EXPLORING DESIGN REQUIREMENTS FOR EDUCATIONAL ROBOTS USED IN K-12 EDUCATION FROM EDUCATOR'S PERSPECTIVE

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ABSTRACT

EXPLORING DESIGN REQUIREMENTS FOR EDUCATIONAL ROBOTS USED IN K-12 EDUCATION FROM EDUCATOR'S PERSPECTIVE

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Robotics field has broad application in human society and design space of robots even broader. In the last decades, robots were started to be used for various purposes after their first examples in industrial settings. Use of robots in various human work domains provide multiple benefits over other technological devices. Education is one of the challenging primary fields in which robots offer advantages over other technologies. Unlike other fields of robotics which requires advanced programming architectures or artificial intelligence, use of robots in education requires more human-centred perspective rather than focusing on the technology itself. Use of technologies in learning environments has a long history. Educational robots are actively used for educational purposes over three decades as a tool for learning activities. However, design and human-centred issues related to educational robotics literature is an overlooked area of research. Therefore, in the light of the previous studies in the area, this study aims to explore design related issues from a human-centred perspective. In the study, questions about the relationship between robot design and learning activities were explored from the educator's perspective. Semi-structured interviews were conducted with 15 respondents from different institutions. Interview results are examined the following issues: the ways robots support education, current and possible challenges of using robots in education, and how the interventions on the design of robots can support learning environments. In the light of the attained suggestions and comments from educators, study explored design requirements for educational robotics as a tool for learning in school environments. Requirements derived from the perspective of educators can provide guidance for designers who are challenged by designing robots for educational environments.

Keywords: educational robotics, human-robot interaction, design requirements, user requirements

ÖZ

K-12 EĞİTMENLERİ PERSPEKTİFİNDEN EĞİTSEL AMAÇLI ROBOT KULLANIMINA YÖNELİK TASARIM YÖNLENDİRMELERİ

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Robotik uygulamalar insan hayatlarında geniş bir uygulama alanına sahip olmakla beraber, robot tasarım alanı daha da geniş bir uygulama yelpazesini kapsamaktadır. Eğitim alanı, robotların bu alanda kullanılan diğer teknolojik cihazlara göre avantaj sağladığı bir alan olarak atfedilmektedir. Gelişmiş programlama mimarileri veya yapay zekâ gerektiren diğer robotik alanlardan farklı olarak; eğitimde robotların kullanımı teknolojinin kendisine odaklanmak yerine, insan merkezli bir bakış açısı gerektirmektedir. Eğitim robotları, eğitimde halihazırda kullanılan araç ve gereçlere kıyasla, birçok zorluğu barındıran yeni bir alandır. Eğitim amaçlı kullanılan robotlar, anaokulu seviyesinden üniversite seviyesine kadar farklı yaş grupları için kullanılabilmektedir. 30 yılı aşkın süredir, eğitim robotları araştırma ve öğretme faaliyetleri için aktif olarak kullanılmaktadır. Ancak, eğitim robotu literatürüyle ilgili tasarım ve insan merkezli konular, fazla üzerine durulmamış bir araştırma alanıdır. Bu nedenle, bu çalışma eğitimde kullanılan robotlara yönelik tasarım konularını insan merkezli bir perspektiften incelemeyi amaçlamaktadır. Araştırmada, robot tasarımı ve öğrenme aktiviteleri arasındaki ilişki eğitimcinin perspektifinden incelenmiştir. Farklı kurumlardan 15 katılımcı ile yarı yapılandırılmış görüşmeler gerçekleştirilmiştir. Mülakat sonuçları aşağıdaki konuları incelemektedir: robotların eğitimi nasıl desteklediği, robotların eğitimde kullanılmasındaki mevcut ve olası zorlukları ve robotların tasarlanması konusundaki müdahalelerin öğrenme ortamlarını nasıl destekleyebileceği. Bu çalışma, eğitmenlerden elde edilen öneri ve yorumlar ışığında, okul ortamlarında öğrenim için bir araç olarak kullanılmak üzere ileride tasarlanacak robotlar için tasarım gereksinimlerini araştırdı. Robot tasarımına eğitimcilerin perspektifinden yaklaşan bu çalışmanın sonucunda elde edilen tasarım yönlendirmeleri, eğitim ortamları için robot tasarlaması beklenen tasarımcılar için bir yol gösterici olabilir.

Anahtar Kelimeler: eğitim amaçlı robotlar, insan-robot etkileşimi, tasarım gereksinimleri, kullanıcı gereksinimleri

There is no spoon

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CHAPTER 1

1. INTRODUCTION

1.1 Background of the Study

From science fiction to the real world, robots are becoming more popular and extending their roles in human society with the advancements in robotic technologies. Robotics is a field which deals with technologies that concern robot construction, design, and operation, and it encompasses various application areas in human society. Robots are specially designed to fulfill tasks or activities in human domains with human direction or control, so regardless of the level of autonomy, the interaction between robots and users occurs, and the nature of interaction varies depending on the context of use and various aspects on robots' design, such as, robot's embodiment, sociality, and multi-modal interaction interfaces that the system contains (Apan et al., 2012; Feil-Seifer & Mataric, 2009; Goodrich & Schultz, 2007a). For a more in-depth examination of the relationship between robots and humans in various contexts, classifying robot types through their application domains will be useful. According to the International Federation of Robotics (IFR, 2015): robots are broadly categorised into three types based on the context they are used, namely (1) Industrial Robots, (2) Professional Service Robots and (3) Non-Professional/Personal Service Robots.

From personal service robots, education robotics is an important area and a grand challenge for the field of robotics (Sheridan, 2016). In 2015, 5,4 million personal service robots were sold which increased by 29% when compared to the sales of 2014 (I.F.R., 2015). According to the 2015 IFR report, between 2016-2019 43 million units are expected to be sold including 3 million for educational and research purposes. These results illustrate the importance of educational robotics as an emerging field. Robots are swiftly integrating into our everyday lives, for the future, it will be a requirement to have fundamentals of the technology that surrounds us. As we can understand from the statistics and predictions of the IFFR, in the recent years there is an increasing interest on educational robots as an educational medium from freshly started robotic start-up companies to crowdfunding projects conducted by pioneers in the robotics field (Eguchi, 2014).

The context of the use of robots for education encompasses different education levels from pre-school education throughout to higher education. Regarding educational robots that may address different levels in education, their complexity of use, and the interaction between users and robots varies according to the needs and abilities of the users (Johal et al., 2018). There is no robot for all educational levels because the developmental stages of individuals differ from each other. Thus overall robot implementation for the selected education level requires specific activities and design features in order to provide age-suitable learning environment (Druin & Hendler, 2000).

Educational robots are a subset of educational technology and a tool for learning which grants educational environments being more fun, flexible, self-oriented and learner-centred rather than traditional learning environments where students are passive consumers of knowledge (Johnson, 2003). Educational robotics also supports a shift from just using technology to designing it and understanding what is going on behind the curtains of the black boxes around us (Resnick, Berg, & Eisenberg, 2000). According to Alimisis (2013), key aspects which can lead educational robotics to success is behind the curriculum and learning environment by embracing convenient learning theories such as constructivism and constructionism (Ackermann, 2001; Kirsh, 2017; Papert, 1991). There are also other learning theories which support robotics based on constructivism philosophy namely; zone of proximal development (ZPD), active learning principles and learning by design (Engeström, 2014; Karim, Lemaignan, & Mondada, 2015).

Nowadays there are numerous educational robots commercially available in various types under two main category that provided by Mataric (2007) namely; *pre-built* robots and various *Do-It-Yourself* (DIY) robots. Also, robot designs or programming scripts can be found online within the open-source communities such as *GrabCad, Arduino* and so forth (Peñalvo et al., 2016). Educational robots are advantageous over many other educational media (computers, smart boards, tablets, cell-phones and more) because of their innovative, three-dimensional and tangible nature (Johnson, 2003; Mikropoulos & Bellou, 2013). Multidisciplinary requirements and complexity of robots provided numerous opportunities compared to other educational mediums over other motivating media to support teaching among children within the Science, Technology, Engineering and Mathematics (STEM) subjects (Leonard et al., 2016; Miller, Nourbakhsh, & Siegwart, 2008).

Moreover, educational robots are more likely to be acceptable for most students who are born in the digital age (Kitts, 2003; Sundar, Waddell, & Jung, 2016). One of the favours of being in the digital age is the technological familiarity of the K-12 students giving a boost for the basics of how to use a computer or any other technological device (Eguchi, 2015). More recently there has been a surge of interest in educational movements and reforms such as, *coding in k-12* and *maker-movement* which promotes *fabrication labs* by using rapid-prototyping tools such as laser cutters and 3d printers (Halverson & Sheridan, 2014; Paulo Blikstein, 2013; Resnick & Rosenbaum, 2013). Also, the information exchange between learners is supported by open source platforms that allow sharing 3D CAD (computer-aided design) models or programming scripts (Olabe, J., Olabe, M., X. Basogain, X., Maiz, I., Castaño, 2011). Based on the movements future goals for learners educational use of robots granted a generic foundation from novice learners to experts in educational contexts by providing comprehensive activities for general aspects of science and arts-related concepts (Chung, 2014; Eguchi, 2014; Mataric, Koenig, & Feil-Seifer, 2007; Vandevelde & Vanderborght, 2013).

Robots for education are the focus of interest in 21st-century education because of their potential to motivate students for future STEM-related career choices and holistic activities to gain 21st-century skills (Khanlari, 2013). Educational robots are used as a motivational tool in schools to provide increased demand for STEM-related jobs in the future and to overcome the lack of interest, gender bias of students related to the STEM areas (Matarić, 2004; Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). In K-

12 education robotic activities provide a collective basis for acquiring versatile skills for students, studies related to using robots in education to improve skill sets of students demonstrated there is a definite change in personal and academic skills of the students (Benitti, 2012; Nugent, Barker, & Grandgenett, 2010). 21st century framework supports future citizens as; entrepreneurs, engaged thinkers and ethical citizens in order to provide them the competencies of a 21st century learner skillsets namely; *lifelong learning*, *self-direction*, *personal management*, *communication*, *digital literacy*, *social responsibility*, *global cultural* and *environmental awareness*, *creativity* and *innovation*, *critical thinking* and *problem solving*, *collaboration* and *leadership* (Binkley et al., 2012; Bocconi et al., 2016). Moreover, using robotics in formal and non-formal educational settings are proved to have a positive impact on the acquisition of skills and abilities related to 21st century framework as an illustration of these competencies such as, cognitive skills (critical thinking, decision making, creativity), conceptual skills (science concepts in physics and math), social skills (collaborative, team-work, leadership), personal (self-esteem, determination, motivation) and academic skills (achievement scores) (Catlin & Blamires, 2010; Eguchi, 2015; Khanlari, 2013).

Application of robots in education can be examined under two broad categories namely; *extra-curricular* and *intra-curricular* (Mubin et al., 2013). Extra-curricular activities are taking place in out of school contexts such as summer schools, robotic competitions, science centres, science festivals and so forth. However, STEM-related activities are generally conducted in out of school and extra-curricular activities because of the current limitations based on lack of robotic activity curriculum that can be integrated into school curriculum (Rode, Stringer, Toye, Simpson, & Blackwell, 2003). Besides in-school activities, robotic competitions provide an opportunity for learning by maintaining a challenging environment between students and student groups in informal settings. Participation of students into robotics competitions shows a positive impact on raising interest on STEM subjects and students understanding of science concepts, technological fluency, social skills such as team-working, communication (Calnon, Gifford, & Agah, 2012; Grandi, Falconi, & Melchiorri, 2014). Intra-curricular robotic activities have to be in-line with the school curriculum defined by authorities and educators plays a vital role to implement a well-fitting robotic activity in formal settings (Bers, Ponte, Juelich, Viera, & Schenker, 2002). Using robots in classrooms for teaching purposes can be a time-consuming activity rather than establishing direct inquiry for the educators, and they need to be supported regarding curricular activities by considering limited time in classrooms (Beraza, Pina, & Demo, 2010; Rode et al., 2003). Thus, types of educational robots are optional to the intention of the classroom facilitator or educator based on to desired learning whether educators can design their activities for classroom or use the ready-made content which is provided by most of the commercially available construction kit type of robots such as, Lego Mindstorms, MakeBlock mBOT, Robotis STEM Kit (Green, Wagner, & Green, 2018; Whitman & Witherspoon, 2003). These robots are shown in Figure 1

Figure 1 - Lego Mindstorms, MakeBlock mBot and Robotis STEM Kit

Type of the robot also determines the type of the activity which can be conducted according to school curricula and can address distinct learning outcome, for instance, using humanoid robot eliminates the time required by a construction kit to design a robot or to build a robot from scratch (Park & Han, 2016; Vandevelde & Vanderborght, 2013). In both formal/informal activities robot can be subject itself for acquirement of diverse technical skills such as; computer programming, using necessary construction tools like screwdriver and so on, or used for to gain academic skills in non-technical subjects such as; social sciences, language, physics mathematics, biology and so forth (Malec, 2001; Mubin et al., 2013; Toh, Causo, Tzuo, Chen, & Yeo, 2016). In the education context of Turkey, there is an effort to provide curriculum for the STEM education in line with the intra-curricular activities (MoE, 2016). STEM education aims to provide students hands-on learning experience by encapsulating all components of the STEM which may lead to innovative approaches to real-world problems. STEM education-based learning experience of students may lead to digital and physical products as an outcome of interdisciplinary work. Therefore, students gain deeper understanding of STEM related topics and prepared to future work environments by combining knowledge from different areas throughout their K-12 education. According to the recent STEM education report of the ministry of education use of robotic technologies in classroom settings seems promising for the applications in schools. Currently, most of the private schools are using robotic technologies as tools for learning by building DIY robots or by using pre-assembled robots for programming activities.

Using robots in the educational environment creates multi-faceted challenges when integrating robotic activities to any level of education because there is no widely accepted curriculum for robots (Matarić, 2004). According to Mataric (2004), one major issue is the integration of robotic activities into the K-12 level school curriculum. Barriers derived from the literature from education point of view for implementing educational technologies which encompass robotics can be aligned as; (1) lack of educator time, (2) lack of educator training, (3) lack of age-suitable academic materials, (4) lack of ready for use lesson materials, (5) lack of institutional support, (6) physiological barriers of educators (Mataric et al., 2007; Sullivan & Moriarty, 2009). Regarding the use of educational robots, significant factors are depended on several factors and strongly related to robots' design and stakeholders. These factors can be listed as; *(1) robots' role during the interaction, (2) robots type, robots behaviour, (3) learning environment (extra-curricular or intra-curricular), (4) perception of stakeholders (parents, students and educators), (5) gender issues* and *(5) importance of robots' design or appearance* (Alimisis, 2013; Johnson, 2003; Mubin et al., 2013; Toh et al., 2016). There are numerous challenges, and it is not possible to address all the challenges just through the design of a robotic system. However, design plays a crucial role on educational outcomes with its flexibility on robotic activities and the way users interact to complete a task to realise an idea with the robotic components.

Design of an educational robot may have direct effects on the educational outcomes and to address various concepts in learning in formal or informal settings (Robinson, 2005). For instance, the time spent during the preparation of robotic construction kits or programming phase via textual or graphical is a critical issue for educators because of their time constraints in classrooms. The usability of programming interface with self-explanatory parts in construction kit can shorten the time spent on building a complete working robot and let users spend more time on the elaboration of their project. Technical capacity of an educational technology is also a limitation for the robotic activities although it can serve as a catalyst to come up with creative solutions to a problem just as in the case of the construction kit called “crickets” while most of the users want more input-outputs and motors designers developed a scaled-down version of the programmable brick to two motor outputs with two sensor input from four motor output with six sensor input version (Resnick & Silverman, 2005, p. 3).

Perception of robots from stakeholders is an important factor which can be examined in several ways. For example, the role of the robot from educators’ perspective and the effects of the appearance of a social robot on children (Serholt et al., 2014; Toh et al., 2016). Stakeholders perception is crucial for the educational benefits attained from robots. For instance; the acceptance of social robots in the educational environments directly affects the interaction quality and willingness of the user to interact with the (Shin & Kim, 2007). Students are central subjects in the learning environments, so educational robots should be designed to address real needs of the stakeholders that involved in the educational context (Hyun, Yoon, & Son, 2010; Resnick et al., 2005).

Moreover, to increase engagement and motivation among students perceived qualities of the robot plays an important role. The study of Woods (2006) investigated the children between 9-11 ages regarding perception of robots. Most of the children attributed aggressive personality to human-like robots and the combination of human/animal-like robots as friendly. Regarding the roles which can be played by a robot, according to Shin & Kim (2007), older children prefer the role of a robot as a tool rather than other roles of robots namely; as a tutor or as a collaborator. In addition, to increase the ease of use and engagement of robots, design features of robot plays an important role such as, programming interface, if the robot has social capabilities (appearance, bodily and emotional gestures, conversational capability), size of the construction parts (Mubin et al., 2013; Resnick & Silverman, 2005; Vandevelde, Wyffels, Ciocci, Vanderborght, & Saldien, 2016). Perception of educator's plays vital role for the implementation of robotic activities. As mentioned earlier, there are several factors which directly affects the choice of using robots for education such as educators psychological barriers and lack of confidence on using technology in the classroom (Bers et al., 2002). Shin & Kim (2007) identified educators' expectations regarding robots' roles as an *instructional medium* (with content provided), as a *educator assistant*, and as a *learner assistant*. Similarly, the interaction roles that defined by educators in Shin and Kim's (2007) study have common ground with the roles defined by other researchers (Eguchi, 2014; Karim et al., 2015; Miller et al., 2008).

Since the design of robot has a significant impact on the stakeholders' (students' and educators') use and interaction with the robots, design specifications that address critical issues must take into account before designing a robot which specialised for educational purposes. Woods (2006) defined these specifications by considering children perceptions on robots including; *physical aspects, robot mode of locomotion (motion of the robot), gender, facial features, and functionality and psychological aspects such as perceived personality attributes and emotions.* In line with the design considerations that suggested by Woods (2006) based on the findings in the literature robots for educational purposes must encompass appropriate pedagogical approach and different styles of play of the children (Resnick & Silverman, 2005)

All in all, educational robots are not the only solution within the educational technology to promote teaching strategies for the learning environments, but with its hands-on nature and rich interactive learning activities, it grants significant benefits for the development of children in many ways. Educational robots create vigorous opportunities for educators in the modes of lesson plans and various experimentations to explain abstract or complex subjects. Studies on student perceptions also made significant contribution to define design requirements for robots and to improve interaction quality for the acceptance of social robots in an educational context. To sustain the beneficial relationship between educational technologies and formal learning environments educators plays a vital role at any level of education as a facilitator among the students. Most of the reviews on educational robots added value to learning experience by using robots and supporting educators to increase beneficial outcomes from the robots as an educational medium (Karim et al., 2015; Khanlari, 2013; Mubin et al., 2013). After all, education consists of both tangible (educational media) and intangible (communication) features which are provided to students for their learning by educators. Thereby, when designing a tool for educational purpose perspective of experts (educators) from the field can reflect the experiences to create pathways for successful design.

1.2 Aim and Research Questions

The goal of this study is to create insightful design considerations for non-autonomous educational robots that is specialised for learning purposes. The study considers this issue based on the perspective of educators who are actively conducting STEM related robotic activities in primary, secondary and high-school levels of education in Turkey.

Experts views from the field are expected to provide information about the expectations and real needs of the users involved during the use of educational robots in line with the educator and student-based challenges faced during the robotic activities. To address the aim of this study, one main research question and two sub-questions is planned to find beneficial answers.

