Control, ventilate, heat, and cool those above, Organize, plug or assemble those above,	K1. Printed circuit boards K2. Switches K3. Displays K4. Batteries, chargers, transformers K5. Controllers, processors and memory units K6. Cables, sockets, connectors K7. LEDs, lighting K8. Electromechanics K9. Sensors K10. Ventilating, heating, cooling K11. Wireless communication
T9. Theories should be classified considering the experience of the industrial designer and the extent of the necessary knowledge.	K12. Beginner level experience K13. Expert level experience K14. Basic level knowledge K15. Superficial level knowledge

Participants often preferred to classify knowledge by its extent and the required experience (Table 2). According to the engineers, the theories based on below domains are the basic level of knowledge which beginner-level industrial designers should have.

Th1. Electrical properties of materials
Th2. Energy and power
Th3. Current and voltage
Th4. Differences between direct and alternating current (DC and AC)
Th5. Transducers and actuators
Th6. User interaction elements

And the basic principles of the concepts below are the superficial level of knowledge which experienced industrial designers should have. The participants remark that the concepts affect materials and manufacturing or the volume and mass of an object.

Th7. Printed circuit board elements
Th8. Communication systems
Th9. Electromagnetism
Th10. Antennas

Methodology: Whether Industrial Designers Have the Knowledge

The classification above clarified what theories concern industrial designers during practice. And the contents in Table 2 remarked on what components affect design projects. Therefore, each question is designed to assess the knowledge regarding one or more of these theories and components. However, how to measure the electronics knowledge of industrial designers in a field study is a matter of debate. Therefore, concluding the interviews, electronics engineers are asked for their expert opinion. All participants argued that calculative and theoretical skills of industrial designers are less beneficial than their reasoning abilities. They suggested designing short questions which represent hypothetical real-life cases.

Reasoning is the ability to draw conclusions from known facts (Cantürk Günhan, 2014). Although closed-ended multiple-choice questions are not optimal for measuring reasoning skills since they fail to assess partial reasoning, they are still reliable and efficient if only the questions and distractors are well-defined (Al Muhaissena et al., 2019; Mullen & Schultz, 2012). Accordingly, 13 cases and closed-ended reasoning questions are prepared in collaboration with two electronics engineers.

A total of 74 people participated in the internet survey, of which 18 reside in countries other than Turkey. Participants are students or graduates of 16 schools, 11 in Turkey and five in other countries. Three of them are in the majority (88%): Singapore, Australia and Greece. While 49 participants are senior-grade, the rest graduated in less than a year. The survey aims to represent the population of Turkey. And it compares the average scores of Turkey and the other countries through Chi-square, Anova, and Tukey’s post-hoc tests and descriptives.

Survey Findings: Proficiency in Electronics Knowledge

The findings for each question are presented in the order of the theories. The order is listed in the final part of the interview findings section. Each case represents a theory and component sets mentioned by the interviewees. How designers are expected to approach the case is presented below for each question.

Case 1: Kettle

Theory: Electrical properties of materials (Th1)
Components: Heating (K10)

The participants are asked what type of material is better for the electrical insulation of a kettle. They are expected to understand that boiling consumes large amount of energy. Therefore they should reason that resistors of kettles often operate in AC. Since AC may cause shock in case of malfunction or misuse, designers should reason that insulation is critical in this case. Therefore, “plastics” is correct, as others are conductive. As presented in Figure 1, notable number of the participants answered correctly.

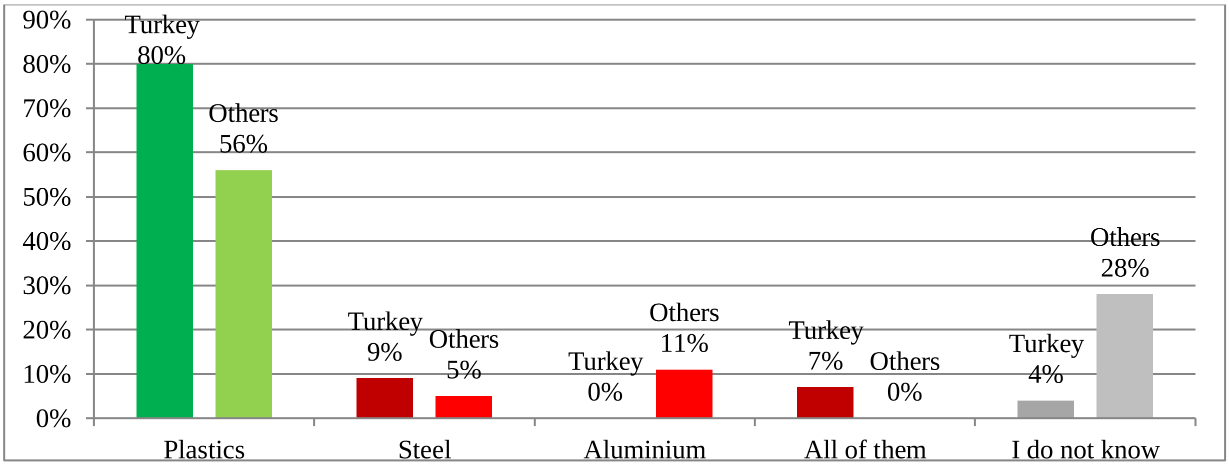

Figure 1. The material of which a kettle body is made to provide better electrical insulation

Case 2: Heating unit

Theory: Energy and power (Th2)

Components: Heating (K10)

The second case is a heating unit that is required to heat a room as quickly as possible. The participants are asked to decide what current type is the most preferable to provide the energy. The designer should reason that heating larger spaces requires a large amount of energy. Therefore, the optimal answer is AC, as AC resistors that operate on mains electricity draw much more power than DC resistors. Figure 2 presents the distribution of answers given. Remarkably, correct answers are less than half.