Main Research Question:

- What are the requirements of user and robot interaction to support learning in educational robotic activities from the educator's perspective?

Sub questions to support main research question are:

- In which ways the interaction between the user and the robot can be improved to better support the learning experience?
- What are the expectations and needs of educators regarding educational robots?

1.3 Structure of the Thesis

The flow of the thesis consists of five major components namely;

1. Introduction
2. Literature Review
3. Methodology
4. Results
5. Conclusion

Major chapters of the thesis are divided into sub-sections in order to provide comprehensive relevant information to the reader according to the goals of the study.

Introduction chapter consist of problem background that highlights the relevant literature from the fields of education, robotics and industrial design to explain the motivation to pursue the aim of the study and research questions that will form the entire structure of the study.

Literature review chapter presents the related works regarding the intersection of Human-Robot Interaction, Educational Robotics and Industrial Design fields to build theoretical basis of the study. Firstly, Human-Robot Interaction section is providing general information about the current status of the relationship between humans and robots and human-centred challenges based on the use of robots in other fields of robotic applications that are related to educational robotics. Secondly, educational robotics field and its relationship with the field of education is examined under the scope of relevant educational philosophies and frameworks that supports the use of robots in education. Finally, the design related recommendations for educational robots that gathered from the literature are presented.

Methodology chapter is concerned with the methodological approaches that have been adopted to conduct qualitative research with the experts from the field of education. Firstly, it explains the purpose of the selected data collection method and the reasons behind it. Secondly, it presents the materials that have been used to conduct selected methodology with the detailed explanation of the procedure. Then, it clarifies the reason behind the selection of the sample group. Finally, in line with the theoretical background data analysis approach and tools that have been used for data analysis are explained.

Results chapter is describing the main findings of the interviews with direct quotations from the respondents. Presented data from the interviews are linked with the previously established challenges based on the design, educational robots and education literature. Three central themes are derived from the interview data to describe the benefits of using educational, challenges that faced by the respondents and design requirements for future robot designs. Lastly, evaluation of the overall results is discussed through in regard of providing insights for the future design of educational robots.

Conclusions chapter highlights the research questions that drive the overall study and summarises the thesis. Then, based on the research findings design considerations for educational robotic are presented. Lastly, the limitations of the study and future research related concerns were expressed.

CHAPTER 2

2. LITERATURE REVIEW

3.

In order to provide a comprehensive background for this study, literature review section is consisting of intersections of diverse research findings from human-robot interaction educational robotics, interaction design and educational philosophy. Firstly, overview of the Human-Robot Interaction will be presented by adopting human-centred view through investigating issues related to interaction and challenges between robotic applications and humans. Secondly, educational robotics field and their relations with the current educational approaches will be presented. Finally, considering issues mentioned in the earlier sections, design considerations for educational robotics will be merged from relevant literature related to desiging for educational technology.

2.1 Human-Robot Interaction

From science fiction to the real world, robots are extended their numbers and shifted their existence from industrial settings to the everyday life of the 21st-century society. The term robot first appears on the play of Czech writer Karel Capek called Rossum's Universal Robots (R.U.R) in 1921 which ends up with a robot rebellion against humans (Capek, 2001). The term "robot" which is used by Karel Capek has its roots on a Slavic word "robota" which means forced labour. Recently, there are many definitions for robots; for instance, according to the Merriam-Webster dictionary the term robot defined as:

> "*a machine that resembles a living creature in being capable of moving independently (as by walking or rolling on wheels) and performing complex actions (such as grasping and moving objects)*"

According to the latest definition of robots, they are improving the human capabilities and skills by aiding them in various human domains. For further investigation of the relationship between humans and robots in various domains, literature provides valuable information. The early example of robots is used in industrial settings for repetitive tasks to improve efficiency for manufacture beyond human capabilities. In the last few decades with the advancements in robotic technologies, robots are significantly enlarged their domains out of the industrial settings to various human work domains such as; homes, hospitals, search and rescue missions, space and military applications, agriculture and more. Technological advancements in robotic technologies such as; micro-computers, sensors and actuators enabled robots to lower their production costs and expand their user groups from professional domains to a variety of users with or without any robotic experience.

To attain benefits from the robots, the interaction between humans and robots is crucial. Interaction between robots and humans is a form of communication through interfaces determined by the current state of the technology in robotic applications; these technologies may be exemplified such as; sensing via sensors, acting and reacting by using motors and actuators or sound and planning by using advanced software architecture (Feil-Seifer & Mataric, 2009; Goodrich & Schultz, 2007; Thrun, 2004). Since the robots have direct interaction with the users usually in a social setting, *Human-Robot Interaction* (HRI) emerges as an essential field of study which is focused on developing interactions, designs, and implementation of robotic systems that used by humans. Moreover, there are studies which highlight the distinction between how children and adults interact with robots to claim that C*hild-Robot Interaction* (cHRI) offers new challenges within the field of HRI such as, interaction styles and perception of robots as a living entity (Belpaeme et al., 2013). The primary goal of the HRI is to design robotic systems which interact with humans in a safe, direct and effective way. In the light of this aim, HRI is an interdisciplinary field of research which requires dedication from diverse disciplines such as; cognitive-science, computer science, engineering, industrial design, social sciences, artificial intelligence, human-computer interaction, psychology, and neuroscience to overcome numerous challenges in the application domains (Dautenhahn, 2007). However, HRI is still in its infancy regarding providing a generally applicable model, theories and evaluation techniques in order to provide generalisable guidelines for the interaction between humans and robots (Lindblom & Andreasson, 2016). Following sections of the reviewed literature discusses significant issues regarding HRI under the headings of *Interaction in HRI, Types of Robots* and *Major Challenges of HRI Research*

2.1.1 Issues Regarding Interaction

Interaction with robots may show differences in the way we interact with our everyday life products. Robots as intelligent systems can create distinct interaction possibilities for humans, and it is mainly affected by the most distinctive feature of robots –called “autonomy". Autonomy is the most distinctive feature of robots from other products in human society which enables them to make decisions under certain circumstances and creates an opportunity to reflect an image of intelligent being in the one’s mind. Autonomy is a robot side of technical concern in HRI. However, it diversifies the interaction possibilities of a robot and affects the perception of humans toward robots (Thrun, 2004). From the human-centred perspective Figure 2 illustrates the how interaction may change according to the level of autonomy of a robotic system.

Level	Description
10	The computer decides everything, acts autonomously, ignoring the human.
9	The computer informs the human only if it, the computer, decides to.
8	The computer informs the human only if asked, or
7	The computer executes automatically, then necessarily informs the human, or
6	The computer allows the human a restricted time to veto before automatic execution, or
5	The computer executes that suggestion if the human approves, or
4	The computer suggests one alternative
3	The computer narrows the selection down to a few, or
2	The computer offers a complete set of decision/action alternatives, or
1	The computer offers no assistance; the human must take all decisions and actions.

Figure 2 - Level of Autonomy - Figure adopted from Coppin, Gilles & Legras, Francois. (2012)

One of the primary concern of the HRI is to develop interactive robots for particular environments and to equip them with a suitable set of skills to correspond the needs of the humans in a functional, emotional and social way (Dautenhahn, 2013). Today's use environment of robots differs in the ways of interaction from the early examples of robots in industrial settings because of commercially available robots which are taking place in our homes and public service areas such as, hospitals and museums. To illustrate the changing needs of domains regarding the level of autonomy of a robotic system in Figure 3 Dautenhahn (2003) provided the requirements for social skills of robots in human activity domains (p. 683).

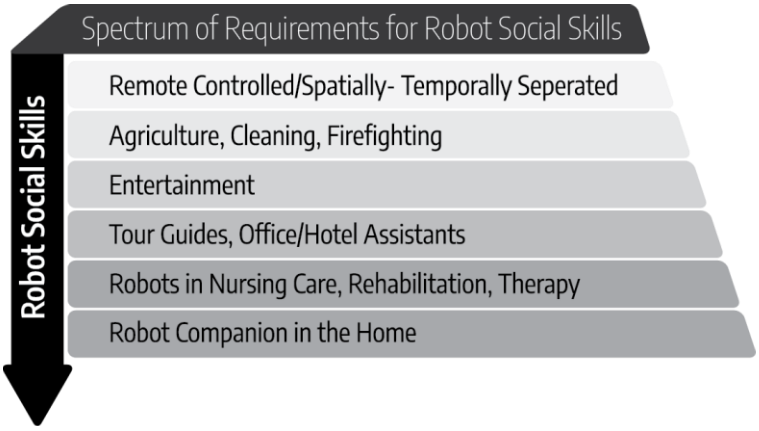

Figure 3 - Requirements for Social Skills in Different Application Domains - Figure adopted from Dautenhahn (2007)

According to Dautenhahn (2007) social intelligence for robots is promising for the goals of human-like *artificial intelligence* (AI), on the other hand research on intelligent robots are generally focused on equipping robots with cognitive attributes for example, reasoning, navigation, planning which enables them to operate in non-social environment and seeing social skills of robots as an attraction for the user interaction. As robots become more available for the personal use, social aspects of robots will be more crucial such as adapting to user's preferences, learning from humans about how to accomplish a task in the real-world environments. However, the social skills of a robot can be an exaggeration for particular application domains. Also, Dautenhahn (2007) provided the evaluation criterias for the social skills of robots (see Figure 4) according to their use domains.

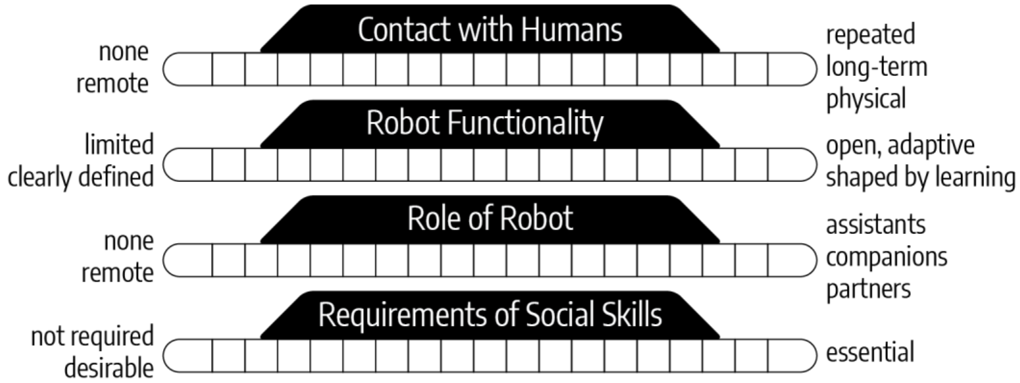

Figure 4 - Evaluation Criteria for Social Skills –

Depending on the requirements that derived from the context of use, different types of robots may be equipped with an advanced software architecture to mimic complex behaviours and communication capabilities from nature such as; similar to relationships in the real world, mimicking social intelligence of humans or animals in order to communication or collectively accomplish a tasks like swarm behaviour and so forth (Fong, Thorpe, & Baur, 2001). Interaction becomes more realistic, fruitful and desirable when the robot has social skills such as emotional expressions and conversational abilities; after all, as human beings, our society is mainly based on social interactions (Dautenhahn, 2003; Malle & Scheutz, 2014). Humans play a central role in the interaction because as human-made systems, robots are designed to support humans emotionally or to extend human capabilities in specific human domains (Woods, Walters, Koay, & Dautenhahn, 2006).

HRI is a broad interdisciplinary research field, because of that conceptual space of the HRI is vast, and research directions may differ according to the approach of the researcher. Designing social robots that are acceptable and able to address the various needs of the humans in various domains social robotics and humanoid robots are seemed to be overarching goals for the HRI research. Therefore, social robotics is one of the mainly focused fields which may encapsulate various technical challenges in the HRI research. Moreover, most of the studies are based on social interaction may provide useful insights for other research fields in the HRI. Due to social robotics field, there are several approaches to HRI research, Dautenhahn (2007) identified the possible approaches to HRI under three categories namely: *Robot-Centred HRI*;

Robot-Cognition Centred HRI; and *Human-Centred HRI.* Figure 5 illustrates the three different approaches to HRI research.

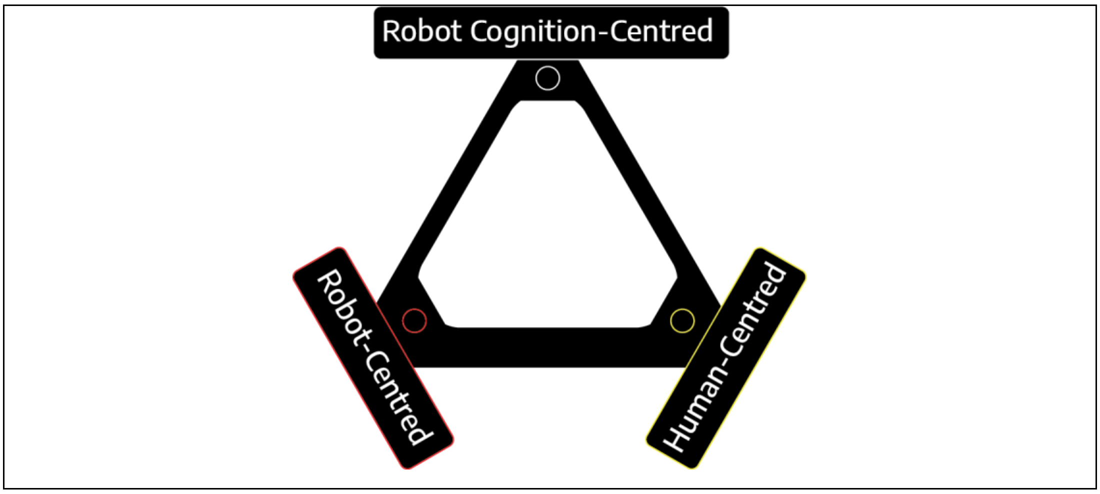

Figure 5 - Three Approaches to HRI Research

Robot-Centred and Robot Cognition Centred approaches to HRI are concerned about the technical aspects of robots such as software architecture, behaviour models, multi-modal sensing and perception of robotic systems (Breazeal, 2004). These approaches are mainly concerned about the technical perspective of the robot design and behaviours regarding providing abilities for robots regarding autonomy and self-preservation during a task.

Human-Centred HRI is concerned about the interaction from the human point of view to provide robots that provide a positive user experience for humans during the interaction with the robots. Human-centred HRI open pathways for the adoption of *Human-Centred Design (HCD)* design philosophy as one of the best approach because *HCD* is based on understanding, defining human needs and capabilities in order to design a tool, service or a system (Marti & Bannon, 2009; Norman, 2013). To support HRI research field through the way of generating design guidelines for complex devices in human environments, adopting HCD approach may provide a better understanding of the nature of human interaction with the designed robots.

Other research issues related with the human-centred HRI may base on the feelings of the humans that emerged from the appearance of the robotic system. This issue commonly referred to in the literature as "*uncanny valley"* which includes various studies concerned about the feelings and perception of humans based on the appearance of the robotic system (Mori, MacDorman, & Kageki, 2012). The notion of the uncanny valley is illustrated in the Figure 6

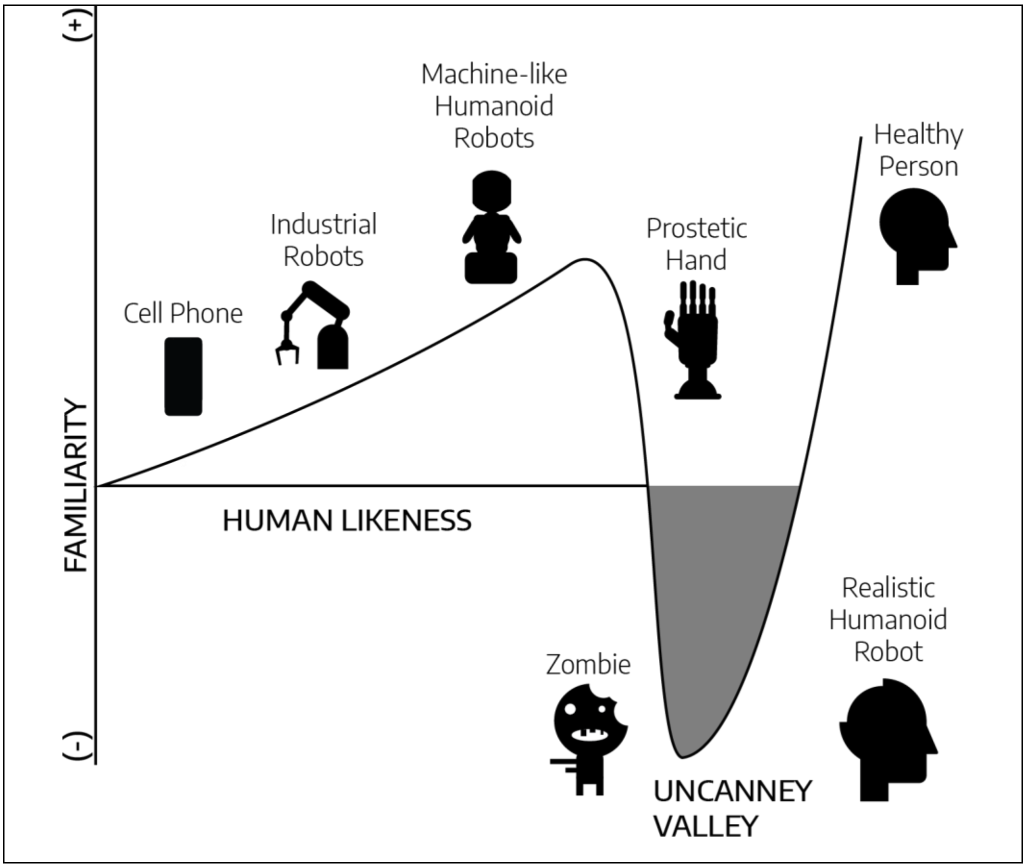

Figure 6 - The Uncanney Valley - Figure adopted from http://www.uncannyvalley.us)

The notion of the uncanny valley is tried to be demonstrated by various researchers to determine if the human likeness is appropriate between the various appearances of the robot's design space (Woods, Dautenhahn, & Schulz, 2004). According to the concept of the uncanny valley, if a robot has the realistic appearance but can be differentiated by humans as a non-living being, it may evoke negative emotions such as, recalling death and then becomes uncanny. Also, regarding the quality and attributes of the robots, providing positive user experience during the interactions becomes an important issue to sustain the relationship between robots and humans in various activity domains (Alenljung, Lindblom, Andreasson, & Ziemke, 2017). To grant positive user experience and to provide adequate design considerations for the further development of the robotic applications, adopting the human-centred HRI approach is more suitable for the scope of this literature review. Thus, the following sections will be presented through the lens of the human-centred approach in HRI.

2.1.2 Issues Regarding Robots

In this subsection, to provide suitable background information for the following sections, significant domains and classifications of different robot types will be explained. Defining robot types that are encapsulated in the field of HRI will clarify the following concepts related to the interaction between humans and robots. To provide a better understanding of diversity within the robot categories, robots that given as an example will be presented according to the level of autonomy and social skills required to (see Figures 7 and 8) for a robotic system within the user context. Also, some challenges related to robots' type and the context of use will be mentioned.

According to their context of use, robots are classified by IFR (2015) under three main categories namely: *Industrial Robots; Professional Service Robots; and Personal Service Robots*. These categories address different research areas in the field of HRI research and may require different interaction styles between the user and the robot.

Industrial robots are commonly used for manufacturing or transportation purposes are tend not to interact with the user directly while service robots (including both personal and professional) may have different interaction modalities than industrial robots such as having social attributes to give emotional responses or physical interaction. Physical interaction between robots and humans is a primary challenging research field of HRI because of the safety concerns on possible accidents and collisions between humans and robots which may cause serious injuries (Haddadin, Albu-schäffer, & Hirzinger, 2007). Regarding all kinds of physical robots, safety is a top priority concern for the field of HRI.