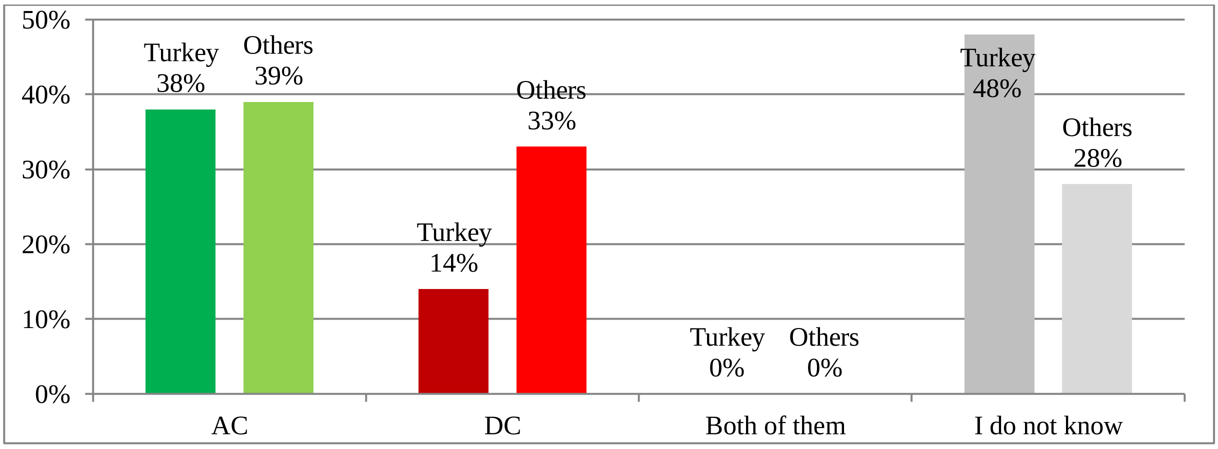

Figure 2. The preferable type of current to provide a large amount of energy for a heating unit

Case 3: Credit card reader

Theory: Current and voltage (Th3)

Components: Connectors (K5)

The third is a malfunctioning rechargeable credit card reader. The participants are asked to predict the probable cause for the overheating charging connector. Although the case is not exactly a design problem, it aims to determine whether designers understand that heat is caused by resistance against the current. Regarding the options connector resistance and overcurrent, participants are expected to comprehend that both are similar concepts and decide to answer both of them. Yet, the distractors represent partial reasoning. Distribution of the answers are given in Figure 3.

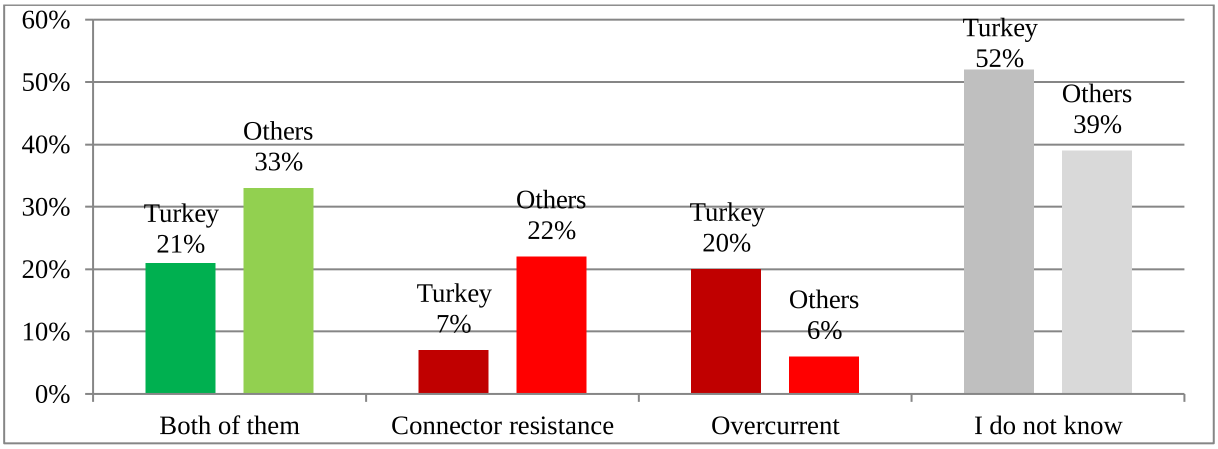

Figure 3. The probable reason for the heating of a malfunctioning charging connector

Case 4: Electric shaver

Theory: Differences between DC and AC (Th4)

Components: Batteries and transformers (K4)

The fourth is an electric shaver that is required to be washable as whole. The participants are asked to decide what type of current is safer for the user. Designers are expected to know that mains electricity is high voltage AC which may fatally shock the user. And they should decide that a battery or an adapter is preferable. The optimal answer is DC in both cases. The participants could have been asked to choose the optimal component or scenario instead. However, they might decide on the battery option as cords limit the usability, or many shavers already operate on battery. Then the reasoning would depend less on the electronics knowledge and more on scenarios and experiences.