Professional service robots are encompassing numerous domains for professional use such as; defence applications, underwater exploration robots, agricultural robots, robots for livestock farming (milking robots), medical robots (in teleoperated surgery settings), human-exoskeletons, logistics systems, search and rescue and others

(I.F.R.R., 2015). PSR is expensive, may require regular maintenance, additionally, to operate or interact with robots in professional domains, to use robots may require experts from the fields or additional training for the use of robots (Goodrich & Schultz, 2007, p. 226). Most of the professional service robots operate under critical conditions and must continue to its purpose under high-stress conditions, for instance, a military robot for bomb disposal or teleoperated robot/s for unstructured environments in search and rescue missions. Professional service robots may create additional challenges for engineers regarding advanced requirements for multi-modal sensing and perception capabilities which might be crucial for some cases (Stiefelhagen et al., 2007). Social and assistive robotics can be involved in this category as a research challenge for the HRI because some of the assistive robots are used in hospital environment to move patients (Özkil et al., 2009) or to fulfil their request while providing companionship (Bharatharaj, Huang, & Al-Jumaily, 2016). To exemplify social and assistive robotics in human domains, Care-o Bot might be a good example. Care-o bot (see Figure 7), is a professional service robot which is designed to fulfil requests of the hospital residents such as, bringing an item or beverage (Mast et al., 2012). Also, it has social interaction capabilities which identify the human and create conversations by calling the name of who interacts with it by accessing the database of the hospital residents. Allowing the robot to access personal information of the hospital residents causes privacy-related issues to become of the primary concern in-line with the other ethical considerations.

Personal Service Robots are encapsulating robots for non-expert personal use without prerequisite training or knowledge. Personal service robots are growing at a rapid pace, within the few years there are many robots appeared in the market for educational and entertainment purposes with the help of crowdfunding and start-up companies. Application areas of personal robots are stated by IFR (2015) namely; education and research purposes, entertainment, robotic toys, household appliances such as vacuum cleaners, lawn mowers and so forth. Moreover, personal social robots are also integrating into human society. As a commercially available built-in social robot "*Jibo*" (see Figure 7) is one of the first examples of its kind for the end users in home context, it has capabilities such as; socially interacting with humans by using language and emotions, taking commands to execute tasks (taking photo, phone calls based on internet, controlling lights and more) (Rane, Mhatre, & Kurup, 2014). Robots that have been mentioned in these categories are shown in the Figure 7

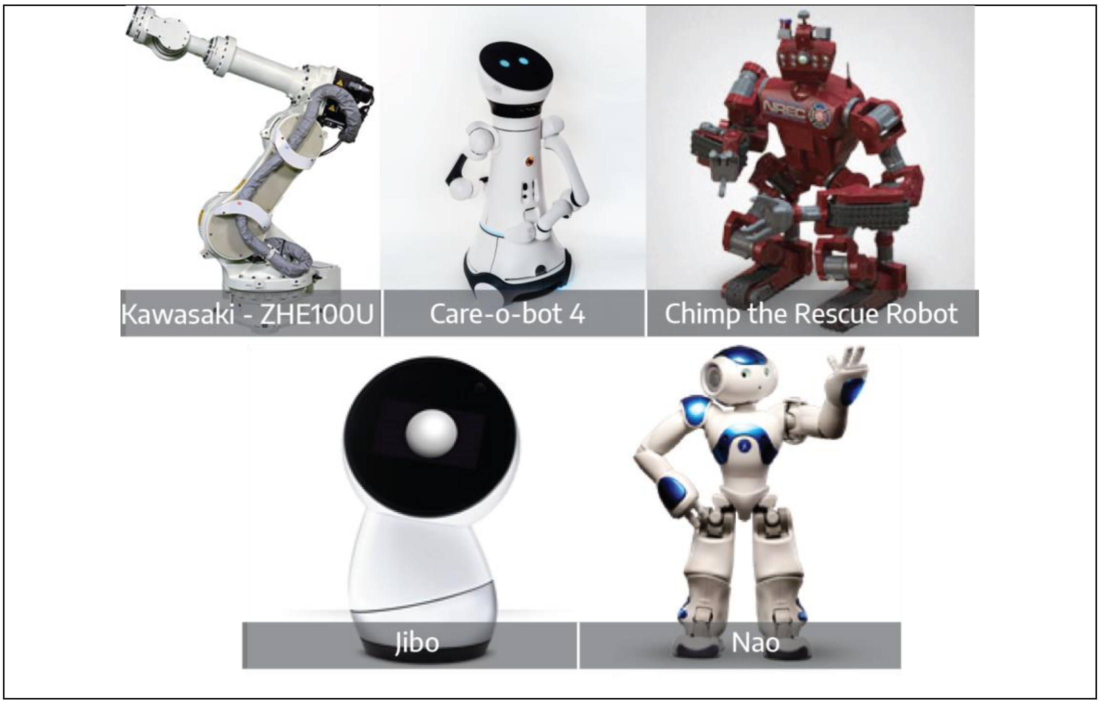

Figure 7 - Types of Robots

From left to right an industrial robot from Kawasaki Robotics, Care-o-Bot 4 as a companion service robot, Chimp as search and rescue robot. On the second line Jibo as a personal robot with expressive emotions and acts as a personal assistant. Finally, Nao of Aldebaran Robotics can be used as an educational robotic platform as well as for research purposes on advanced programming.

Regarding three broad categories in various context, additionally, the morphology of the robot design is also affecting the how people interact with the robotic system. The appearance of a robotic system may differ based on the use environment and the purpose of the interaction. For instance, Paro (Chang, Šabanović, & Huber, 2013) have a cute appearance to evoke positive feelings while a robot for search and rescue robot have a machine-like appearance because of the functional consideration that is required for the unstable environment. Fong et al., (2003) provided four categories for the embodiment of robots namely; *functional (machine-like)*; *anthropomorphic (human-like)*; *zoomorphic (animal-like);* and *caricatured*.

Related studies with similar issue claimed that the intended interaction and functional capabilities of robot should be reflected by the robot's design such as, a human-like robot may reflect the feelings of a robot with social capabilities and movements or on the contrary a functional robot without social cues in design may evoke a product-like feelings to humans (Breazeal & Brooks, 2005; Knight, 2011; Walters et al., 2011). Figure 8 converges the given examples of industrial robots, professional service robots and personal service robots with the previously mentioned issues with robot's morphology, level of autonomy with additional comments from the researcher. Types of robots are codependent with their user group and the usage context. Moreover, interactions may differ according to context and types of robots which will be presented in the next section.

Robot	Robot's Category	Robot's Morphology
 ZHE100U	Industrial Robot	Machine-Like
 Care-o-bot 4	Professional Service Robot	Human-machine like
 Chimp	Professional Service Robot	Human-machine like
 Jibo	Personal Robot	Caricaturised
 Nao	Personal Robot	Human-like

Figure 8 - Morphology of Robots

2.1.3 Interaction Roles in HRI

Humans are playing a central role in HRI and interacting with people is a prominent concern of HRI because robots are artificial creations which are built to operate individually or work in teams with humans (Groom & Nass, 2007; Sharma, Young, &

Eskicioglu, 2012). In order to provide such wide variety of services to humans, robots should be able to communicate with humans understandably and reasonably. When we consider the large application domains and design space of interactive robots, the interaction can take a variety of forms. From the robot side, the interaction between robots and humans shapes by mimicking the human attributes and the way that humans perceive their surrounding world which considered as biologically inspired or functionally designed (Fong, Nourbakhsh, & Dautenhahn, 2003). Therefore, for the HRI research, humans are the essential piece of the puzzle because even for a fully autonomous robot interaction with humans happens (Thrun, 2004).

Goodrich and Schultz (2007) maintained that interaction might be classified into two broad categories namely; (1) *Proximate Interaction* and (2) *Remote Interaction* (p.204) which is also known as teleoperation for mobile robots which enable humans to directly control robot/s from a distance via variety of interfaces such as; speech, display monitors, controllers, keyboard and other analogous control tools. Also, rich application domains of robotic systems may require social interaction, mobility or physical manipulation to move objects to desired locations or to accomplish simple tasks. *Proximate interaction* may be defined as which humans and the robots are in proximity or collocated in the same environment such as; service robots in hospitals to help hospital workers on their duty by bringing medical kits or by serving patients soft drinks; or pet-like robot for therapeutic purposes for the people who are unable to interact with real pets because of hygiene problems. On the contrary remote interaction occurs when humans and robots are not sharing the same physical space nearby. For instance; space exploration missions on mars or search and rescue missions (Bogue, 2012; Nourbakhsh et al., 2005). *Remote interaction* is crucial to fulfilling the task for inhabitable environments in human work domains such as, hazardous waste cleaning, space explorations or physical manipulation of objects which humans cannot intervene. On the other hand, robots with social skills may require proximate interaction rather than remote interaction because social interaction involves emotional, cognitive and moral aspects of human society which may not be experienced during the remote interaction.

Moreover, Thrun (2004) has similar categorisation for the interaction between human and robots as being (a) *Direct Interaction*, (b) *Indirect Interaction*. This categorisation takes the control and the flow of the information as a basis to distinguish between interaction interfaces among humans and robots. *Direct interaction* occurs when the flow of the information is bidirectional between agent and robot such as; having a verbal conversation by taking turns or robot responding behaviour of its user and user responds back. In *indirect interaction*; human interacts with the robot as an operator and the flow of the information is directional, for instance, a search and rescue team member operates a robot from a distance with the help of an interface to search for the survivors in the disaster area (Voshell & Oomes, 2006). The main difference between direct and indirect interaction is caused by the flow of the information. Direct interaction occurs when human and robot are on equal footing, however, an indirect interaction, the interaction is one-sided. Personal service robots and industrial robots are tending to interact with humans indirectly such as; an industrial robot working in the factory district, transporting materials from one point to another if it senses a human via sensors, it may ignore the human as an obstacle. However, robots with social capabilities that share the same environment with people may require direct interaction with humans and tend to communicate with them. Some of the professional service robots may be an example for this case, for instance, care-o-bot. To present the two different approaches to HRI in a holistic way, regarding Thrun's and Goodrich's categorisations Table 1 provides how users interact with a robotic system based on previously mentioned robots in this section.

Table 1 - Interaction Styles of Robots

Robot's Type	Robot's Name	Interaction Style
Industrial robot	ZHE100U	Indirect/Remote
Companion robot	Care-o-bot 4	Direct/Proximate
Search and rescue robot	Chimp	Direct/Remote
Personal assistant	Jibo	Direct/Proximate Interaction
Educational robot	Nao	Direct/Indirect/Remote/Proximate

Humans are in need of an interface in order to interact with robots. Regarding industrial robots as the first examples of robot kind, humans are usually interacting with robots through using computers to programme them in order to make them fulfil the desired actions of the users. Advancements in the new technologies, allow interaction interfaces of robots to become more natural and allow humans to interact with a robotic system by using speech, gestures or gaze (Salter, Dautenhahn, & Te Boekhorst, 2006). Regarding the interaction interfaces between robots and humans. Takeda et al. (1997) defined four kinds of interactions for HRI namely: (1) *Primitive Interaction* which is based on computer interfaces; (2) *Intimate Interaction* which occurs when robot and human directly communicates through gaze, gestures or touch; (3) *Loose Interaction* which happens at a distance; (4) *Cooperative Interaction* which may include more than one robot and humans in case of needed interaction scenario. Figure 9 represents the four kinds of interaction between humans and robots to provide a better understanding of the variety of interfaces may be required for each category. As the quality of communication between robot and human develops, the interaction interface is becoming more natural and human-like such as using speech to give commands or having a conversation (Zhao, Tu, & Xu, 2014).

Kinds of Interaction	Example Interfaces
Primitive Interaction	Mouse/Keyboard/Controllers
Intimate Interaction	Haptics/Touch sensors/Artificial skins
Loose Interaction	Supervision/Speech/Gaze/Gestures
Cooperative Interaction	Augmented and virtual reality

Figure 9 - Four Kinds of Interaction - Figure adopted from Takeda et al. (1997)

Four kinds of interactions are beneficial to define the quality of the interaction derived from the interfaces that have been used in a robotic system to provide information exchange between humans and robots. Information exchange is one of the essential considerations for designing interaction between humans and robots. Interaction dimensions mentioned by Goodrich & Schultz (2007) based on information exchange consists of visual interfaces (augmented reality, graphical user interface), gestures (including bodily movement), speech, non-speech-based audio (buzzers, alerts), physical interaction and haptics (including augmented reality). These dimensions form the information flow between robots and humans according to constraints and user-based considerations on the robot design.

Due to the issues above related to interaction, the autonomy level of a robot plays a significant role in designing interactions for a robotic system. Roles that been played during the interaction may change according to the level of autonomy of a robot. For instance, a space exploration robot is required to work fully autonomous during the time of conditions which are not suitable for humans to intervene or a socially interactive robot may require autonomous behaviours to sustain a conversation with humans while reflecting an image of a socially intelligent being (Cowley & Kanda, 2002). On the other hand, a robot-assisted surgery requires minimal autonomy or do not act without human supervision in order to minimise the risk of error made by a robot during surgical operation (Camarillo, Krummel, & Salisbury, 2004).

Considering the level of autonomy and human intervention in human-robot interaction Figure 10 represents the relationship between the level of human intervention and the autonomy level of a robotic system.

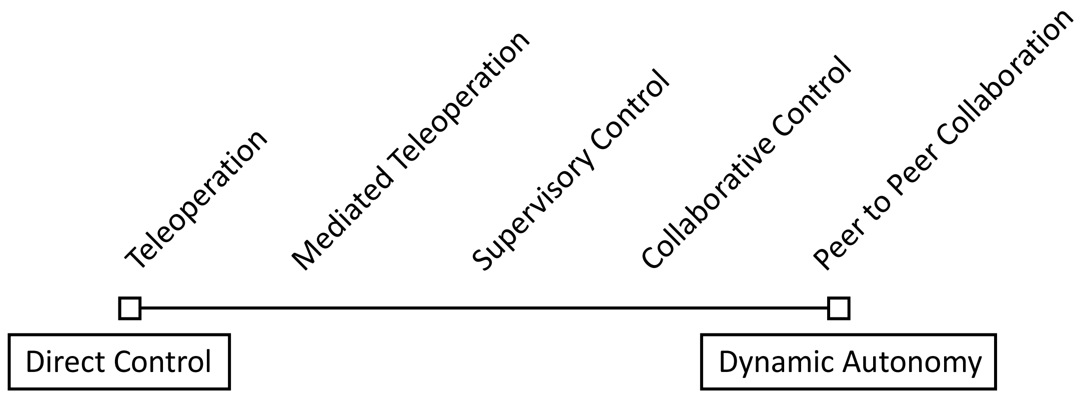

Figure 10 - Level of Human Intervention - Figure derived from Goodrich & Schultz (2007)

As discussed above, the interaction between humans and robots' shapes through their physical distance between robot and human in-line with the requirements of the work domain. During the interaction, robots may play various roles when performing tasks or goals in a specific environment. Interaction roles in HRI can be defined as a taxonomy of roles that a robotic system/s may present to the user/s. Due to various situations, a robot can play more than one role or adapt its behaviour according to its peer in line with the requirements to support the user. For instance, during a search and rescue mission, a mobile autonomous robot may search for human survivors autonomously until it finds one. Afterwards, it may switch to teleoperated control to not harm injured humans or may send information to its supervisor. Generic interaction roles that robots and humans may assume in HRI are maintained by Goodrich & Schultz (2007) namely; (pp.233-234)

Based on the Donald Norman's seven stages of interaction HCI model (Norman, 2013), first five interaction roles are provided by Scholtz (2003) and later on, Goodrich & Schultz (2007) pp.223 provided two more roles namely, mentor and bystander. Given interaction roles are further described in the Table 2 according to their context of use and interaction with humans. Interaction roles that provided above are applicable for human activity domains where robots take place. Also, roles are intertwined with the other dimensions of the interaction such as distance and interaction interfaces.

Table 2 - Interaction Roles

Kinds of Interaction	Example Interfaces
Supervisor	Human supervisory control of independent robot/s
Operator	Operating a system by direct human control
Mechanic	Human who repairs and maintains the system
Peer	Interacting with robot as peers
Bystander	For instance, a human who waits to saved by a robot in an area
Mentor	Robots tutoring students/humans
Information Consumer	Human only consumes information one directional interaction

Table adopted from Goodrich & Schultz (2007)

According to use the context of the different robots, interaction roles that have been taken between humans and robots are exemplified in Table 2.2. Human work domains have different workloads assigned to each person who works in the same environment. Also, robots are a part of this division of labour to complete the desired task or to achieve a major goal with the contribution of other actors in the work environment. If we assign the roles given by Scholtz (2003) between the three robot categories, industrial robots and their users may play constant roles rather then changing roles according to their surrounding because industrial settings are specially designed as fixed environments to increase the efficiency of the production. However, for personal and professional service robots' roles between humans and robots are often interchangeable, from the robot's perspective, showing adaptation to complete a task by learning from a human being can be an option to provide satisfactory results on user goals. Thus, the role of robots may change according to the situation faced during the activities or for preferences of its user. Figure 11 includes robots from different domains based on the three major categories to present interaction roles that might be taken by the robot and user according to different user context.

Application Domain	Robot's Name	Interaction Role
Industry	ZHE100U	Supervisor/Mechanic/Operator
Healthcare	Care-o-Bot 4	Supervisor/Peer
Search and Rescue	Chimp	Supervisor/Bystander/Operator
Home	Jibo	Peer/Information consumer
Education	Nao	Tutor/Operator

Figure 11 - Relationship Between Interaction Roles and Robots

For various domains of HRI, to provide and make a decision on the interaction roles suitably are offering multi-facet challenges based on the three HRI research approaches as mentioned earlier in the Section 2.1.1. Moreover, to increase the benefits gained from the use of robots providing users discoverability and understandability of the system is essential for the quality of interaction (Norman, 2008). In this way, users in various roles may adapt to situations easily derived from the robot and may disregard the additional challenges from the user-side besides the technical problems caused by the robot. However, designing advanced robotic systems are require interdisciplinary work because of the complexity and challenges offered by designing robots to operate in real-world settings to fulfil the needs of the humans. Moreover, this complexity based on both technical and user side for the field of HRI, for instance, vulnerability of the humans during interaction, sense of feeling secure, privacy of the conversation, perceived capabilities of robots and more (Bartneck & Forlizzi, 2004; Feil-Seifer & Mataric, 2009; Goodrich, 2003) In the section that follows, the major challenging issues related to HRI will be discussed.

2.1.4 Challenges of the HRI Field

As mentioned in the earlier section 2.1.2, HRI has a broad range of application domains, and each application domain has its unique challenges considering the intersection of the various disciplines. HRI field is constantly evolving in the light of the researches within the field and rapidly updating itself according to developments in the robotic technologies. Therefore, within the scope of this study, it is not possible to cover all aspects of the challenges offered by the field of HRI. However, there are commonly shared challenges across the robotic application domains will be presented in this section.