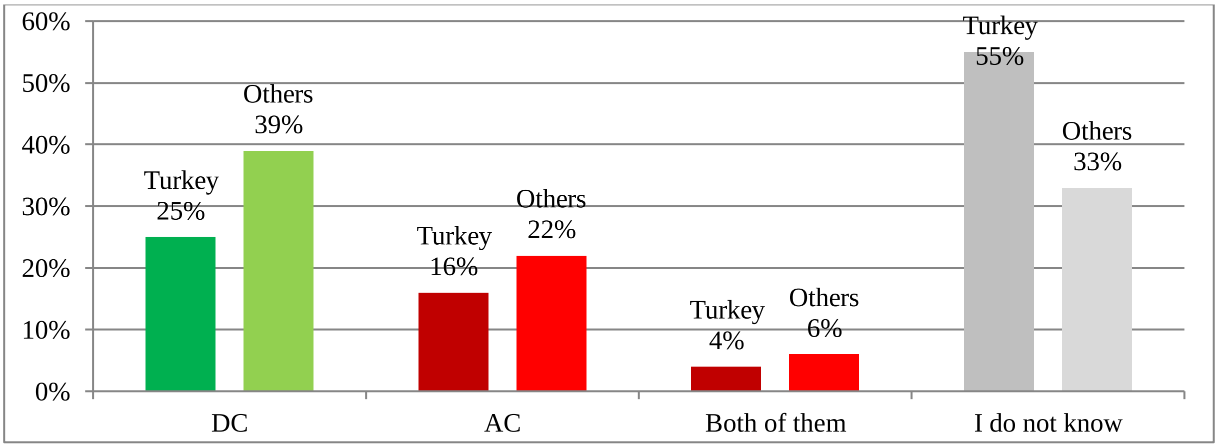

Figure 4. The safer type of current in which a washable electric shaver operates

Case 5: Desktop computer

Theory: Differences between DC and AC (Th4)

Components: Transformers (K4)

The participants are asked the reason why a power supply unit is placed inside a PC. One who knows the differences between DC and AC should be aware that computer-like objects often operate in low voltage DC. And mains electricity is high voltage AC. Therefore, one should know that the power supply is both a transformer and a regulator. However, as both of them are correct, distractors present partial reasoning in this case (Figure 5).

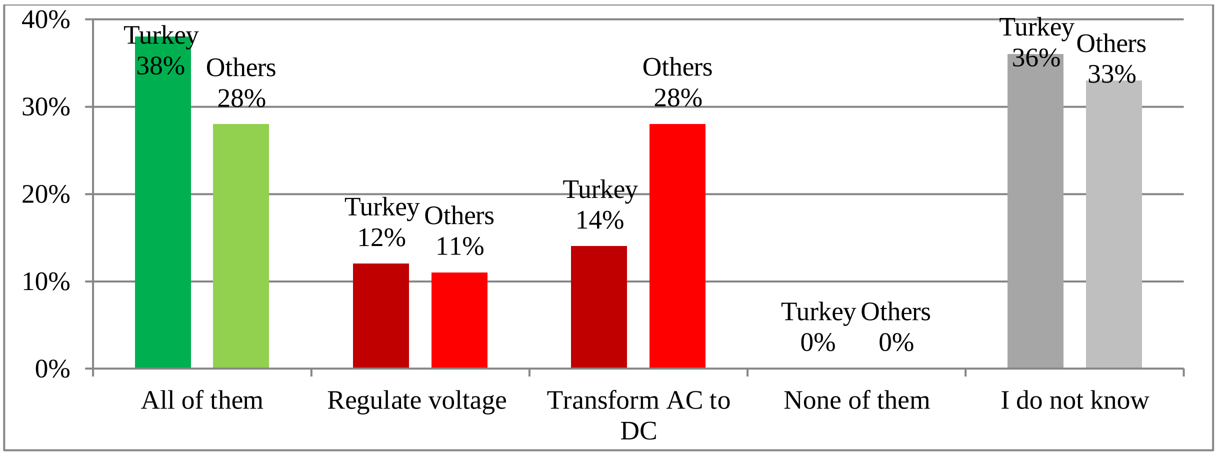

Figure 5. What a power supply is used for inside a desktop PC

Case 6: Robotic vacuum cleaner

Theory: Transducers and actuators (Th5)
Components: Electromechanics (K5) and sensors (K9)
The participants are asked what type of sensor is unsuitable for a robotic vacuum cleaner to detect obstacles without contact. Designers should know that limit switch is typical for detecting contacts. And one, who reasoned that infrared is an invisible frequency of light and ultrasonic is a term related to sound, might conclude that these two options do not require contact. As presented in Figure 6, participants in Turkey answered remarkably less correctly than the total of other countries.

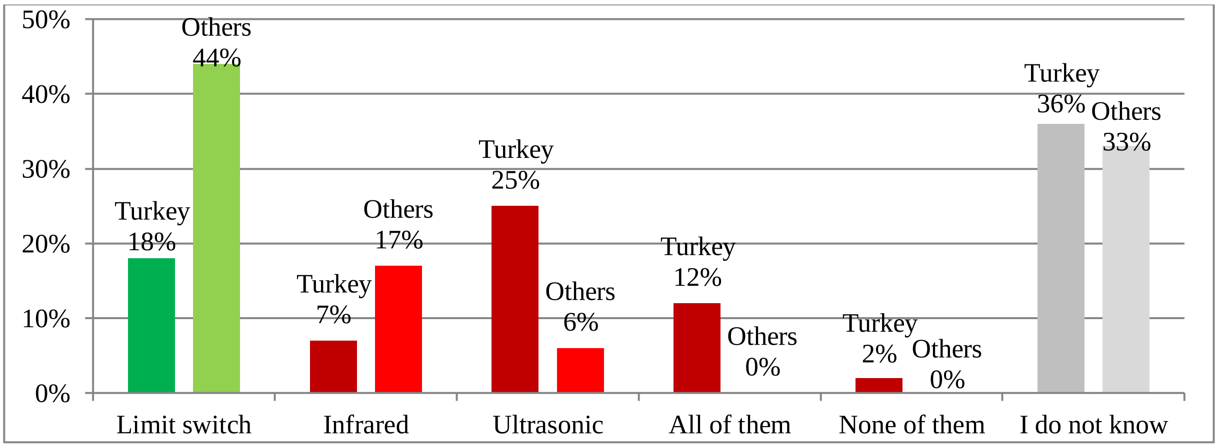

Figure 6. The type of sensor which is not suitable for detecting obstacles without contact

Case 7: Electric oven

Theory: Transducers and actuators (Th5)
Components: Sensors (K9)

The participants are asked to decide on the component that measures the inner temperature of an electric oven. And a display digitally shows the value. As resistor is a heating element, it is a distractor choice. Almost all of the participants reasoned that a resistor is not suitable. On the other hand, one-third of the participants from countries other than Turkey, decided that a bimetal thermostat is preferable (Figure 7). A bimetal thermostat may be considered a sensor. Yet, it is more of a switch which activates when a specific temperature is reached. Therefore, designers are expected to reason that bimetal thermostats cannot make measurements.

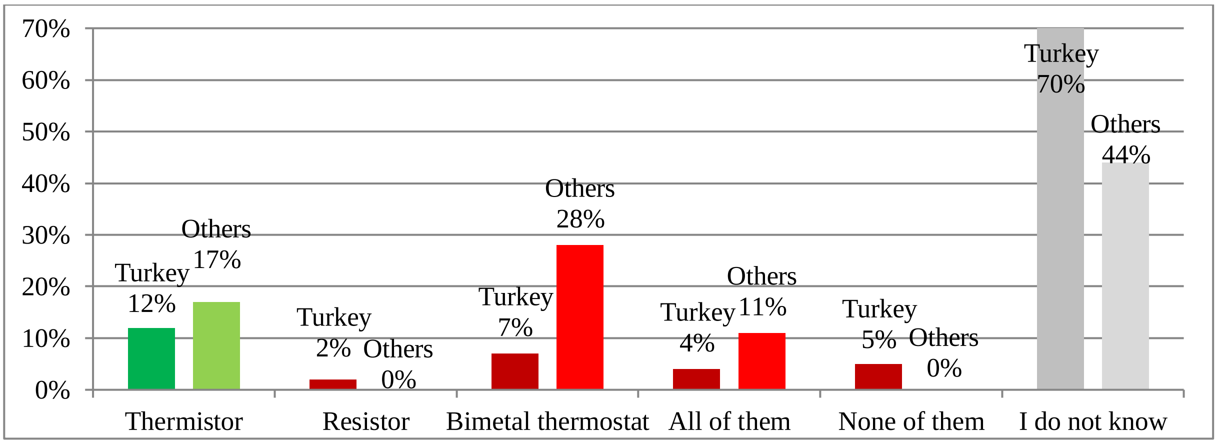

Figure 7. The type of component which is suitable for measuring the temperature of an oven

Case 8: Medical device

Theory: Transducers and actuators (Th5)
Components: Electromechanics (K5) and sensors (K9)
The next case is a device that injects medicine precisely into a patient's vascular access. The participants are asked to determine components that may serve the purpose. They are expected to know that injecting fluids can be done by pumps. And the pumps are driven by motors. Designers, who learned the terminology of transducers and actuators, should reason that stepper motors and encoders offer precision control. And feedback from a flowmeter may help control the speed of a pump. Although that "all of them" is the correct answer, distractors present partial reasoning in the case (Figure 8).