Challenges within the field of HRI are generally domain specific because of different interaction patterns and elements of robot design that shapes due to the needs and constraints of the application domain which will robots take place. Main challenging robotic application domains are stated by Goodrich & Schultz (2007, p. 235) namely;

- *Search and Rescue*
- *Assistive and Educational Robotics*
- *Entertainment, Military and Police*
- *Space Explorations*
- *Uncrewed Air Vehicles and Uncrewed Underwater Vehicles.*

Similarly, Feil-Seifer & Mataric (2009) argued that *Service Robotics*, *Assistive Robotics*, *Social Robotics* and *Educational Robotics* as challenging research domains within the field of HRI. Robots with social abilities might be applied to the other domains above such as educational robotics, assistive robotics and many others. Alongside the highly financially supported robotic application areas such as, search and rescue and military robotics; social robotics is one of the high-profile research areas that capture the particular interest of many researchers to design more sociable robots like human beings to create more natural and multi-modal interaction interfaces between humans and robots (Gorostiza et al., 2006). Nevertheless, all kinds of robots are designed by humans and work with or for humans to fulfil the needs of the society in various ways and no matter how independent the robot acts, the interaction between humans and robots may occur in diverse forms (Sidner, Lee, Kidd, Lesh, & Rich, 2005). Thus, there is no clear division of challenges as robot-based and human-based so, challenges are shaped accordingly by requirements from both human and robot-based concerns.

Most of the challenges are born from the direct uses of robots in specific domains that specified earlier. HRI challenges are interconnected with all three elements that form itself which are humans, robots and the interaction between them. To identify challenges from different perspectives, we can examine the challenges offered by the diverse robotic application domains under three folds, namely; *Research-Based Challenges*, *Robot-Based Challenges* and *Interaction-Based Challenges*. These three categories are not separated from each other yet provide an opportunity to highlight challenges that are specific for research, robots and interaction between humans and robots.

2.1.4.1 Research-Based Challenges

Research-based challenges are concerned about the methodological and practical approaches to HRI studies from both human and robot side. Robot-based challenges are in-line with the Robot-Cognition Centred and Robot-Centred approaches which are highlighted by Dautenhahn (2007) as perceptual abilities and satisfying inner needs of a robot itself such as, detecting obstacles and preserving its existence. Robot-based challenges are concerned about the technical challenges of design and use of robots in the real-world environments; these challenges are also intertwined with the interaction-based challenges. Afterall, the capability of a robotic application affects the quality of the interaction with humans. Interaction-based challenges are concerned about the human-centred point of view within the field of HRI such as cultural differences, media effects on interaction, human values and ethical concerns.

Regarding HRI research challenges, one of the significant challenges is the lack of appropriate foundational methodologies and lack of reproducibility of other experiments (Baxter, Kennedy, Senft, Lemaignan, & Belpaeme, 2016; Walters, Woods, Koay, & Dautenhahn, 2005). Major challenging issues regarding HRI research are stated by Dautenhahn (2007) as not using precise methodological approaches, directly implementing human-human interactions to HRI, and replication of other research results because of everchanging robot design space. Moreover, there are numerous challenges while designing HRI experiments such as, safety and comfort level of the subjects, ethical concerns and permissions required to study with vulnerable groups, practical challenges on studying with humanoid robots, how to evaluate the interaction between robot and the subject, recording data via using video cameras or sensor data of robot to measure physical interaction (Robins, Dautenhahn, Boekhorst, & Billard, 2005). There is no one-for-all applicable research methodology for the HRI field; many researchers are conducting qualitative and quantitative studies to gain generalizable knowledge about the HRI. However, cultural differences may show differences in how people interact with robots thus creates barriers for foundational background knowledge to create a generally applicable methodology for the HRI research. Therefore, regarding the used robot type and application domain, selection of appropriate methodology is critical. HRI is a relevantly new field of research. Thus it benefits from the methodologies that developed in other research fields especially from *Human-Computer Interaction* (HCI).

HRI field is strongly related to *Human-Computer Interaction* (HCI) field and adopts methodologies from the field of HCI but shows some differences because of the tangible nature of robots and challenges offered by real-world environments for the operation of robotic systems. Table 3 shows the distinct differences between HCI and HRI.

Table 3 - Differences between HCI and HRI

HRI	HCI
Autonomy	Controlled by human
3 Dimension	2 Dimension
Complex	Simple
Dynamic user model	Static user model
Movable	Fixed and portable
Vision, audio, touch, face to face	Mostly vision and audio

Table adopted from Han et al,. (2005)

Most of the HCI related methodology implications to HRI are based on evaluation methods. HRI also in need of methodologies to evaluate hedonic and pragmatic qualities of robots as an interactive artefact, based on user experience and HCI techniques (Lindblom & Andreasson, 2016); methods used for evaluation of HRI are commonly scenario-based evaluations (Xu et al., 2012), Wizard of Oz (WoZ) (Steinfeld, 2009), interviews and surveys and focus groups (Espinoza, Baxter, Nalin, & Wood, 2011). User experience-based methodologies are required for the HRI studies to provide overarching goals for interactions between robots and humans according to the real users in the activity domains. For instance, in Figure 12 Dautenhahn et al., (2007) provided a timeline of methodological approaches for the robot development of an HRI study.

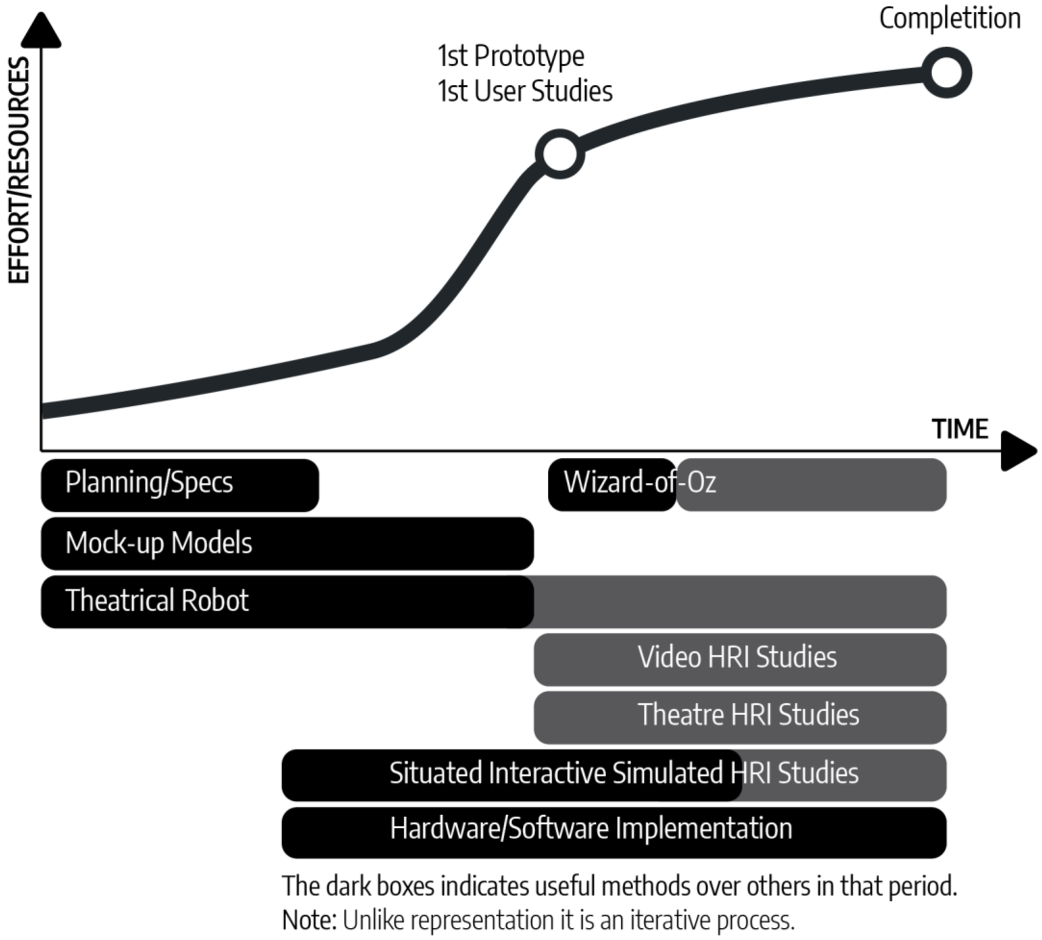

Figure 12 - Methodological Approaches to Develop a HRI Study - adopted from Dautenhahn et al., (2007)

During the first phase of the study, in line with the planning and specifications, mock-up models help researchers to explore and iterate hardware and software development of the robot. After reaching a working prototype with satisfactory safety requirements, WoZ method or video-based methods are become applicable to test possible interaction scenarios of the robot with subjects. WoZ studies are generally performed with semi-autonomous robots which are controlled by an operator/s by using pre-programmed behaviours. During the WoZ studies, operators are located in the different area (which is not visible to the subject) from the experiment space. WoZ studies may shape according to the subject's responses during interaction similar to an advanced autonomous robot which may adapt to various situations but in a manual way. Thus, using the WoZ method provides advantages of saving time and effort during the HRI studies to programme fully autonomous robots. Testing interactions via using video-based method are mentioned as a suitable method for the pilot tests in the early phase of the development of a robotic project (Woods, Walters, Koay, & Dautenhahn, 2006b). Video-based methods are exposing videotaped human-robot interactions to subjects to gain insights about different interaction scenarios that robot can perform with humans. Woods et al., (2006) conducted a study about the comfort level of the users on human-robot encounters and compared video-based and live HRI interaction scenarios among the subjects. Using videotaped interaction scenarios shows no significant changes when it compared to live HRI scenarios which are also found beneficial regarding cost and effort for the studies. Theatrical robot method is another low-cost method to test interaction scenarios for humanoid robots by merely using an actor to perform specific robot-like actions according to a script (Chatley, Dautenhahn, Walters, Syrdal, & Christianson, 2010; Lu & Smart, 2011). According to previous studies, theatrical robot method is applicable throughout the beginning of the studies until the end of the study. However, it becomes insufficient if the researchers have a working physical prototype of the robot.

2.1.4.2 Robot-Based Challenges

Robot-based challenges might be examined under two distinct approaches for the HRI research that stated in the previous sections namely; *Robot-centred* and *Robot-Cognition Centred*. Both categories are covering the technical and practical challenges of robotic applications to provide desirable interactions and to perform tasks in virtual and real-world environments. Robotic application domains differ from each other and may require different level of autonomy and diverse abilities from robots such as, social skills to interact humans in public areas, physical interaction from a companion robot (Odetti et al., 2007), direct control of the system for search and rescue missions or supervisory control of one or more robots (Chen & Barnes, 2012). To overcome the challenges that offered by numerous domains, physical, perceptual and behavioural capabilities of robots plays a significant role.

The robot-centred approach is considering robots as a living entity which in need of fulfilling its own needs and motivations by interacting with humans even without executing tasks (Breazeal, 2004). Researchers that focused on the robot-centred approach is more likely to pursuit engineering-based challenges of building motor controls for robots, models and architecture of emotions and behaviours that regulates the social interaction. Robot-centred challenge problems are based on understanding the human sensory-motor system from the computational and mathematical perspective (Turk, 2014). For instance, Breazeal (2005) designed a social robot named *Kismet* (see Figure 13) which interacts with humans by using facial emotional expressions and speech. Kismet is regulating the interactions according to its own needs. When the person who interacts gets too close in sensor range or not locates herself/himself in suitable interaction distance robot reacts with emotional expressions and motor-based behaviours to give social cues about the desired distance. As an illustration Figure 14 shows the behavioural reactions of the robot to regulate interaction with humans.

Figure 13 - Kismet the Emotional Animatronic Head - Image retrieved from Breazeal (2005)

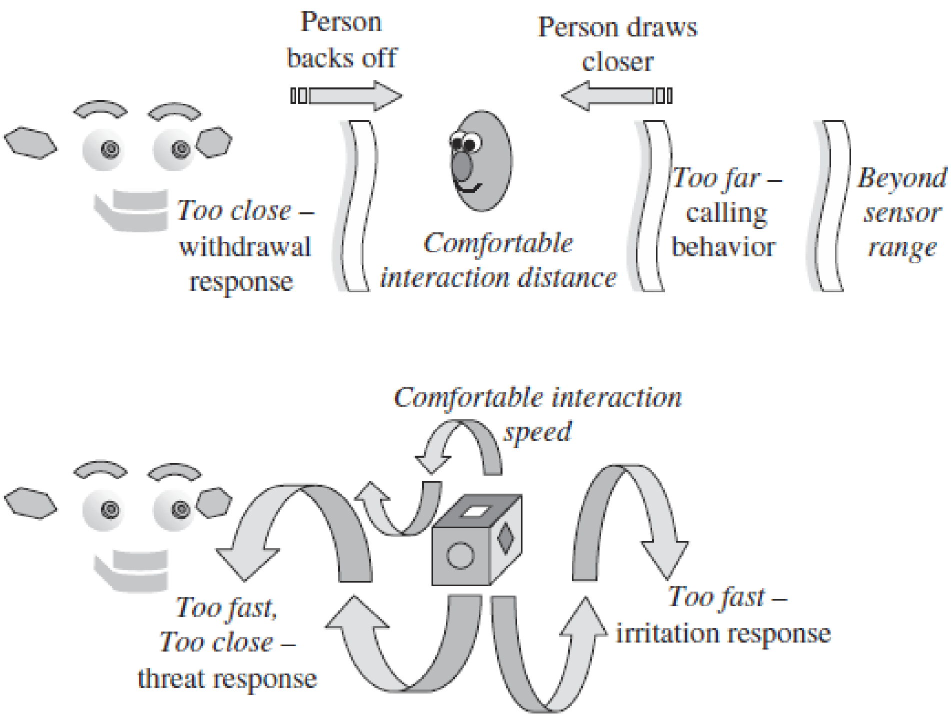

Figure 14 - Kismet's Reactions – Image retrived from Breazeal (2004)

From the robot perspective, another challenging issue is to design robots with abilities to survive in the real world like living beings. Robots are dependent on their batteries to perform actions in daily life also without their computational hardware and actuators they will not be able to plan or act. Regarding these issues, durability and longevity of robots are essential issues to consider to address the challenge of designing a life-like machine. To address the challenges of the designing life-like robots future developments in the robotic technologies may provide support in the ways of creation of new materials, sensors and actuators such as soft materials with sensory perception to imitate skin, self-replenishing batteries and so forth.

Robot-cognition centred challenge problems are based on the overarching goal of designing intelligent robotic systems. In contrast to human beings, robots are depending on limited sensor data to identify objects/humans, behaviours, intents and their environments. Therefore, to behave in an autonomous way to solve problems, making decisions and executing tasks in various situations robots require suitable cognitive architecture (Stubbs, Wettergreen, & Hinds, 2007). Most of the robots are performing in specific domains and may require different kinds of perceptual capabilities. So, the perceptual capabilities of robots aid them to perceive, understand and perform actions accurately and acceptable to humankind (Feil-Seifer & Mataric, 2009). For instance, if an autonomous search and rescue robot cannot distinguish a person from a non-living object, it may cause unwanted consequences in the disaster area. In order to communicate with humans, perceptual capabilities of robots are crucial to exchange information with humans by using various communication mediums that address three senses of humans such as, touching, hearing and seeing (Hartson, 2003; Steinfeld, Fong, & Kaber, 2006).

Variety of interfaces are used as a way of communication between robots and humans but from the robot, perspective understanding human actions by using sensor data is offering open challenges and require interdisciplinary work from diverse fields such as, cognitive science, linguistics, human factors engineering, design and so forth. The complexity of the required cognitive model and software architecture of robot is based on the robot's level of autonomy. The more independent the robot is, the more complex system it requires to act on its own. Thus, the effort to create intelligent systems that can make decisions in various situations creates domain specific challenges. For instance, search and rescue robots are not required to be fully autonomous to save humans from a disaster area because of imperfect perceptual and cognitive capacity of robots due to the current state of the technology. Social robotics, socially assistive robotics and educational robotics are some of the few problem domains that are directly affected by the robot-cognition based challenges. Social robots, socially assistive robots and educational robots are envisioned as future's fully autonomous robots that may interact with people in diverse human domains and social environments such as, schools, science centres, museums, shopping malls, homes, health care centres, hospitals and so forth. A robot with social competencies may require high-level cognition in order to empathise, understand, and react to humans in real-time interactions.

Moreover, there is an effort to construct personality and autobiographic memory to social robots in order to richen the interactive experiences and to keep the flow of the interaction as natural as human-human interactions. Some studies concerned about the how a robot's personality affects the human likeness and create motivation for humans for further interactions. In the study of Walters et al., (2011) people tend to favour robots that are showing similarities to their personality rather than a robot with different personality traits which highlights the importance of the adaptation of robots to human beings in various ways. Similar to events and experiences that shape a human's personality, providing robots with an autobiographic memory is another challenge for robotics that creates an opportunity for adaptation and expansion of robot's personality according to its past experiences. For example, for a companion robot that has the appropriate cognitive architecture to learn when the user/s more likely to share information about themselves and things they prefer, as time goes by robot may adapt its behaviours and attitude according to its user preferences by which may also support long-term interactions.

However, beyond equipping robots with personality and memory, to simulate a social being creates multi-facets challenges such as, understanding human intentions and emotional expressions, using language to create meaningful sentences that suit the conversation, adapting behaviours according to humans and so forth. These traits are naturally happening with or without little effort during the interaction between humans, yet it is hard for robots to understand and make an estimation about the humans through pre-defined software architecture. The effort to understand emotional state of the humans from social cues such as, facial expressions and bodily gestures is crucial to sustain the relationship between robots and humans in long term for various application domains that involves direct interaction with humans such as, healthcare robots that socially interacts patients by conversation or a companion robot which take place at homes to help people doing daily tasks (Busso, Deng, Yildirim, & Bulut, 2004; Sung, Grinter, Christensen, & Guo, 2008). Moreover, with the aid of the wearable sensors robots may benefit from physiological information of humans such as heart rate, temperature, blood pressure to understand the situational changes in emotional and health status of the humans to perform a behaviour or to make warnings (Munteanu et al., 2016). However, providing robots that fully understand the human-based information remains a grand challenge for the HRI research.

Application domains that require verbal and non-verbal interactions to communicate with the robotic systems are directly affected by the perceptual capabilities of robots which is also have a direct impact on the interaction with humans as well as the quality of the interaction. This issue is addressed in the book of Breazeal (2002) as one of the grand challenge under the topic of *embodied discourse* (p.236) which creates challenges to a robotic system that required to interact with humans on equal footing to sustain natural conversation by using paralinguistic features such as, gaze, gestures, facial expressions and bodily movements. Hence, from the robot-cognition centred issues emphatising with humans, understanding humans in social terms, constructing a robot personality and autobiographic memory, adapting robot's behaviours to the human user and learning from humans to execute a task remains as multifacet challenging problems for the HRI research (Adams, 2005; Nicolescu & Mataric, 2001; Wainer, Feil-Seifer, Shell, & Matarić, 2007).

2.1.4.3 Interaction-Based Challenges

Interaction-based challenge problems will be examined from the human-centred point of view. Until robots can survive without any human intervention and choose not to interact with their own will, regardless of the type or the autonomy level of the robots humans are always in the loop of the interaction. Considering human perspective in the HRI, major challenging problem areas are interrelated with contributing research fields such as cognitive science, human factors, psychology, design, ergonomics and so forth. Anthropomorphism, providing long-term interactions with robots, media effects on HRI, safety and trust in automation, and respecting human values can be listed as major challenging issues from the human-centred point of view for HRI research (Cockshott & Renaud, 2016; Epley, Waytz, & Cacioppo, 2007; Lee & See, 2004; Sheridan, 2016; Złotowski, Yogeeswaran, & Bartneck, 2017).

Anthropomorphism can be broadly defined as attributing human-like characteristics to a non-human thing, for example, the owner of a car calls it by a human name, or a child might think clouds are crying when it rains. Humans are also anthropomorphising robots and make assumptions before interacting with robots. These assumptions are mainly affected by the robot's physical appearance and design of its behaviours. The anthropic robot designs also affect the mental model of the user and shape the possible interaction scenarios beforehand (Fink, 2012). In a nutshell, a mental model can be defined as based on person's prior experiences conceptual understanding of things that surround them such as, how to interact with objects or how to interact with humans based on their culture (Kieras & Bovair, 1984; Stubbs et al., 2007). For example, a humanoid robot may give an impression of an intelligent human being, and the realistic design of the robotic system may reflect the conceptual model of the performance of the real human body and communication (Sharkey, 2011). However, according to the current state of the technology providing the exact functions of the human body is not possible, so the human who interacts with the robot may be disappointed after discovering the incapability's of the robot. Also, for the realistic anthropomorphic robot appearance, there is a risk to evoke negative feelings and repel people from interaction which is referred in the literature as "The Uncanny Valley".

Considering anthropomorphic attributes of robots such as humanoids and human-like machines, designers and researchers tend to avoid uncanny valley until the technology allows to produce super-realistic robots. The degree of anthropomorphisation of robot design is vital to reflect the perceived behaviour and intelligence of the system as well as satisfying user expectations (Tapus, & Matarić, 2009; Wainer, Feil-Seifer, Shell, & Matarić, 2006). The physical appearance of the robot is the first thing people encounter before interacting with the system, so the morphology of the robot's design reflects upon the level of anthropomorphism and perception of the humans regarding robot's personality and other functional and non-functional capabilities. Based on different morphologies such as human-like, machine-like and animal-like; Woods (2006) evaluated different types of robots to explore the design space of robots and found that children tend to attribute aggressive and bossy type of characteristics to human-like robots while animal-like and human-machine like robots found in a friendly way or cute. The concept of anthropomorphism is particularly crucial for the interaction between children and robot because several studies proposed that children tend to attribute more human-like characteristics to robots rather than adults (Belpaeme et al., 2012, 2013). For the educational purposes of robots, anthropomorphic attributes made by children may create barriers for the interaction for long-term interactions because when they understand the actual capabilities of the robot, it may cause frustration which can end up by not interacting with the robot at all. Similar to bias that caused by human-like attribute to robots, media-based fictional robot characters are also affecting the approach to interact with robots.

Media-based understanding of robots creates pre-defined interaction scenarios or expectations from robots to people without experience with the real robotic systems which may have positive or negative implementations for the future and current use of robots. Robot characters from science-fiction movies, cartoons and literature have a direct effect on the acceptance and perceived qualities of the robots in the real world (Bartneck & Hu, 2004; Bartneck, Kulić, Croft, & Zoghbi, 2009). According to the studies in the literature on the effects of media on user perception to robots, Sundar et al., (2016) found that users perception of robots on perceived usefulness and ease of use are related with previous fictional robots that have been seen in the movies, the degree of sympathy to that fictional robots, and the human-likeness of that fictional robots. Results of the study have shown that the higher level of sympathy felt to fictional robots and more characters recalled from the movies the lower level of anxiety felt towards the robots in the real world. Also, the study offers recommendations on the design of a robotic system such as the autonomous operation is an expectation of companion and social robots while assistant robots should be designed to reflect positive perception on ease of use by using simple voice commands, user-friendly interfaces. Moreover, to invoke mental models of robots to users and to make decisions on the morphology, interactions and dialogue scripts, the study also suggests that positively evaluated fictional robot characters may provide a basis point for the socially acceptable robots (Kaber & Endsley, 2004; Kiesler & Goetz, 2002). The perception of robots, in general, is critical for the integration of robots in the daily life of humans. Exposed media related to robots may create both positive and negative results. However, they are offering opportunities based on benefit from mental models that shaped with the aid of the media exposure to interact with robots which may also support long-term interaction-based challenge problems in various application domains.

Providing long-term interactions with intelligent systems that adapt and change according to user preferences is one of the common goals for HRI, especially for personal robots. As robots are becoming a more personally available offering, fruitful interactions which can endure after novelty effect ends is one major challenge (Dautenhahn, 2007). In contrast to short-term interactions with humans in laboratory environments, robots that exist in daily life for a variety of purposes such as, caregiver, social companion or other task related work to clean or cook, should motivate humans for further interaction. Previous research has established that to motivate people on weight loss diet, a socially interactive robot named "Autom" interacts with the subjects in a daily basis to understand the current situation of their activities and further motivate them by giving advice and suggestions on their current progress (Kidd & Breazeal, 2008). According to the results of this study, a socially interactive robot that uses dialogue and touchscreen to interact with users is found more beneficial than a computer and paper-based systems to keep track of their daily dietary activities. Autom the robot also has established a closer relationship than other media because the robotic system designed similar to human to the human relationship between the caregiver and the patient who is supportive, positive and helpful. Providing robots that interact with users on a daily basis for long-term is based on the numerous factors.

However, to create a positive relationship between the user and the robot may be a solution for long-term interactions with robotic systems. To establish a positive relationship, feelings that evoked by the robot during interaction is crucial for user satisfaction and to succeed at goals such as, robotic assistants (Kiesler & Goetz, 2002). The ways to provide such long-term positive relationship, the safety of the users, their level of trust in the automation are two majors of many challenges.

Human safety comes first. The physical safety of the humans during an interaction with the robotic system is the primary concern of HRI research for the use of robots in human environments. In the structured environments such as automated factories with industrial robots, providing safety precautions are relevantly easier and have standards, unlike unstructured environments in other human environments such as homes, public spaces and so forth. Regarding proximate interactions with autonomous robots, possible cases of collisions between robots and humans are mostly avoided by software architecture; if it is not possible, robot designs allow physical shut-down control buttons for different scenarios. The reflected image of a robot's design directly affecting the hidden safety features as well as the dependability of a robotic system. For instance, an anthropomorphic robot design such as an animal-like robot can give an impression of a pet and implies the mental model of the living creature in real life. However, the mechanical and software design of the system may not be able to match the exact mental model of the user. Thus, unexpected behaviour from the user can cause critical injuries during an interaction with an autonomous system (Severinson-Eklundh, Green, & Hüttenrauch, 2003). In the first place, safety and dependability of a robotic system can be reflected by the interface design to create awareness to the user about the capabilities of the robot during an interaction (Alami et al., 2006; Heinzmann & Zelinsky, 2003). To provide safety and dependability to a robotic system passive and active precautions are considered for the possible cases of injuries (De Santis, Siciliano, De Luca, & Bicchi, 2008). Physical aspects of the design such as the lightweight design of the overall system, soft edges, rubber coverings and artificial skin may reduce the collision impact and give the passive impression of dependability and trust to the user (Schaal, 2007; Zinn, Roth, Khatib, & Salisbury, 2004). Moreover, active safety precautions are hidden behind the system and driven by the software architecture or inner mechanisms of the system. Safety and dependability depend on several factors when designing robots from human-centred view. Firstly, based on the physical and functional aspects of robots such as mechanical design, appearance/degree of anthropomorphism, actuators and sensory perception of its environment. Secondly, considering software architecture, providing safety in hidden features of robot's computing system such as designing modular software architecture for the ease of maintenance upon failures and human-oriented planning to avoid or detect collisions (Cowley & Kanda, 2002). Afterall, humans are the central subject of the HRI and because of the expectable nature of humans, providing safe interaction with robots remains as a significant challenge for many application domains of personal and professional service robots.

Alongside with the challenges above regarding the interaction between humans and robots, adding value through the use of robots is another significant concern for HRI field. Since the robots are interacting with humans in a more mobile and social way by using various interfaces, there are new challenges appeared to provide social benefits as well as problems considering human values. Social benefits of using robots are addressed by, social robotics, assistive robotics, socially assistive robotics and educational robotics fields. These fields are concerned about robots that help people physically and emotionally as well as robots that support and enhance human capabilities in various domains. For instance, a social companion robot that serves as an personal training assistance to motivate its user to continue his/her exercise in a regular basis (Fasola, Matarić, & Member, 2010), a socially assistive robot that can be used for therapeutic tool (Bharatharaj et al., 2016) or an educational robot that can enable a student to participate in classroom from a distance by providing physical body (Newhart & Olson, 2017). Regarding the social benefits offered by robotics, there are several aspects to consider in order to respect human values in the human society such as providing positive experiences and protection of user's privacy (Feil-Seifer & Mataric, 2011; Kopacek, 2014).

Providing positive experiences to users is essential for the integration of robots into the daily life of humans as companions, assistants or many other roles in interaction. Studies showed that in line with the physical appearance, behavioural actions of a robotic system is vital to give social cues to humans in order to communicate in an effective way to (Syrdal, Dautenhahn, Walters, & Koay, 2008). Humans are social beings so they expect social cues from robots such as the gaze direction of the robot may imply where it will going to take action or its posture may give the signal of emotional state or direction of movement (Walters et al., 2011). For example, in the study of Woods, Walters, & Dautenhahn (2006) researchers tested the comfort level of the users in a simulated home environment with different approaching scenarios of the robot. Respondents rated the frontal approach of the robot as least comfortable while front-left and right approaches rated as most comfortable. Thus, a personal robot may provide comfort to its user by adapting its behaviours during task operations.

From the user point of view, the comfort given by the robot is dependent on various factors such as likeability of the robot, duration of the interaction, and physical distance between the robot and human (Mumm & Mutlu, 2011). Likeability of a robot is based on the robot's physical appearance and perception of the user. Duration of the interaction can be explained as the time spent during overall interactions such as eye contact, physical contact, conversation. Also, several studies identified that user preferences on robots are related with the various factors that caused from cultural and individual differences such as, gender, personality, health factors, physical attributes and so forth (Syrdal, Koay, Walters, & Dautenhahn, 2007). Regarding user preferences, in the study of Tapus, & Mataric (2008), personalisation of hand-off assistive robot creates an opportunity to encourage and motivate post-stroke users for rehabilitation exercises. Also, the adaptation of the autonomous robot to the user's preferences and personality provided better engagement for the user's tasks. In the case of using robots for socially assistive and educational purposes, robots are adding value over other tools for the human-centred work environments by supporting humans in a social way such as encourage rehabilitation patients to fulfil their daily tasks and motivating students for learning a new language (Kory, Jeong, & Breazeal, 2013).

Besides the robots that are used for assistive purposes, educational robots are also providing benefits regarding providing a positive learning experience, accessibility and promote social interaction between students. Moreover, the intelligent robotic system can contribute to the learning process by reducing the workload of educators by assisting them in teaching. However, previous studies of using educational robots in learning environments found that educators are being critical about replaced by robots and rejected the idea of the direct use of robots for teaching purposes (Reich-Stiebert & Eyssel, 2015). These issues create barriers to the acceptance of companion robots in learning domains from different cultural perspectives also, provides valuable information from the user's perspective on how robots should be used for educational purposes. Another valuable use of robots in educational settings is to provide access to students who are not able to participate in the social and educational setting in schools because of their serious health issues. To examine this issue Newhart & Olson (2017), carried out a qualitative study on the effects and adoption of using telepresence robots in classrooms settings. By drawing on the concept of telepresence robots, Newhart & Olson (2017) has been able to show that students who are attending to lessons by using robots have challenges considering robots design and interaction-based issues with educators. Design related issues are based on the robot's battery life, visual and audio perception to sustain interaction with the classroom environment. Interaction-based issues are related with providing privacy for both sides and training of educators and parents for the interaction with the system because some educators stated that they were afraid to touch the robot and cause something undesirable. Moreover, it has been noted that other students in school call their friends by their name instead of acting the robot as a mechanical thing. According to the results of this study using telepresence robots provided both academic and social development for the students who are unable to attend a classroom. Overall, these studies highlight the beneficial effects of using robots in a variety of human environments from the human-centred point of view and addresses the challenges that are specific to the HRI field.

2.2 Educational Robotics

Educational robotics section consists of three major parts. Firstly, the theoretical background that supports the use of educational robotics is explained by providing information about the pedagogical learning theories and educational frameworks that support the use of robots in educational contexts. Then, the robot's roles and types that are used in education are further investigated. Secondly, based on the literature findings, the relationship between robots and education is investigated to identify benefits derived from the use of robots and significant issues for the acceptance of robots in 21st-century education. Finally, according to previous studies, robot design related issues are aggerated to provide a suitable background for the outcome of this study.

2.2.1 Theoretical Background of Educational Robots

Educational robotics is considered as an educational technology to engage learners in diverse learning experiences by encapsulating a wide range of subjects for learning (Karim et al., 2015). Educational technologies can be productive and innovative tools for learning to improve the learning experience in the light of appropriate pedagogical learning theories. Educational technologies that are used in educational contexts are vast and include both software and hardware-based products. For instance, web-based e-learning platforms, smart boards that are connected to the internet for making a presentation to the classroom and, computers for various educational purposes (Robertson, Macvean, & Howland, 2012). School authorities widely accept all of these aforementioned educational technologies, policy makers and educators to improve instruction and learning quality in educational contexts. In contrast to currently accepted tools for learning, educational robotics as a subset of educational technologies is a relevantly new tool and still struggles with getting involved in school environments. In order to provide widespread acceptance of educational robotics in learning environments, pedagogical approaches that support the use of robots for educational purposes and satisfying the needs of stakeholders in educational context plays a significant role (Alimisis, 2012). Moreover, in line with the pedagogical approaches, demonstrating the benefits of using robots for the development of learners is another essential aspect for the acceptance and use of robots in school settings.

The first educational philosophy that supports the use of computer-based technologies for learning activities is rooted in Seymour Papert’s work called “constructionism”. According to Seymour Papert constructionism can be defined merely as learning by doing (Papert, 1991). Considering constructionism learning occurs when children actively construct their knowledge by designing artefacts with the aid of various tools and share the designed product with the community. These tools can be computers to create programs, tangible artefacts to design a solid structure or combination of various materials to realise the understanding of the various concepts in the individual's mind as a public entity. Constructionism is an educational theory which is inspired from Jean Piaget's constructivist approach on the theory of knowledge about how children learn, think and construct knowledge out of their real-world experiences (Ackermann, 1996; Piaget, 1965). Unlike traditional methods of instruction that directly transfers the knowledge from educators to learners, both approaches are taking the learner as a central subject. Instead of the direct transfer of knowledge, constructivist and constructionist approaches are offering self-directed learning opportunities to learners by providing numerous entry points to discover and reconstruct concepts to understand the world surrounding them. While constructionism is more concerned about the creation of a physical artefact in the real world to reinforce the construction of knowledge, shared goal of both approaches is based on constructing a deeper understanding of the individuals themselves and the world surrounding them (Ackermann, 2001). After all, learning is a never-ending process and continues for a lifetime for humans, so both approaches are concerned about the life-long learning opportunities.

Technology is not providing the learning alone the appropriate educational strategies are vital for the acceptance of technologies such as robots in educational environments. Thus, adopting educational activities that are based on constructionist and constructivist approaches provides a suitable ground for the practical use of the technologies to create learning opportunities. There are several principles for the implementation of both constructionist and constructivist approaches in education (Mikropoulos & Bellou, 2013). These principles are shown in Table 4.

Table 4 - Principles of Constructionism and Constructivism

Principles of Constructivist Approach	Principles of Constructionist Approach
Provide experience of the knowledge construction process.	Learning by designing meaningful projects, creating things and sharing them in community.
Encourage the use of multiple modes of representation.	Using manipulative objects to help concrete thinking about abstract phenomen
Provide experience and appreciation of multiple perspectives.	Identifying powerful ideas, tools to think with from different realms of knowledge.
Embed learning in realistic and relevant contexts.	learning by reflection.
Encourage ownership and voice in the learning process.	
Embed learning in social experience.	
Encourage self–awareness of the knowledge construction process.	

Table retrieved from Ackermann (2001)

Regarding educational robots, the combination of digital and physical aspects such as programming behaviour and components, allows them to be a suitable tool for the externalisation of the individual's knowledge as a public entity. Also, educational robots are providing multi-facet opportunities to extend educational activities that cover various concepts as a whole such as, science, technology, engineering, mathematics, arts, social sciences and so forth (Miller et al., 2008).

Educational robots are also found beneficial for the attainment of 21st-century skills for the students. 21st-century skills are defined as crucial skills for the envisioned future work environment of the knowledge-based society (Trilling & Fadel, 2012). The shift from the industry-based economy to the information-based economy has changed the skill demands for the future work environments. In the last 50 years with the rapidly evolving technologies, tasks in work domains are changed from manual and routine to more abstract ones which require different cognitive and social skills (Autor, Levy, & Murnane, 2003). In contrast to prior work environments, today's work environments require high levels of communication between different cultures, multi-disciplinary work in teams, technology-rich environments to work on ill-defined problems and abstract tasks rather than manual and routine tasks. Thus, the shift from the industry-based economy to the information-based economy has created global awareness for many countries to act for the future society's demands and these issues are reflected their education systems (Binkley et al., 2012). Considering worldwide designed curriculums which address the 21st-century education, Binkley et al., (2010) classified ten crucial 21st-century skills under four main categories. Skills that are related to these four categories are shown in Table 5.

Table 5 - 21st Century Skills

Ways of Thinking	Ways of Working
Innovation/Creativity	Information literacy
Problem solving	Information and communication literacy
Decision making	
Critical thinking	
Learning to Learn	
Tools for Working	**Ways of Living in the World**
Communication	Local/Global citizenship
Teamwork/Collaboration	Personal responsibility
	Social responsibility

Retrieved from 21st century education framework (Partnership for 21st Century Learning, 2015)

21st-century education frameworks are based on addressing student needs and interests on an individual basis to reach beyond academic performance. Moreover, providing interactive learning environments, collaboration and share of information between students and developing technology fluency for the use of various technological devices around them are some of the critical goals. Based on the prior studies to evaluate benefits of using robots as an educational tool for the attainment of the 21st-century skills found beneficial regarding developing self-confidence, self-awareness, teamwork, problem-solving, systems thinking skills and to provide technological fluency (Khanlari, 2013). Alongside the attainment of 21st century skills, robotic activities that are based on the constructionist theory of learning is generally supported by *Project-Based Learning* (PBL) approach in educational contexts which promotes students to design and develop their own projects around various subjects in learning (Capraro, R., Capraro, M. & Morgan, 2013). PBL approach is a student centred approach where educators are more likely to be the facilitators during the process and guide the project instead of giving direct instructions (Susan Bell, 2010). Moreover, it provides a suitable ground for the robotic activities to teach STEM subjects as well as other subjects in schools such as history and so forth (Blikstein, 2013). Use of educational robotics in education providing numerous opportunities for the implementation of PBL activities and the acquirement of 21st-century skills for students by providing the first-hand experience for constructing new and reconstruction of existing knowledge.

2.2.2 Educational Robots and Their Relations with Education

Until becoming a favourite tool for learning amongst the K-12 levels in education, robots were commonly used in university level of education for engineering-based departments technically. However, with the requirements of 21st-century education and aid of educational movements robots are also proven as a useful tool for the education of K-12 grades to provide interactive learning environments and motivation to students for subjects. The primary advantage of using robots for young students is fun and playful nature that maintains motivation to students and increase engagement during activities. Robots are also enabling educators to cover various aspects related to 21st-century skills and STEM subjects in one activity by making calculations to design an intended behaviour, using programming concepts to improve computational skills and forming student teams to develop communication and collaboration skills.