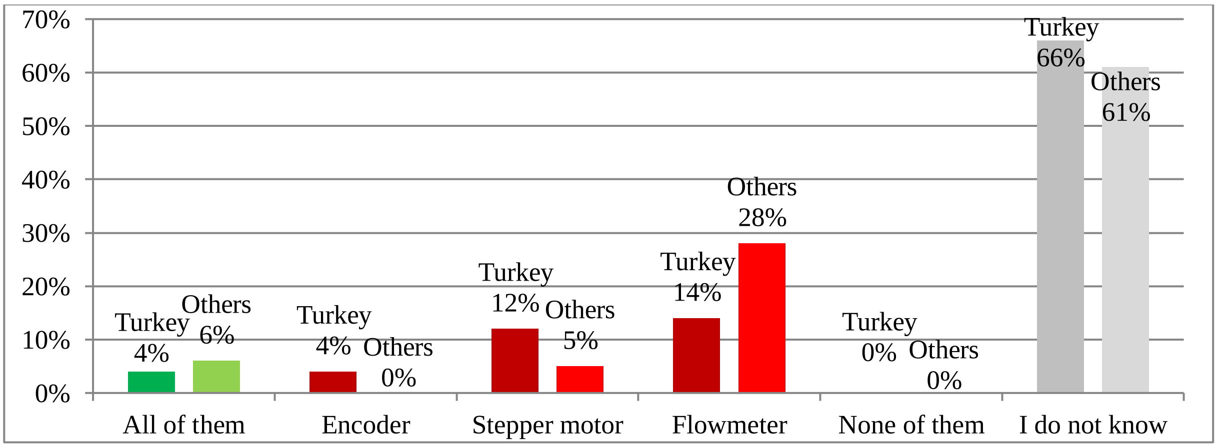

Figure 8. The suitable component for controlling the amount of medicine injection

Case 9: Digital watch

Theory: User interaction elements (Th6)

Components: Displays (K3)

The ninth case is a watch, of which the display only shows the time digitally and is always on. Participants are asked to decide what display type is the most efficient to achieve a longer battery life. The always-on requirement prevents the case from getting complex depending on various scenarios. E-inks are well-known for low energy consumption compared to all other display types. Therefore, designers should reason that it is the most efficient. Nearly half of the participants from the countries other than Turkey answered correctly (Figure 9). However, it appears that the types of displays are less known among the participants in Turkey.

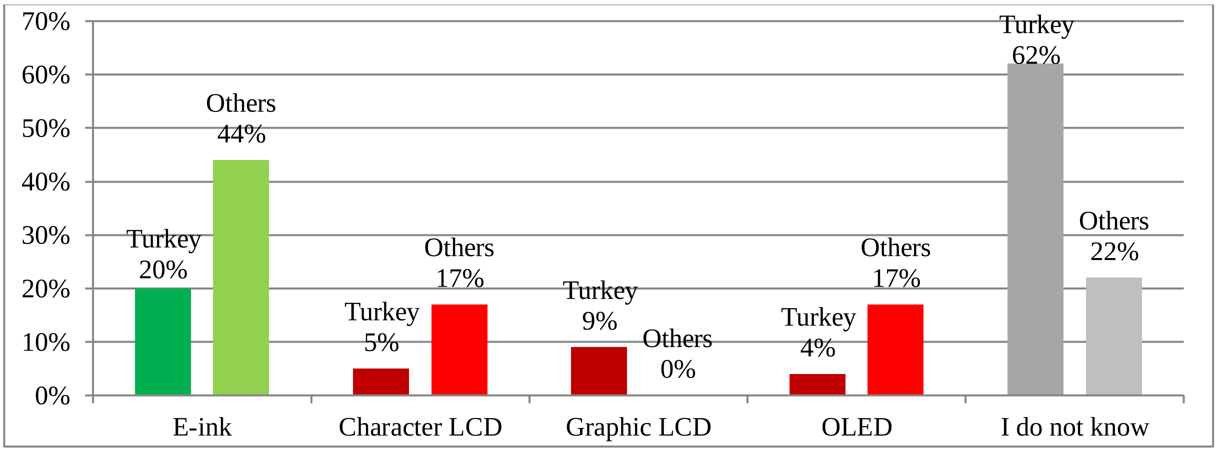

Figure 9. The type of display that is the most efficient to achieve a longer battery life

Case 10: Hair dryer

Theory: User interaction elements (Th6)

Components: Switches (K2)

The participants are asked to choose what component is suitable for adjusting the fan speed of a hair dryer. Capacitors and transistors are decided as distractors. As they are critical circuit board elements, designers may experience these often getting mentioned in transdisciplinary practice. However, they are irrelevant to the task. Therefore, designers are expected to know that these are not user interaction elements and conclude that the potentiometer is the only switch type among choices. The distribution of answers is presented in Figure 10.