The literature on educational robotics highlighted several dimensions related to use and implementation of actual robots in 21st-century education based on several reviews (Karim et al., 2015; Lye, Wong, & Chiou, 2013; Mubin et al., 2013; Toh et al., 2016). Educational robots can be used in education in several ways. All kind of robots is providing an educational or developmental outcome in the light of the pedagogical approach and educational goals that aimed by facilitators. Also, several robotic competitions attract students to STEM subject by annually changing themes or with fixed themes to build a variety of skills that related to 21^{st}-century education framework. Besides competitions robots are rarely used in school environments because of a variety of challenges based on educators and external factors such as financial factors and integration of robots into curricular activities. However, except the time that is spared for curricular activities, educators and students are working in teams on educational robots either to learn about robot itself to participate a competition or for experimental purposes to lead better learning of a variety of subjects. According to educational goals and aims of competitions, types of used robots may differ. Educational robots that are used in education can vary from social companion robots to robotic construction kits which users design and programme their robots and even toy robots just for entertainment purposes.

Moreover, design aspects of educational robots play a vital role for the acceptance of robotic applications in an educational setting by stakeholders and the robotic activity with their functional and non-functional qualities (Cysneiros, do Prado Leite, & de Melo Sabat Neto, 2001; Odetti et al., 2007). Stakeholder views are another particularly important dimension for the future development and implementation of robots as an educational medium in school environments. For the acceptance and effective use of robots in education, stakeholder such as parents, students and educators provides valuable information for the design aspects (Toh et al., 2016). Based on the actual robots that are used in education, Mubin et al., (2013) classified the significant dimensions of educational robotics under five broad categories namely; (1) domain of the learning activity, (2) context of the learning, (3) robot's role in the learning, and (4) types of robots that are used in education.

The domain of the learning activity is examined under two folds as; non-technical and technical subjects. Robotic activities regarding non-technical subjects are the domains of science education by including subjects of learning in schools such as mathematics, chemistry, biology and so forth. Technical education is about studying robot itself to learn about robotic technologies, programming and sensor-reading. Robotic activities are concerned about providing a new set of skills for recognition of new technologies or developing a various set of abilities such as cognitive skills, social skills and personal skills (Catlin & Blamires, 2010). The more significant part of the literature on the use of robots in educational environments focusses on the STEM education and teaching languages with the aid of social robots (Mubin et al., 2013). Also, robotic activities that are concerned about the STEM education are mainly focused on the topics of mathematics and physics (Benitti, 2012).

The context of learning is concerned about the location of the where learning takes place such as in a school setting or out-of-school setting. According to observations of the Mubin et al., (2013) robotic activities can occur as an intra-curricular or extra-curricular activity. Currently, most of the robotic activities are conducted at out-of-school settings as an extra-curricular activity, the reason behind this is the need of support for educators, time limitations in school lessons and lack of curriculum for robotic activities to suits in classroom environments (Matarić, 2004). For instance, summer camps, robotic clubs, weekly workshops, and robotic competitions such as First Lego League, RoboCup JR are regarded as extra-curricular activities for students (Bevan et al., 2010; Eguchi, 2015; Ma & Williams, 2013). Implementing robotic activities in formal education environments is a problematic issue and offers various challenges regarding involved stakeholders in those domains. These stakeholders are commonly defined as educators, school authorities, students and parents and plays a vital role in the acceptance and effective use of robots in educational environments (Toh et al., 2016).

Robot's role in the learning environments may divide into three main categories. (Alimisis & Kynigos, 2009; Eguchi, 2014; Miller et al., 2008; Mubin et al., 2013). Table 6 provides information about the roles of robots in education regarding the context and the type of the activities based on relevant literature findings. The first role of the robot as a learning object is a commonly adopted role for engineering education as well as to introduce robots as a learning tool for further use. As a learning object robot's itself becomes the subject and students are learning about how to programme a robot by using various programming interfaces and other robotic components such as, sensors and actuators that provide movement. As a learning tool, the robot itself is not the primary focus but act as a mediating tool to construct knowledge between the subject and the individual's mind. The third role of the educational robots is more likely to be performed by social robots or autonomous robots with advanced interaction capabilities. Robot's role as a tutor is a problematic issue because of the shared misconception of replacing robots with humans amongst educators as well as concerned parents who do not want their child to be friend with a robot. The idea of using robots as a tutor is also unwelcomed by middle and high-school level students because of the lack of empathy and emotions in the current state of the robotic technologies (Shin & Kim, 2007). However, instead of replacing human's role with a robot, the overarching goal of the robotics is to empower and improvise existing human relationships by adding value. An appropriate solution of the role of an intelligent robot for learning purposes might be a tutor or teaching assistant to students under the supervision of the educators as an extension of an educator's mind.

Table 6 - Robot's Role in Learning

Robot as Learning Object	Robot as Learning Tool	Robot as Tutor/Companion
Learning robotics	Project based activities	Teaching language
Robot programming	STEM subjects	Learning through social interaction
Robot construction	Computer science	Empowering social relationships
Artificial intelligence	Curricular subject	Motivator for study/exercise

Types of robots that are used in education may differ according to the objectives of the user. Mataric & Feil-Seifer (2007) provided two broad categories for the educational robots namely; (1) *do it yourself* (DIY) *robots*, and (2) *pre-assembled robots*. DIY robots can be listed as robotic construction kits, modular robotic kits and open-source robots (Karim et al., 2015). Pre-built robots can be social robots or robotic dolls to teach language or robots for research purposes for advanced programming. Educational robotics has a broad design space of robots, and it is not possible to illustrate every single robot, but in the website of (http://www.theoldrobots.com), there are numerous examples of first wave personal and educational robotics until 2000's. Also, ER4STEM (educational robotics for STEM) project provided a resource to examine educational robots based on their types in the following link, (https://educational-robots.zeef.com/roberta.roboter0)

Majority of the robots that are used in schools are robotic construction kit type robots because of their flexibility to design various robots and ease of programming via drag and drop graphical user interfaces for novice users. Also, based on the educator's goals in learning different types of robots can be used in the robotic activity. Using robots to teach programming may not require a physical robot design so educator's and the student may prefer pre-assembled table-top robots to save time from the building process. If the goal of the educator is the education of the children with autism so she/he may prefer a pre-built social robot to build a communication bridge with students (Robins, Dautenhahn, & Dubowski, 2004). However, selection of the type and design of robot based on educational purpose and age group of students is crucial to enable students to design and to programme their robots or to engage students for interaction by using appropriate robot appearance in the context. For instance, kindergarten students may not be able to stick small parts of a construction kit to design a robot because of their developing fine-motor skills. Also, they are unable to programme a robot by using text-based programming language, so most of the robots that are specialised for the use of kindergarten students are commonly have bigger parts, physical programming blocks or interfaces and use bigger visual icons (Hourcade, 2007). Addressing all kind of learner with an evolving educational robot that transforms to provide further learning opportunities according to developed skills and knowledge of the students is one of the significant challenges for the field of educational robotics.

Robots are considered as a powerful mindtool for the synthesising knowledge of the students into a physical artefact by enabling them to express themselves and their understandings through designing and programming a robot. Considering major dimensions of educational robotics in K-12 education, most of the factors that form the dimensions depend on the educational goals of the institutes, educators or curriculums. Based on the 21st-century education frameworks majority of the robotic activities are used for teaching STEM-based subjects, language and increase the engagement and motivation of students to be better learners. Students that are engaged in robotic activities are more interested in science concepts and have a better understanding of the technologies around them because of experiencing and making those technologies in the first hand. Robotics after gaining popularity as an educational activity with the worldwide competitions; most of the uses of educational robots remained narrow and focused only to technical aspects of the robots (Rusk et al., 2008). Therefore, to attain most of the students with crucial skills for future society such as technology fluency, there is a need to reach all kind of learners with different areas of interest. Rusk et al., (2008) provided essential strategies to broaden participation to robotic activities and encourage robotic workshop conductors to focus on broad themes instead of engineering-based challenges and combining diverse materials to enhance creative activities of students.

Moreover, encouraging storytelling for robotic activities proposed as an attraction for students with different play styles to provide better engagement. These different styles of play are based on the studies of Shotwell et al,. (1979) and categorised into two main categories namely; "patterners" and "dramatists". Patterners are described as players of puzzles, building blocks and children who are interested in structures and patterns. On the other hand, dramatists are more likely to interested in acting conversations between toys and pretending social interactions with the materials around them during play. In conclusion, the previous studies demonstrated that addressing all kinds of learners and students with diverse areas of interests is crucial for the engaging robotic activities to provide learning outcomes for a higher number of students (Alimisis, 2013; Blikstein, 2015; Khanlari, 2014; Yanco, Kim, Martin, & Silka, n.d.).

Since most of the robots that are used for educational purposes are used as a tool for learning or teaching robot itself, robotic activities in school settings are generally based on constructionist learning theory. Guided by the constructionist theory of learning, PBL approach is one of the most commonly adopted strategies to implement robots as intra/extracurricular activities. While using robots lead students to design their ideas and generate opportunities for conceptualising subjects based on their way of understanding. According to the principles of the constructionist theory of learning, based on the previous studies Table 7 provides the technological and project-based steps of integration of robots in education.

Table 7 - Robotic Activities From Student Perspective

Project-based Steps of Integration of Robots in Education
Designing a robot - based on student's imagination.
Developing a program using a programming environment
Downloading the program on the robot.
Executing the program.

Retrieved from Dagdilelis et al., (2005)

Steps that shown in Table 7 is based on PBL activities by using robots. However, using robots to teach students language via social interaction or other subjects not demand hands-on activities from students. Instead, it requires advanced intelligent capacity and engaging interaction qualities from the robot to make the learning activity fun and beneficial. Beyond using robots for directly providing educational benefits, telepresence robots are used to create access for students who are not able to attend in real school settings because of critical health issues (Newhart & Olson, 2017). Robots may provide a variety of benefits to serve educational outcomes either directly or indirectly. PBL approach for robotic activities, learning by design, using social robots to teach students a new language and building a communication bridge between educators and students by using robots are included robots to the learning process as an active tool or peer. Also, such uses of educational robots' aid students to develop new skills based on the objectives of learning. For instance, using a telepresence robot to enable a student to attend classroom is a way of using robots indirectly by excluding robot from the learning experience. Robots that are used for educational purposes provides numerous benefits on development and behaviours of students while encapsulating diverse subjects for learning to act as an all-in-one tool for educators. However, using relevantly new tool for learning creates challenges for the stakeholders that are involved in learning activities also for the design and development of educational robotics. The more detailed account of the benefits and challenges of educational robotics is given in the following section.

2.2.2. Benefits and Challenges of Educational Robotics

In this section based on the relevant literature benefits and challenges are investigated from the educator and student perspective. Benefits of robots are presented related to 21st-century education goals and other beneficial effects regarding student skill and behaviour development. Challenges of educational robots are presented to provide information about the major challenges for the use and acceptance of educational robotics in learning environments by considering educators, students and external factors such as cost and policy related issues.

2.2.2.1 Benefits of Educational Robots

Benefits of using robots for educational purposes is examined only for student age groups according to K-12 levels of education and mostly related to developing self-efficacy, self-regulation, and cognitive and social skills. Examination of benefits that derived from the use of robots is related to adopted educational strategy, focused age group and focused subject matter. Much of the literature on educational benefits of robots focus on the STEM-related skills as well as skills related to 21st-century education frameworks by using non-autonomous robots as a tool or as a learning subject in different levels of K-12 education. According to high-cost and required extensive background knowledge of robotics, only a few studies are concerned about using socially intelligent robots for educational purposes. For example, for the children who are under treatment in the hospital environment, robot-assisted learning is applied to encourage them to their diet and to grant motivation via speech for physical exercises (Espinoza et al., 2011; Nalin, Baroni, Sanna, & Pozzi, 2012).

Regarding robots in formal and informal education settings, there are several systematic reviews that provide generalisable information in order to understand the benefits of robots in terms of addressed subjects, adopted pedagogical strategies, commonly used robot types and perspective of the stakeholders (Benitti, 2012; Karim et al., 2015; Khine, 2017; Mubin et al., 2013; Toh et al., 2016). As a common outcome of these reviews problem solving and teamwork skills are most mentioned beneficial outcome of using robots. However, the influence of robots on the acquisition of new skills and improvement of existing skills for students are commonly mentioned in the literature as cognitive and social skills.

The effort to change the educational systems from traditional educator-centred to student-centred classroom is accelerated the integration of learning concepts with robots in learning environments. In the long term, use of educational robots is expected to attract students into STEM-related professions. Use of robots for education also crucial to provide fundamental skills for the future work domains such as technology fluency and ICT literacy. There are common views on the use of robots that provide positive change in the development of social and cognitive skills of students (Khanlari, 2014). Also, use of robots improves student's self-efficacy and self-regulation strategies with the offered challenges such as work in teams, debugging a written code, defining/solving a problem and so forth (Park & Han, 2016). Multidisciplinary nature of robots makes them suitable tool for learning technical and non-technical subjects in constructivist/constructionist learning environments. Robots that are used for educational purposes are increases the motivation of students by igniting their curiosity with engaging activities that are facilitated by educators. Therefore, robots provide fun and entertaining learning environments to students while allowing them to explore new concepts through trial and error.

Toh et al., (2016) classifies benefits that are based on using robots on student skill development into four broad categories namely; cognitive, conceptual, language, and social. Cognitive skills can be broadened as problem-solving, critical thinking, systematically thinking, research skills, decision making, and creative thinking (Alimisis, 2013). Moreover, previous studies in the review demonstrated that use of robots deepens the understanding of abstract concepts of science through directly experiencing them in the physical world. These concepts can be related to geometry, fundamental laws of motion, forces and so forth. Social skills of students are developed through active learning environments which encourage learners to communicate their ideas by respecting other. Multidisciplinary nature of robots requires students to work in teams and collaboration to reach a common goal. Therefore, students learn how to communicate their ideas transparently, making decisions to solve a problem and sharing their ideas to help each other in a robotic activity or competitions. Also, designing robots through an iterative process develops students self-efficacy and self-regulation strategies, such as self-confidence and emotional control (Saygin, Yuen, Shipley, Wan, & Akopian, 2012). Designing and controlling robots based on constructivist/constructionist approaches provide students with personal meaning and deepen their learning with joy (Johnson, 2003). Robotic activities that only study robots itself from the technical point of view may remain narrow to provide a full range of skill sets to students or to attract students for the construction of new knowledge (Rusk et al., 2008). Thus, combining robotic activities with art is also maintains new directions for learning as well as to acquire new abilities such as learning new craft materials, internalising science concepts through a personalised artefact, improving aesthetics perception and so forth (Hamner & Cross, 2013; Yanco et al., n.d.).

However, active development of skills and changes in behaviours of students is based on educator's competencies rather than robots. Robots are only a tool with a wide range of possibilities for educators to provide motivational and meaningful learning environments to students. Conducting robotic activities is one of the significant challenging issues for the educators. For the acceptance of educational robots as a tool for learning in school environments educators plays a vital role. Integration of new technologies to learning environments is concerned about a variety of factors from stakeholders to products itself. In the following section challenges regarding educational robotics is presented.

2.2.2.2 Challenges of Educational Robots

Challenges of educational robotics are commonly based on the acceptance and the actual use of robots in the educational settings. Educators and students as primary users of the robots are two of the essential stakeholders for the acceptance of robots in education. Other stakeholders are parents, policymakers and institutional authorities. Especially educator's role is essential for the further use of robots as an intra-curricular activity in formal education, and they needed to be supported in various ways. Other challenges are research-based issues to assess educational benefits of robots whether they are increasing the achievements of students or improve learning from robotic activities (Alimisis, 2012; Nugent et al., 2010). Also, suitable planning curriculum for the use of robots is commonly addressed the issue as a challenge.

From the educator point of view of challenges, Mataric et al,. (2007) maintained the challenges of educators namely; *lack of educator's time*, *lack of educator's training*, *lack of suitable academic materials*, *lack of ready for use lesson materials*, and *lack of a range of affordable robotic platforms*. Also, Sullivan (2009) defined that *lack of institutional support*, and *educator's beliefs, attitudes and practices about teaching and technology* as barriers for the integration of the new technologies in classroom environments.

Educator's time is generally limited during the school hours because of their heavy workload to keep on track of the pre-defined curriculum. Integrating robotic activities requires time to create an overall plan, the arrangement of the materials, tests of the tasks and so forth. In the case of a robotic activity with construction kits, a messy working environment and after activity time can require practical work from both educators and students. Moreover, constructivist/constructionist learning activities require more time investment than existing curricular activities (Sullivan & Moriarty, 2009).

Training of educators is crucial to attaining desired benefits from the robotic activities. A large number of studies focuses on the educator training and creation of models for training educators about the new technological concepts to provide background knowledge as a starting point (Trantow, Stieger, Hees, & Jescke, 2013). Also, many educators feel uncomfortable with the idea of using robots because they do not find themselves capable enough regarding practice and knowledge of robotic technologies. Therefore, training of educators may overcome these set of challenges if provided by the experts from the field of educational robotics (Matarić, 2004). The scope of the training is commonly concerned with providing technical and pedagogical ways on how to use educational robotics as a learning tool (Frangou, 2008; Kim et al., 2015). Use of robots for other purposes than learning tool also requires training for educators to make them feel comfortable to physically interact with robots such as, using teleoperated robot to enable a student to participate in classroom or give lectures from a distance by educators (Edwards, Spence, Harris, & Gambino, 2016; Newhart & Olson, 2017).

Lack of suitable academic materials and *ready for use lesson materials* are provided by many commercially available educational robot producers. However, recipe-like manuals for lesson plans by using robots creating barriers for a more profound understanding of used technologies. Also, firmly followed directions of design manuals/lesson plans is limiting creative solutions to problems and possible discoveries of concepts for learners (Vandevelde & Vanderborght, 2013). Provided ready-to-use lesson materials for the implementation of robotic activities should be flexible enough to adapt educator's pedagogical approach and goals.

Lack of a range of affordable robotic platforms is another major problem for the implementation of robotic activities in formal education. Besides wealthy private schools, most of the schools are lack of funding to purchase a large number of robots (Matarić, 2004). Using robots for education also requires other technological platforms such as, laptops, desktop computers or tablet for the programming of robots which means additional purchases for schools without proper laboratory setting. Moreover, to enrich the range of activities commercially available robotic kits may require additional purchases of actuators, sensors. Student/robot ratio is vital to gain benefit from robotic applications because a large number of student teams may not allow all students to interact with the system to design, build or programme (Bers et al., 2002; Ucgul & Cagiltay, 2014). Therefore, to support the use of robots in education providing low-cost compatible robotic platforms with a wide range of applications is essential (Saleiro, Carmo, Rodrigues, & Du Buf, 2013; Weinberg & Yu, 2003).

Educator's beliefs, attitudes and practices about teaching and technology is one of the most vital aspects of the challenges. Implementing new methods for student-centred teaching which is not familiar to the educator may generate challenges for the use and acceptance of the technologies such as, computers, educational robots. Employment of the student-centred approaches shifts the educator's role from the competent authority to facilitator or peer in learning so that this shift may bring additional challenges to educators in the learning process of the students. However, technology itself does not lead to change in the practice of the teaching of educators. Instead, school policy, a personal reflection that derived from the use experience and the training programmes are proven to be lead changes in the ways of teaching of educators (Windschitl & Sahl, 2002). Moreover, technology acceptance of educators is related to perceived usefulness and ease of use of the systems (Hu, Clark, & Ma, 2003).

Other challenges are based on how students use robots and behave during the robotic activities. Also, increasing the rate of participation amongst a diverse range of learners from the different social background, academic performance, and learning style is a mutual challenge for all kinds of robotic activities (Cho, 2011; Rusk et al., 2008; Virnes, 2014). Since the use of robotic systems is more likely to based on the robot's design features, interaction capabilities and physical appearance young students tend to anthropomorphise robots more than older students in middle and high-school level (Shin & Kim, 2007). Therefore, other robots except used as a tool for learning are expected to be more intelligent and capable than its real interaction capabilities by younger age groups. Also, physical appearance/visual appeal of robot design plays an important role to engage students to interaction and affecting the non-functional qualities of the system such as likeability, perceived usefulness and ease of use and so forth. Also, the familiarity of students with the robotic technologies another significant aspect for the fluency of robotic activities. Since students are with different skills, academic performance, interests and social background robotic activities with broader perspective may provide learning experience regardless of differences. However, students can develop their abilities as good as the tool's capacity to provide wide-range of challenges that suits the subjects and suitable for the student's competencies.

All in all, challenges are mostly concerned about the learning outcomes and motivating students and support for educators. Design related challenges of educational robotics is an overlooked area of research besides the learning outcomes and curricular issues. The overall design of robots and robotic kits has a direct influence on the learning experience and to support educators using programming user interfaces, assembly parts, electronic components, micro-boards and so forth. In the following section design considerations for educational robotics is presented based on the previous studies in the literature.

2.3 Design Considerations for Educational Robots

Widespread use of educational robotics is as an educational medium for learning to provide progressive learning experiences and attract students to more learning in educational environments. Compared to educational concerns of using robots, less emphasis is given to the design of robotic systems. However, robotics mainly based on sensing and acting according to a given programme which requires interaction from users with programming interface and physical components of a robot that designed by other humans. Before presenting issues related to the design of educational robotics as a system for revisiting the types of robots for educational purposes might be beneficial. Educational robotics are under the category of personal robots which can be autonomous robots, programmable robotic platforms or robotic toys. A typical use of robotics in educational activities is programmable robotic platforms and robotic toys because of the high cost and unavailability of suitable autonomous robots. Advanced robotic platforms are more likely to use for research purposes to mimic nature or designing social robots with advanced software architecture. Previously, types of educational robots are classified namely; *robotic construction kits*, *open-source robotic platforms*, *pre-assembled robots*, *robotic toys*, *self-build* and *micro boards* (Catlin & Blamires, 2010; Karim et al., 2015). Since the constructionist/constructivist learning approaches are commonly adopted for the robotic activities, construction kits are providing a wide range of projects to allow students to express their ideas in various ways. Chioccariello et al,. (2004) provided possible modes of robots can be created by using robotic construction kits namely; *vehicles*, *mobile robots*, *kinetic sculptures*, *animated constructions*, and *soft toys/dolls*.

These types of robots are believed to provide relief for the use of inexperienced educators. Also, robotic activities can be planned in order to design robots from scratch by purchasing micro boards, sensors, actuators and using different methods to produce robot parts such as 3d printing, laser cutter or manually (Vandevelde & Vanderborght, 2013). While designing robots from scratch provides more learning in contrast to others the process is much more time consuming and not suitable for the novice user to quickly realise their ideas. Providing access to users from different levels of expertise with one educational tool is an essential aspect for the sustainability of learning activities and the product itself.

Moreover, enabling students for the creation of their technologies and exploration of concepts is one of the primary goals when designing robotic construction kits. Robots that are built by students are suitable tools for working on ill-defined real-world problems that form suitable themes for the PBL activities. In the learning environments without direct instructions, educators and students both go through the design process of robots together and learning together. According to previous studies educators are having difficulties during the design process and in need of suitable design process guide to guide students through projects (Burdick & Willis, 2011; Hjorth, Smith, Loi, Iversen, & Christensen, 2016). Hjorth et al., (2016) maintained a design process by combining design theory, in-school practice and peer-to-peer learning to educate educators for further development of new practices. The mentioned design process is shown in Figure 15. According to the proposed design process, educators may play various roles such as, for the introductory courses they can be an instructor, facilitator of activities, and mentor for student groups to create reflections by asking more question to make them think as individuals and in groups.

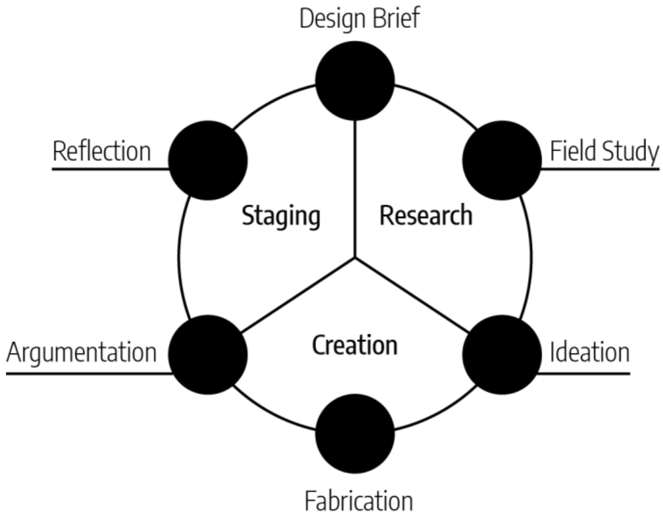

Figure 15 - Design Process for Digital Fabrication – Figure is adopted from Hjorth et al,. (2016)

Similar to challenges that educators face during the use of robots, these challenges are understanding the complicated design process, managing digital technologies and design materials, and balancing different modes of teaching (Hjorth et al., 2016). According to a case study in the research, some of the educators had challenges in understanding complex iterative design process thus judging student ideas as right or wrong instead of helping them to generate and develop ideas. However, adopting a flexible design process through activities is helping educators to save time and progress systematically (Rasmussen, & Christiansen, 2013).

Students and educators as direct users of the robotic products may require additional specialised features from robots based on their needs. To address active users of the educational products Learner Centred Design (LCD) and User Centred Design (UCD) approaches are adopted by various researchers and developers in the field of educational robotics (Fernaeus, Ljungblad, Jacobsson, & Taylor, 2009; Kim, Oh, Choi, Jung, & Kim, 2011). Both approaches are taking user as a central point to develop and design new technologies while encouraging users to provide feedback through the design process by using various methods (Marti & Bannon, 2009). Grounded on constructivism, LCD focuses on three broad principles while designing interactive interfaces namely; *growth*, *motivation*, and *diversity*. *Growth* principle is an effort to cover all students with diverse developmental needs from different age groups as well as to provide progressive learning to master skills or technologies. *Motivation* is crucial to sustaining the interest of students to subject or topic and should be taken into consideration from the planning phase of the activities. *Diversity* is another consideration to address students from different cultures and backgrounds. Also, the relationship between students and robotic technologies are examined by Chioccariello et al., (2004) namely; *play material*, *software* and *learning practice/environment.* Play materials are mostly sensors, actuators, micro-boards, and construction materials. Robotic construction kits are providing various materials to build and design, but planners of the activities may also adopt using different materials such as cardboard, pipe cleaners, papers, plastic cups and so forth. The software is a crucial aspect of educational robots to the provide students ease of use to control robots by efficiently using a set of commands according to their level of expertise and age group (García-Peñalvo et al., 2016).

Design principles and considerations are commonly based on the interaction between students, and educational robotics is strongly related to students' play style and learning activity themes. Different styles of play, interaction and perception of students are examined in the numerous studies for the tangible educational tools and educational robots (Alves-Oliveira, Paiva, Arriaga, & Hoffman, 2017; Cowley & Kanda, 2002; Goh & Aris, 2007; Price & Jewitt, 2013; Resnick et al., 2000; Ben Robins et al., 2010; Zuckerman, Arida, & Resnick, 2005). Robins et al., (2010) provided valuable information on how students play and suggestions on both the design and play themes for educational robotic toys. Different styles of play and play themes of educational robots are listed in Table 8.

Table 8 - Student Playstyles and Play Themes with Robotic Toys

Exercise play	Symbolic play
These kind of games played alone or collaboratively with other children. Enjoyment is an important aspect for these kind of play themes.	This kind of play involves role playing and enacting. Narrative based themes can benefit from this type of players.
Assembling play	**Play with rules**
These types of games may provide practical experience to by construction of artefacts.	These kind of plays such as, board games can be played with educators and other students collaboratively.

Adopted from Robins et al., (2010)

Different styles of play provide a stimulus for the students to explore new concepts while having fun through the process. Using non-programmable robots by users and programmable robots may differ regarding play scenarios and styles. While programmable robots may provide incremental learning opportunities with increasing complexity of design and play themes; non-programmable robots may remain insufficient if they are not evolving due to user's development. According to current available cost-efficient technologies for the direct use of a considerable number of students and educators, programmable robots are preferred over intelligent social robots.

Programmable robots grant suitable ground for the constructionist/constructivist learning environments by allowing students to control, design and construct their artefacts with the aid of various software tools, physical tools such as screwdrivers, electronics, and other manufacturing equipment. Design of programmable robots is sufficient as long as they allow gradual progress of the students through their lifetime school life. From beginner level to learn the basics of programming and design through the expert level to design complex robots with complex behaviours, users must have broad access to the system. In order to provide in-depth access to users for the use of educational tools, *Beyond Black Boxes* (BBB) project aims to encourage students to build their own technological devices through scientific explorations and understand the technology surrounding them (Resnick et al., 2000).

Moreover, the project uses separate electronic measurement devices and actuators to provide freedom of design as well as the use of a variety of design materials. Black box term refers to technological devices that users cannot understand the inner working mechanism or how they work. For instance, sensors that are making measurements or many other consumer electronic products. Use of such tools are not providing a personal connection, so transparency is a crucial aspect for black-box tools to construct more knowledge through scientific activities. However, hiding some elements of design sometimes can be more beneficial than exposing everything. Making design decisions on the appropriate transparency that provide access to the user is a challenging issue also allow designers to highlight critical concepts for usage (Resnick et al., 2000). Also, making the right decisions on black boxes and transparent objects is crucial for the design of robotic construction kits. Resnick et al., (2000) highlighted a few crucial aspects of micro-computer based scientific activities namely;

- Computational technologies are focusing on exploration and creation of new tools by students rather than following pre-designed demonstrations such as provided by science experiment books and other resources.
- Using computational technologies in activities provides advantages to explore and simulate science concepts that are not possible in real-life environments
- Computational technologies are loosely affected by the constraints derived from form and function relationship because the function of the most computational technologies such as sensors is independent of the form.
- Interpreting sensor data not just for analysis of the experiments but to control motors, lights or other electronic devices which may result in creative projects.
- Programmability of the computational technologies that allows modification, customisation and extension of functions improve the quality of constructions.
- Ease of use of the control and sensing based computer programmes enable students to design new projects or understand/read previous ones easily.

- The mobility of the tool which allows students to carry the tool with them also provide opportunities to embed components into other objects or remote control/operation of components from a distance.
- Use of wide range of materials to combine with other existing robotic construction kits also fosters creative and personal artistic representations on projects.

Moreover, designing robotic construction kits are often related to constructionist learning theory. Thus, the philosophy behind the tool has a direct result on the design of the whole system to provide expressive activities that allow students to construct various of knowledge and artefacts in learning environments. Educational robotics are consisting of three essential parts namely; *programming environment, construction materials for the physical embodiment,* and *set of electronics* including sensors, actuators, micro-computers and so forth. Robotic construction kits are including the same elements. Based on three decades of their experience, Resnick et al., (2005) provided guiding principles for designing robotic construction kits namely;

- *Supporting Exploration* – Supporting exploration is related to learnability of the tool as well as ease of assembly and disassembly or trying things with easy turnback options. Also, the modularity of the system is crucial to provide users to try out a variety of options comfortably. To support exploration addressing conceptual models of users while reducing cognitive load for a task is vital to communicate the flexibility and fun nature of the tool.
- *Low threshold, high ceiling, and wide walls* – Low threshold means allowing novice users to efficiently realise their ideas with the tool while high ceiling offers expert users to work on complex projects. Wide walls refer to provide wide set of interaction possibilities with the learning tool not just for the creation of robots but also other types of artefacts such as, smart home systems, small-scale city simulations or in the digital environment to create narratives, stories, characters and so forth.
- *Supporting Different Styles* – Users of the educational robots are individuals with different personal interests, social background, and learning style. Hence, supporting differences between users through a flexible tool to adapt to

different ways of learning, playing and thinking is another crucial aspect when designing tools to support creativity. Some users may prefer to go through a trial and error process while others may prefer to consume more time on abstract thinking and planning.

- *Supporting Collaboration* – Collaboration is one of the primary skills in the 21st-century education framework as well as for current and future work environments. Collaboration involves abilities to work in teams, a division of workload due to strengths of the team members and sharing of information in a variety of forms from internet communities or via speech or written document. Designing learning tools that allow collaboration during the design process empower students social and communication skills.
- *Supporting Interchange* – refer to using not only one tool but the combination of tools to extend explorable areas of knowledge based on user's interests. To support this interchangeable document types that allow export and import from different tools is crucial to allow extension of the cognitive workspace for the user.
- *The simplicity of Design* – Instead of offering more features with intricate designs which are not easily usable by users. Minimally designed technological tools are helping users to accomplish more complex tasks with ease. For non-adult users, the simple and easily understandable design is essential not to cause frustration during learning activities. A simple design may refer to functions of the tool as well as the level of abstraction. For instance, micro-computer based robotic construction kits can have large numbers of input and outputs for actuators and sensors. However, with fewer inputs and outputs than user's demand is proven to lead more creative solutions and more demand for tools (Martin et al., 2000). The simplicity of design is also addressed by other researchers regarding reducing the information given from the tool but only make the detailed information available when asked to provide discoverability (Dillenbourg et al., 2011).
- *Choosing Black Boxes* – The idea behind when designing tools for learning to decide the hidden elements and other fundamental elements that users can

shape. The overall design of the tool by including programming environment and physical components may adjust the level of interference of users according to learning goals that possible. For instance, drag and drop based programming environment enable novice users to manipulate representative numeric values to control motor power or sensor values by hiding actual code into blocks. By exposing these black-box programming blocks, same programming environment may also allow expert users to reach raw code. Also, actuators and sensors that are used as black boxes can be designed by students if the tool provides enough flexibility for design.

- *Balancing User Suggestions* – Involving users in the design process of learning tools is critical to address real user needs and requirements for the tool. There are numerous methods to involve users directly and indirectly by implementing methods such as user interviews, observations, and focus groups to gather feedback on the design requirements (Druin & Hendler, 2000). However, there are challenges in order to balance the user involvement. User's requirements sometimes can be unfeasible as well as occurred changes in the tool may go unnoticed. Providing positive user experience that makes changes in the use of the tool is crucial.
- *Iteration* – Testing prototype ideas with real users in real settings in an iterative way is vital for the successful design of a learning tool. Trying multiple alternative tools with functional prototypes provides valuable feedback from users. Therefore, to create functional prototypes brings challenges for rapid prototyping instead of only using storyboards and possible scenarios. This process defined in three steps; (1) observation of users with the functional prototype, (2) making changes according to user feedback, (3) applying changes into the functional system and iterating again.

Given principles encapsulating general aspects of the design of non-autonomous educational robotics. Previous studies extracted functional and non-functional requirements from the mixture of user interviews, observations, focus groups and through tests of functional prototypes (Blikstein & Sipitakiat, 2011; Resnick &

Rosenbaum, 2013; Resnick & Silverman, 2005; Robins et al., 2010; Vandevelde et al., 2016). Requirements derived from different types of robots that share the same perspective on design because most of them are considered as robotic construction kits or DIY robotic construction kits. These requirements are commonly based on durability, reliability, compatibility, modularity and complexity of the design of robots.

Durability term is used to address physical durability of the robotic system regarding how to resist unexpected behaviours of students or impacts to protect internal vulnerable electronic components.

Reliability is concerned about the recovery upon the user and system-based failures on active components of the robotic system such as programming interface, sensors, and actuators. For example, user-based errors can be accidentally adding or deleting some commands on the interface or closing the programming interface after transferring the code to the robot.

Compatibility of robots for learning purposes is also provided common ground for exploration and use of a variety of tools for robotic activities. Commercially available robots are mostly using their programming environment to transfer designed programme code into the robot. Also, some robotic construction kits are using specific connections for plugging electronics while not allowing third-party electronic components. Incompatibility of educational robots with third-party applications and components creating barriers to expand learning experience by providing a wide range of alternative designs.

Modularity and complexity of design are related to the adaptability of the educational robots according to student age group to provide age-appropriate learning activities. Modularity is concerned about ease of assembly and disassembly of the construction materials and electronics. Also, related to extending some sensors, actuators or micro-computers by connecting each other in various ways based on their design decision. Modularity offers a wide range of possible robot designs and high-ceiling for the users who want to work with the more complex robot. Adjusting features and components affects the complexity thus creates opportunities for a diverse range of learners from different levels and age groups.

In conclusion, the fun aspect of educational robotics is an attraction for students because they are unique tools for learning activities that provide a hands-on learning experience. Regarding students, anthropomorphism also plays an essential role in making robotic activities fun and exciting because students tend to attribute human-like emotions in their designed robots while they are playing (Goh & Aris, 2007). Design of educational robots also includes social aspects into consideration such as, supportive communities that share knowledge on specific problems or to sharing projects in forums to inspire other users to remix their code and so forth (Martin, 2015). However, for the implementation of educational robotics into school environment design of the robot should be taken into consideration as a system that involves a clear understanding of the curriculum, social community platforms, tools to work and think with and keeping stakeholders informed about the current developments in the field to empower educators

CHAPTER 3

3. METHODOLOGY

This chapter focuses on the methodology adopted in this study. First, the purpose of the interview is explained together with the justification of the methodology and then adopted qualitative research methods are expanded. Interview contents are described regarding how they refer to research questions of this study in line with the expected outcomes. Afterwards, sampling strategy is described together with the challenges faced while finding respondents. Finally, decisions made for the data analysis are presented, and the toolkit which facilitated data analysis briefly mentioned.

3.1 Researcher's Experience with Robotic Activities

During the study, the researcher conducted several workshops with students between 8-16 age range through five months by using LEGO Mindstorms core set. During this period, three different robotic activity themes were selected to design robotic projects with students. First, two of the robotic workshops were conducted simultaneously by grouping students according to their age. Young student groups were between the ages of 8 and 10. Older student groups age range were between 11-12. The third workshop was more like a robotic club that lasts for two months which students attend four hours per week after their school. The researcher designed the workshop themes and materials. However, the length of the overall robotic activities, workshop hours were determined by the institution that hosts the robotic workshops.

Throughout these workshops and robotic club, researcher, faced numerous challenges that are already mentioned in the literature and also by the respondents such as, classroom management, keeping the balance in the student teams for an appropriate division of labour, lack of institutional support, and many others. These workshops provided the first-hand experience for the more in-depth understanding of challenges that educators faced by using robots with students on robotic activities. Therefore, experiencing what educators face when working together with students throughout a robotic project provided the researcher with a great insight during the data analysis process.

3.2 Purpose of the Interview

The primary purpose of the study is to elicit design requirements for educational robots to support educators in their robotic activities within the range of primary and secondary levels of education. Within the scope of educational robots, the purpose of the interview is to explore user-related challenges and perceived and experienced benefits of using robots as a learning tool. To support educators and learn about their needs in the learning context, understanding their prior and actual experiences on the use of educational robots is crucial. Various methods have been proposed to test effectiveness of educational robots as a learning tool. Some of the previous studies focus on outcomes of using robots in education (Eguchi, 2015; Park & Han, 2016; Sullivan & Bers, 2016). These studies investigated the benefits of robots to learning outcomes on understanding of science concepts and positive behavioural change of the students in long term by using robotic construction kits in different activities. Instead of focusing on robot design, previous studies' focus is more on quantitative evaluation of student learning outcomes. Therefore, there is a need for qualitative studies which provide more in-depth understanding of using robots to support learning activities. Moreover, qualitative methods are offering an effective way of gaining more in-depth understanding of the user experience and the real needs of the educators for the further development of robots for education (Law, Roto, Hassenzahl, Vermeeren, & Kort, 2009). Regarding active users of educational robots, educators are also important stakeholders as students because they can observe student's interaction with robots by the first hand. Also, educators might have different needs from educational robots as user. As implemented in this study, stakeholder interviews are one of the most commonly-used techniques used for collecting data for the development of systems, products or services (Hartson & Pyla, 2012). In this study, not all stakeholders are involved in the interviews but educators who actively uses robotic toys, robotic construction kits or DIY robots. Instead of students, educators are the only stakeholder focused within the study, because one educator observes at least a dozen students in classrooms and familiar with all kinds of learners with different abilities.