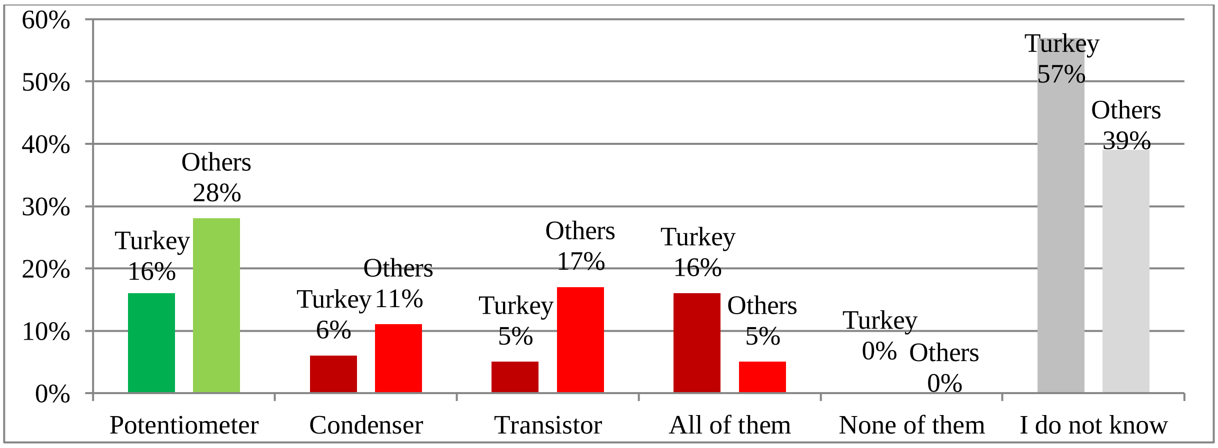

Figure 10. The type of switch that is suitable for adjusting the fan speed of a hair dryer

Case 11: Video camera

Theory: Electromagnetism (Th9)

Components: Wireless communication (K11)

The eleventh case is a video camera that transmits live footage to a cellphone. The participants are asked to decide on the material of the camera body that makes establishing wireless communication easier. Conductive materials are likely to form a Faraday cage that blocks wireless signals. Therefore, aluminum and steel bodies may limit the antenna design. Consequently, designers should reason that preferring plastics is optimal. Although the theory of electromagnetism is regarded as expert-level knowledge by interview participants, it is answered more correctly (Figure 11) than many beginner-level questions.

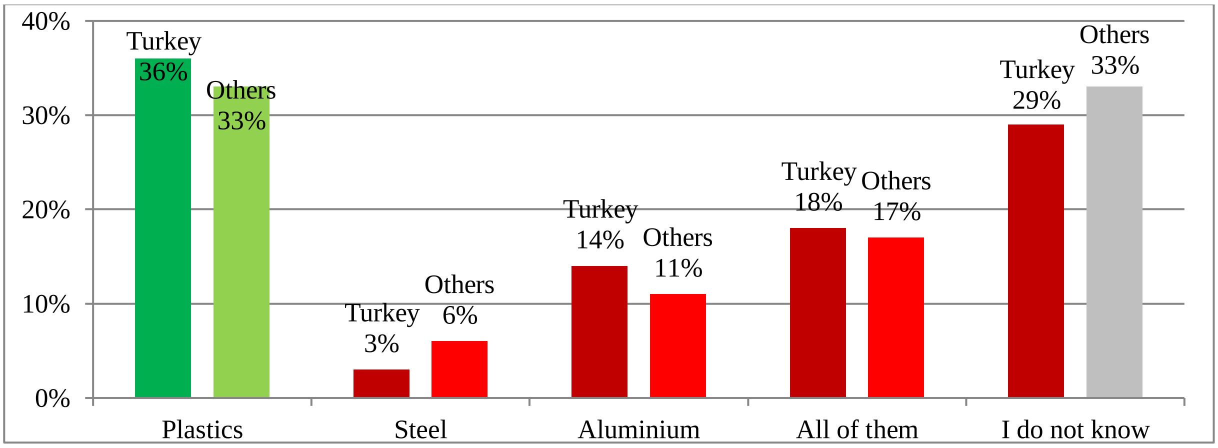

Figure 11. The material of which a camera is made to provide wireless communication easier

Case 12: Jungle fire detector

Theory: Communication systems (Th8)

Components: Wireless communication (K11)

The participants are asked to decide on a wireless communication protocol that does not necessitate another device nearby. An object that detects jungle fires by measuring temperature and transmitting the data to a fire station will benefit from the decided protocol. One who learned the theories of wireless communication systems should conclude that Bluetooth and Wi-Fi communications require receivers nearby. However, GSM is a mobile network that communicates through base stations. Although interviewed engineers decided that knowledge of communication systems is expert-level, more than one-third of the participants answered correctly (Figure 12). The participants may have reasoned the correct answer based on their everyday experiences, as connected devices are common.

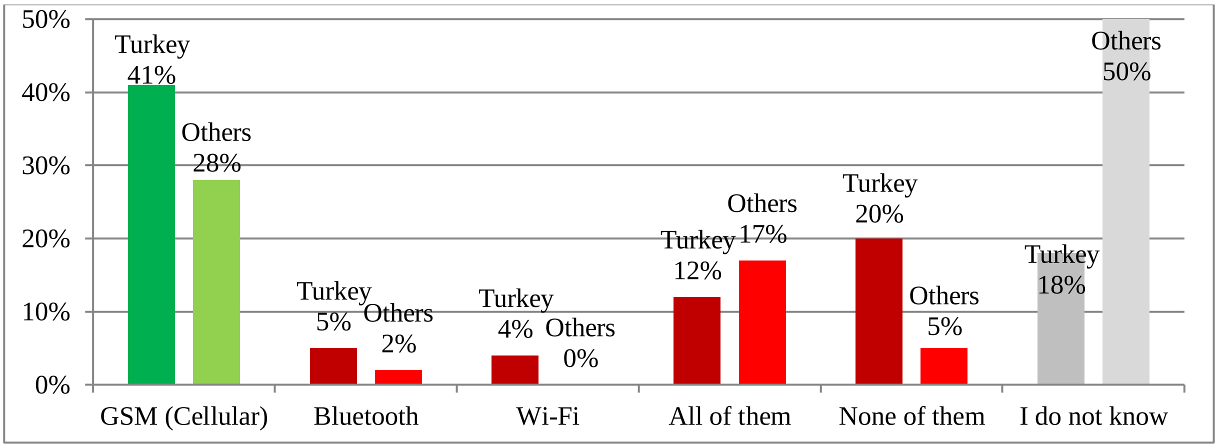

Figure 12. The communication system which does not necessitate another device nearby

Case 13: Flashlight
Theory: Printed circuit board elements (Th7)
Components: Controllers, processors and memory units (K5)
The last case is a flashlight, which operates with only one button. Yet the combinations of pushing the button should dim and change the color of the light. The participants are asked to decide on the component that is required. The Peltier is a cooling element. And the buzzer is a sound generator. Yet, a microprocessor serves the purpose, as it is a computing component where the data processing logic and control are included. Although it is classified as expert-level knowledge, more than one-third of the participants reasoned correctly (Figure 13).

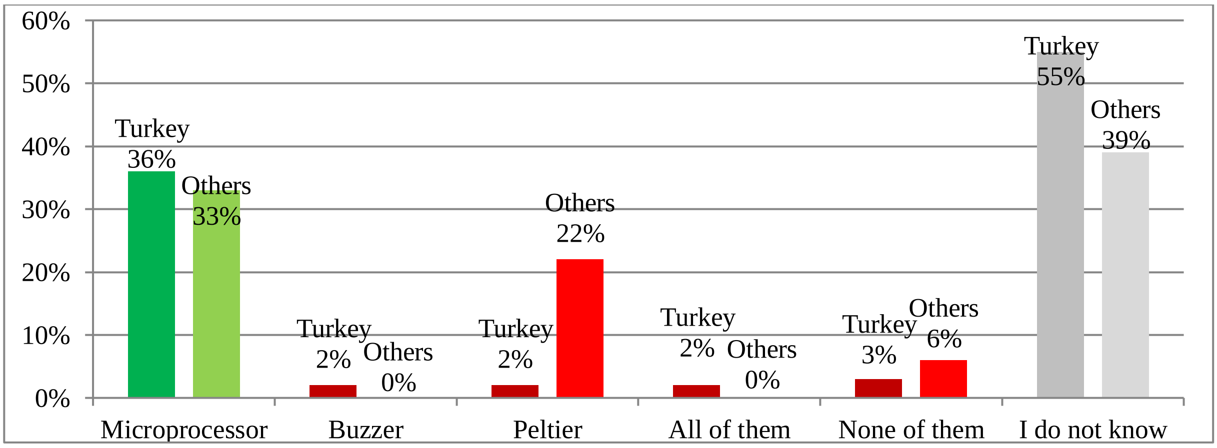

Figure 13. Survey question 13

Remarkably, correct answers given to the beginner-level questions (Cases 1-9, x̄1=31%) are noticeably close to the experienced-level ones (Cases 10-13, x̄2=29%). Notably, questions based on the electrical properties of materials and concepts of energy, power, current, voltage, and differences in DC and AC are given more correct answers in total average (Cases 1-5, x̄1=41%) compared to ones based on user interaction elements (Cases 6-13, x̄2=25%).

Although 95% of the students in Turkey have never taken any courses related to electronics or physical programming, 61% of the participants in other countries have attended at least once. However, there is no significant difference between the scores of the participants in Turkey

($\bar{x}^1=30\%$) and the average of the other countries ($\bar{x}^2=33\%$) despite they are trained differently in electronics (Anova, $\Delta\bar{x}=3\%$, $n=74$, $p=0.183$).

The scores of the participants in Turkey are not equally distributed dependent on the program they study or graduated from (Anova, $n=46$, $p=0{,}033$). The post-hoc tests indicate, participants of the highest-scoring program (49%) and the lowest-scoring one (19%) are significantly different in their scores ($p=0{,}022$). Yet, there is no significant difference between the others.

86% of those who participated from Turkey and 61% of those from other countries failed to reason correctly. The highest score in Turkey is 77%. In other countries, it is 62%. Scores of graduated participants in Turkey ($\bar{x}=29\%$) are significantly higher ($n=47$, $p=0{,}013$) than the senior year students ($\bar{x}=23\%$).

Although the majority of the participants strongly agreed (42%) or agreed (32%) that they have found answering the questions difficult, the majority of them strongly agreed (31%) or agreed (31%) that an industrial designer should be capable of giving correct answers to the questions. Participants who strongly agree and disagree are more in other countries (39% and 28%) compared to Turkey (29% and 12%). However, there is no statistically significant difference in their opinions, depending on whether they have participated from Turkey or other countries ($n=74$, $p=0{,}603$ and $n=74$, $p=0{,}429$).

Senior-year students who attended or are attending the electronics-specific courses scored higher in 8 of the 13 questions. However, they scored at least 10% higher only in 4 of them, and at least 20% in only 1. Statistically, there is no significant difference between the scores of those who did and did not attend courses on electronics, except for a question. The question is about deciding on an appropriate sensor (Case 7, $n=50$, $p=0{,}036$). Although it is significant, those who attended electronics courses scored only 4% higher ($\bar{x}^1=28\%$, $\bar{x}^2=24\%$).

Discussion

The conceptual framework clarifies that the interest in electronics increased compared to a decade ago. Many programs offer electives. Some of these courses are experiential. It appears that these courses approach electronics through CDIO and systems thinking approaches. Even a few of these courses are compulsory. Considering the curricula, there is a similar trend in Turkey. However, those who attended these electives are still less than 5%. Unlike Europe, Turkey does not offer diversified design programs, except for a few engineering-titled ones. These few programs include many compulsory courses in a variety of technical domains. Therefore, arguably they should not be referred to as a version of industrial design (Akbulut, 2015).

It is noteworthy that the participants, who did not receive electronics training in Turkey or other countries, and those who did, all achieved similar scores. Arguably, designers implicitly learn a little electronics in the studio courses. And interestingly, attending a specific course had little effect on the scores. Moreover, the participants lack electronics terminology more than electrical theories. Industrial designers lacking terminology is a decade-long argument (Varekamp et al., 2014).

Designers may benefit from the knowledge they gained through courses in pre-higher education. In fact, some of the theories determined through this research concern physics courses in pre-higher education. Moreover, many countries, including Turkey, offer compulsory courses based on electronics, robotics, coding, and technology during pre-higher education (Kılıçkaya Boğ, 2019). Besides, these courses are often hands-on. Nevertheless, teachers in Turkey criticize that they lack the necessary competencies, and are not educated to teach electronics, Arduino, and sensors (Akbaşlı & Akyüz, 2021).

Conclusions and Recommendations

Benefitting from complex electronics in everyday objects has become widespread. Therefore, the interactions between humans and machines have become more intense (Prisecaru, 2016). It is clear that many products which concern a designer presently include electronics. However, design education has not developed a common ground yet, regarding the approach to electronics knowledge. Design programs around the world have diversified. Design, industrial design, product design, and design engineering are the most common. Those which are titled engineering have already covered electronics. However, they offer curricula that consist of many technical domains. Therefore, the approach of design engineering programs to aesthetics differs from a traditional design program. They often put more emphasis on technical courses and producible designing. However, many design programs offer electives on electronics as well. Yet, many others still do not. The findings mark that these electives are less common and rarely taken in Turkey.

The motive to the study is the prediction that traditional design programs regard electronics knowledge often as out-of-field, theoretical and calculative. And it is predicted that, similar to materials and manufacturing, electronics is essential for designing better experiences more than making producible designs. Contrary to what this study suggests, digital product design is often regarded as the design of things that include displays and/or what the displays show (Oygür İlhan & Karapars, 2019). A few studies argue that interface elements, such as LEDs, switches, displays, speakers, and microphones, concern designers (Frens, 2018). However, a compact list of components and theories is missing in the literature. Therefore, this study aimed to clarify why and what knowledge is necessary by generating a list through interviews, and then to measure whether industrial designers have the listed knowledge.

The conceptual framework presents that approach to electronics in design education is not generalizable as theoretical. Multiple studies acknowledge that electronics necessitate hands-on learning. It is remarked that Arduino and physical programming are beneficial. Besides, numerous programs appear to focus on experiential teaching of electronics. And teaching via Arduino became common, both in higher and pre-higher education. Arduino is a popular programmable electronics kit that offers a plug-and-play circuit board and mountable accessories such as sensors or LEDs. Therefore, building with Arduino is hands-on. And it naturally focuses on systems thinking. However, only a few real-world objects are produced benefiting from Arduino or its plugins. While acknowledging that Arduino is paradigm-shifting in electronics education, it is debatable that it simulates the structure of an end product. The debate is rarely discussed in the papers and it may be the reason why electronics is still a bottleneck for designers (Seetsen et al., 2019).

The survey findings remark that even the terminology of interface elements and sensors is less known than the knowledge of electrical theories. Besides, the overall score in the survey is barely 30% and being trained in electronics courses had only little effect. Thus, the theories and the terminology that interview participants mentioned as essential are not commonly known. The study recommends the below approaches to the programs which do and do not include electronics, in order to train industrial designers more in electronics:

- Electronics courses interest more design programs.
- It is argued that making decisions on which electrical theories and components concern and communicating in the electronics terminology while collaborating with engineers is an industrial designers task, as well as product designers and design engineers.
- Electronics courses might be given compulsory in more programs.
- Components and theories affect fundamental aspects of an object. Therefore, it is argued that electronics knowledge should be emphasized as much as materials and manufacturing.
- Electronics should be trained using other hands-on methods in addition to Arduino.
- Courses often focus on building circuits via Arduino. Whether over-emphasizing Arduino limits the learning of real-world design problems is a debate. Yet, the discussion is beyond the purpose of this study. However, another approach is worth further researching: Tearing down objects (Romero et al., 2012). It is hands-on. And it may fit the CDIO approach because the C stands for conceiving.
- Electronics education should focus more on the terminology and the basics of electrics.
- Terminology and theories knowledge in electronics education should be in balance with experiential learning. The study argues that an interactive learning kit may be beneficial to achieve this balance. The learning kit should issue terminological and practical real-world design problems via teardowns, comparisons, and reviews. The authors plan to design and test the learning kit as a further study.

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