Considering the previously mentioned issues, interviews were conducted in semi-structured format to gather data from the educators. The reason behind using semi-structured interviews is to collect information about the design aspects of the educational robots by additional probes that can shape according to flow without being diverted with irrelevant topics or limited by the fixed set of questions. The flexible structure of the semi-structured interview provided opportunities to probe open-ended questions for more profound understanding of responses and guided respondents throughout the interview (Seidman, 2006). Also, visual media of commercially available educational robots was used to stimulate respondents to criticise and compare different types of educational robots that are foreseen to be used for learning purposes with different roles and different levels in education. Visual media consists of short explanatory video-footages of robots, printout papers of programming interfaces, and if available programming applications for tablets.

3.3 Interview Materials and Questions

Interview consisted of four different, yet interconnected parts that have been designed to provide projected outcomes on design requirements, understanding benefits of robots from educator’s perspective, and needs of the educators. Four parts of the interview involved questions which cover different aspects of the use of educational robots in learning environments. These aspects were respectively arranged as (1) educator-based questions; (2) learning-based questions; (3) robotic activity-based questions; and (4) comparison of existing educational robots.

Educator-based questions are about the educator's personal experience in teaching and training and his/her experience with robots. *Learning-based questions* focus on the educator's objectives regarding robotic activities and perceived benefits of using robots on the development of student competencies. *Robotic activity-based questions* are about process and plan of the robotic activity and challenges faced during the activity. This group of questions are concerned about the process steps of the previous robotic activity that were identified by the respondent. During the interview, these process steps were written down on a sheet of paper by the researcher. Since the adopted design strategy differs between educators, to ask questions on various design process written process steps provided guideline. Lastly, in the *comparison* part of the interview, four commercially available educational robots were presented to the respondents. These robots were chosen among two different types of educational robots focusing on different learning purposes as mentioned in the literature review in the Section of 2.2.2. namely *pre-assembled robots* and *DIY robots*. These two types of robots are chosen because in learning environments popular role of robots are as learning tools or learning subject. Moreover, DIY robotic components/robots and pre-assembled robots are more affordable when compared to intelligent robotic systems or humanoid robots for research purposes. In the robot comparison part of the interview, only a combination of robot images and their programming software were presented as visual stimuli on printed papers and programming interfaces in applications as well as to further discuss interaction related issues. Two sheets of A4 sized printed papers per robot, which involve images of the robots with screenshots of their programming interfaces were used. However, after first two interviews, due to the respondent's suggestions on the interview media to be more effective; representative videos of the robots (mostly advertisement videos of the robots) were used. Also, available programming applications were installed to researcher's tablet to be consulted during the interviews, if required.

Two of the robots that have been shown to the respondents were robotic construction kits while the other two were pre-assembled robots which do not allow any changes in the robot's embodiment. One of the pre-assembled robot (Ozobot) was designed for the table-top use which may stimulate educators on further criticism because of the typical physical limitations of the classroom settings with desk and chairs. Robotic activities require large spaces for construction materials, components and other tools to design robots which is similar to workshop environments. Thus, using robotic construction kits with various parts can be problematic in small classroom settings. Other pre-assembled robot (Romibo) has animal-like appearance with language capabilities and allows users to modify or design verbal interactions. It was selected as a stimulus because it has been thought that it might cover the other pedagogical concerns of the educators than other robots such as, teaching a foreign language and to empower social interactions. Mentioned robots are shown in Figure 16.

Figure 16 - Types of Robots Used in the Study

3.3.1 Procedure

Interview questions together with visual materials involved in the interview and informed consent form which is intended to inform respondents about the scope and aim of the study were sent to respondents via e-mail. Before the meetings, all the interview media and content are shared with respondents. Also, a preview of video-footages requested from the respondents to smoothly proceed during the interview sessions. Prior to interviews, ethics committee approval was received from Middle East Technical University (Protocol Number: 2016-FEN-073). The interview consent form can be found in Appendix B. Original and translated version of interview questions can be found in Appendix C. Also, other printed materials that have been used in interview can be found in Appendix D. Respondents were informed about the length of the interviews that range between 45 minutes to 90 minutes. Interviews are conducted as face-to-face with a total number of 15 respondents from different educational institutions. Interviews were recorded and transcribed verbatim for data analysis. There was no fixed place to conduct interviews, so the most appropriate place was selected according to respondent's desires. One practical advantage of using semi-structured interviews is that according to the response given to the questions, flexible structure of the interview allows the researcher to bend the flow of the interview and probe questions for deeper understanding

First and second part of the interview was conducted as a question-answer session if possible with additional probes unique to each respondent. In the process-based questions part of the interview, respondents were asked to give an example of one of their previous robotic projects with the students and further asked to the respondent if they followed a planned design process. According to stated design process of the respondent, researcher asks for permission to write down the process step by step together with the educator. Also, the researcher taken notes through the process-based questions and comparison part of educational robots are presented to respondents for their approval if there were any misunderstandings in the writings. Afterwards, short videos of the robots (mostly advertisement videos) were watched at the beginning of the comparison part of the interview. Some of the respondents did not need to watch videos of the educational robots again, some of them did. Amongst the four presented educational robots, respondents were free to select which one to start making comments and answering the related questions. Printed robot images were arranged side by side to make the comparisons easy for the respondents.

3.4 Sample

For the use of educational robotics in the learning environments, based on the literature review significant stakeholders were identified. Therefore, as one of the stakeholders, educators play a vital role for the integration of robotic activities into learning environments and to provide a revolutionary shift in the traditional learning settings. However, there are many aspects of providing encapsulating design requirements for the educational robotics remains missing which can be further improved by including other stakeholders such as, students, parents, and school managers. Educational robots are relatively new tools for learning and not as widespread as other technological devices in the learning settings. Thus, the majority of the educators in the primary and secondary education have little experience or no experience with robots. Keeping these issues in mind, a purposive sampling technique is adopted for the study (Tongco, 2007). Educators who used and currently using educational robots with the student age group within the primary and secondary education were selected as a sample group. However, finding appropriate respondents required an extensive effort and took a long time to reach educators because most of them were so busy during the school semesters and a large number of the interviews delayed to the summertime when educators are on holiday. To conduct face-to-face interviews, without considering the distance, researcher travelled to appropriate locations for the respondents including long distances, for instance, two of the respondents were 450 km away from the place where the researcher lives. Respondents of the study varied in different branches and titles from the primary and secondary education. Table 9 below, presents the respondents of the study regarding their, personal experience and branches in education, personal training and experience with educational robotics, currently preferred robot and robotic activity types, and their area of responsibility in the educational institution.

Table 9 - Sample Group

Respondents	Institution	Branch	Professional Experience
R01	School	Math	12 years
R02	Private Course	ICT	7 years
R03	School	Science	16 years
R04	School	Science	14 years
R05	Private Course	Computer Engineer	1 year
R06	School	ICT	11 years
R07	School	ICT	9 years
R08	School	Design & Technology	26 years
R09	School	ICT	5 years
R10	School	ICT	13 years
R11	School	ICT	20 years
R12	School	ICT	20 years
R13	Private Course	ICT	3 years
R14	School	ICT	8 years
R15	School	Math	20 years
Respondents	**Robot-Based Experience**	**Activity Setting**	**Preferred robot**
R01	2 years	Extra-curricular	Construction Kits
R02	6 years	Extra-curricular	Construction Kits
R03	5 years	Extra-curricular	Construction Kits
R04	2 years	Extra-curricular	Construction Kits
R05	1 year	Extra-curricular	Construction Kits
R06	2 years	Extra-curricular	DIY Robots
R07	2 years	Intra-curricular	Micro board Kits
R08	8 years	Extra-curricular	DIY Robots
R09	2 years	Extra-curricular	Construction Kits
R10	3 years	Extra-curricular	Construction Kits
R11	5 years	Extra-curricular	Construction Kits
R12	15 years	Extra-curricular	DIY Robots
R13	3 years	Extra-curricular	DIY Robots
R14	4 years	Extra-curricular	DIY Robots
R15	2 years	Extra-curricular	DIY Robots

Educational institutes were called by using the phone, and other social media platforms were used to reach for the educators who are interested in using educational robots as a learning tool. Interviews were conducted with the respondents mostly in the schools which they worked for or at a restaurant near to the respondent's house which is quite enough to record voice with lesser background noise. Moreover, snowball sampling strategy was implemented after challenges faced during the finding phase of the first respondents for the study which supported the study regarding finding new respondents more easily. Also, third-party connections (former companies that the researcher worked with) were used to arrange meetings and interviews with the respondents. However, to avoid capturing a group of educators with a similar perspective on the educational robotics; not each respondent was asked to suggest additional respondents for the study.

3.5 Data Analysis

After the separate transcription of each interview, all transcript files entered to the Atlas Ti which was used as a qualitative analysis toolkit to analyse the data gathered from the respondents (Friese, 2014). A mixture of deductive and inductive reasoning approaches applied while analysing the interview data (Fereday & Muir-Cochrane, 2006). Content analysis method has been adopted in line with the thematic coding approach for the qualitative data analysis of the interviews. During the initial process of the data analysis, deductive reasoning approach is adopted for thematic analysis that provided opportunities to create a codebook as a template for the initial codes and categories based on the relevant studies within the literature (Saldana, 2013). Codebook also provided a template for the first categories and themes and evolved throughout the data analysis process which can be found in Appendix B. Categories in the codebook used colour codes to differ between concepts related to students, educators and robot-based challenged and benefits (DeCuir-Gunby, Marshall, & McCulloch, 2011). Afterwards, inductive reasoning approach is adopted for the content analysis to generate data-driven codes by careful examination and repetitive reading of the interview data.

Moreover, *activity theory* framework provided a different point of view to analyse and understand the relationships between the educational robots with the other elements of the system. Activity theory is a commonly used framework in education and artefact related research in order to understand the relationships between subjects (students and educators) and the artefacts (educational robots and other educational technologies) within the broader context of the activity (Hashim & Jones, 2007). However, activity theory framework did not directly implemented into the study but, provided some insight and new ways of thinking as an approach to better understanding of educational robotics as a learning tool on a broader context. The flow of the data analysis is shown in the Figure 17

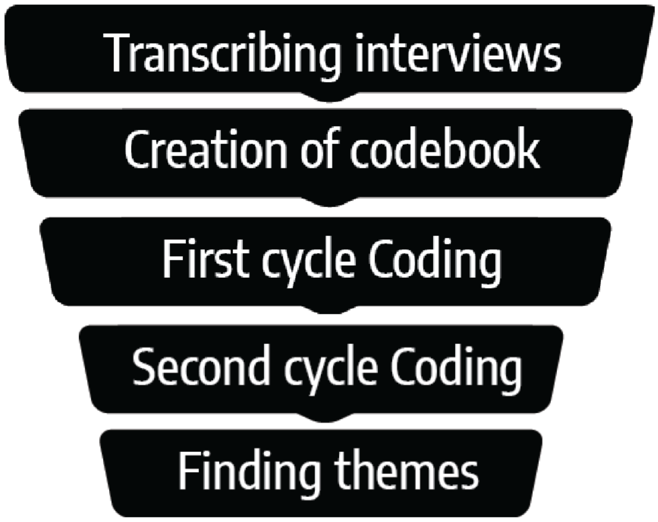

Figure 17 - Data Analysis Process

During the data analysis, Excel sheets were used for creating codebook, logging process approaches of the respondents, saving general information about the respondents and transferring codes to accelerate the merging process of similar codes in an isolated platform. From coding process to development of themes, data analysis consisted of two cycles of coding (Saldaña, 2010). In the first cycle of coding, codebook provided an initial template to categorise similar codes under the pre-defined, literature-based categories related to the research questions of this study. Then the first categories were elaborated throughout the second cycle coding process that leads to the central themes after an iterative process of renaming and recategorising of codes. From the beginning to the end of the data analysis Atlas Ti was used, and it was found beneficial to understand the hierarchy between the codes, merging the similar codes and creating code families to develop categories and themes. Figure 18 presents the example of the overall coding process by using Atlas Ti as a qualitative data analysis toolkit.

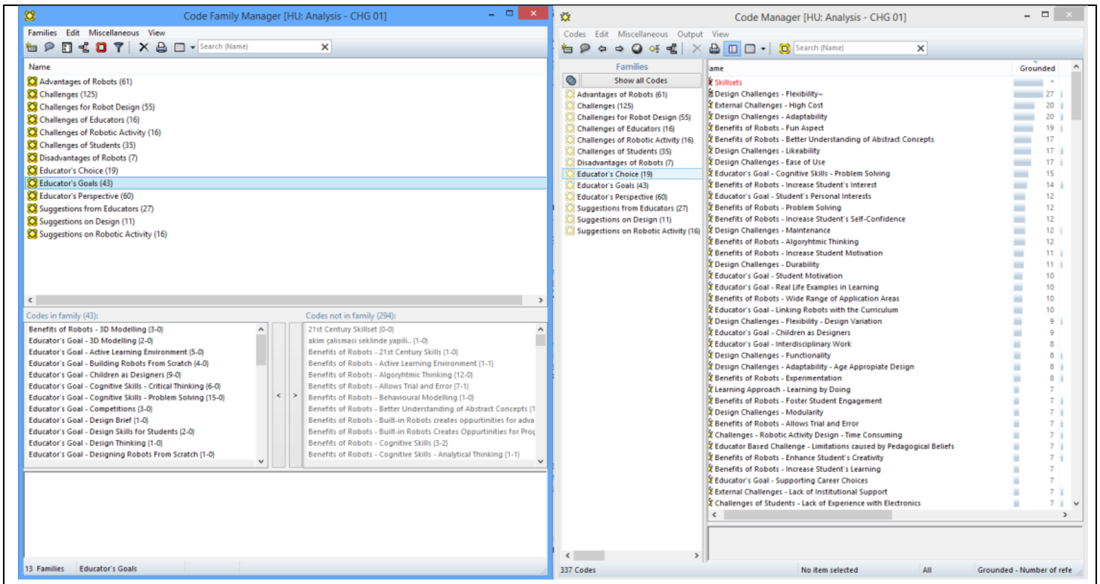

Figure 18 - Qualitative Data Analysis with Atlas ti

Themes are grounded on the raw data of the interviews and besides the literature-based codes and categories that take place in the codebook; there are also new categories and codes were found during the analysis of the raw data. During the data analysis process, there was a constant renaming and recategorization of the outcomes. In the final phase codes and categories with similar meanings were combined and lead the study to themes which will be presented in the next chapter.

CHAPTER 4

4. RESULTS and DISCUSSIONS

In this section, findings are briefly presented under three main themes namely: Benefits of Educational Robots in K-12 Education; Challenges of Using Educational Robots in K-12 Education; and Interaction Design Requirements. All the central themes are interconnected and affect each other regarding providing design requirements for educational robots. Section 4.1 and Section 4.2 explores the issues based on the use of DIY robots in the educational context of Turkey. Also, all the interviews were conducted in Turkish and translated by the researcher. Numbers within the square brackets indicate the quotations in the Appendix A, where original versions can be found.

4.1 Benefits of Educational Robots

This theme presents the benefits and disadvantages of using educational robots in learning environments based on educators' perspective who participated in this study. Benefits of robots are questioned in the interview under two directions as *educational benefits* and *developmental benefits* for students. Also, respondents were further questioned to add their opinion about other benefits alongside educational and developmental benefits of robots. Concerns were expressed about benefits of robots is intertwined with the educator's goals in the learning environment.

The categories of *skill sets*; *student motivation* and *learning opportunities* recurred throughout the dataset within the benefits of educational robotics. A majority of respondents attributed skillsets as 21st-century skills and remarked that using educational robots develop different ways of thinking, for instance, computational thinking, creative thinking and critical thinking. Educational robots are also found beneficial regarding providing student motivation and foster student engagement in the activities. From the perspective of the respondents using robots for education empowers student motivation and ignites curiosity because of their fun and physical nature which also creates diversified learning opportunities for students. The categories of *skill sets*; *student motivation* and *learning opportunities* recurred throughout the dataset within the benefits of educational robotics. A majority of respondents attributed skillsets as 21st-century skills and remarked that using educational robots develop different ways of thinking, for instance, computational thinking, creative thinking and critical thinking. Educational robots are also found beneficial regarding providing student motivation and foster student engagement in the activities. From the perspective of the respondents using robots for education empowers student motivation and ignites curiosity because of their fun and physical nature which also creates diversified learning opportunities for students.

4.1.1 Benefis to Skillsets

In the 21st century, communication and information technologies changed the ways of how we learn things and created various possibilities to become a lifelong learner in our lives. Revolutionary technology development also affected the traditional ways of instruction for educators. From computers to educational robots, these technologies may require different kinds of effort from both students and educators to obtain benefits regarding active learning. Information and communication technologies provide various pathways to access to knowledge however, information gained from the internet sources requires critical thinking to make accurate decisions between true and false. In line with the developing technologies, humans need to adapt their behaviours and develop a new set of skills accordingly. Moreover, acquiring such versatile competencies that are offered by the 21st-century education frameworks educational robots may act as a catalyst by supporting educators through their goals [01]. One respondent remarked that:

> "As I said, I see these developments in a significant place in terms of the adoption of 21st century skills. Developing these skills should be our main goal, because that will be the future, and even today we need these skills for our needs in the field. I think that these benefits are crucial in raising students who can think analytically and solve

> problems. It also has an important place in the development of psychomotor skills, because the students are supposed to situate the pieces of the robot, and their skill of design is very important in this regard. We usually do not use ready-made mechanical parts, we get the parts from our 3D printer. Most of these are designed by our students themselves, and the rest are given to them by our team." (R14 – on 21st century skills)

Educator's concerns were expressed about the benefits of educational robotics with the possible recruitment criteria and needs for the work domains. Respondent suggested that people who can solve complex problems and have advanced algorithmic and analytical thinking skills are needed in the future and these skills can be regarded as essential skills for 21st century. Based on the comments of the educator, using robots for learning activities prepare students to future work environments. Also, educator observed that robots are beneficial for the development of student's problem solving and algorithmic thinking skills [02]. Talking about the benefits of educational robotics as a tool for learning a respondent said:

> "Having certain tasks off-loaded to robots in a relaxed way just like using a calculator makes it easier for students to use their minds in more creative activities. In this respect, a brain that is fully cognitive-intensive in the classroom can also focus on a social activity and a creative activity at the same time this is because the robot takes on certain ordinary tasks which might otherwise tire the brain. We can understand this as similar to using a calculator. Just as a calculator buys us more time in the drawing of a graphics, just as it makes some statistical calculations much faster, the students can use the available extra time to develop their high-level skills under their educators' guidance." (R01 – on reducing cognitive load)"

Respondent highlighted the reduction of the cognitive load of students by using tools that support learning. Moreover, the space attained from the cognitive load may be directed to creative and social activities with the help of the educator who guides the robotic activity. The analogy of the calculator shows the respondents preference of use for educational robots in learning environments, as tools. Educators role remains crucial to fill the space occurred from the release of cognitive activity such as calculations, graphs, to further develop new skill sets for students [03]. A different aspect of beneficial effects that educational robots have is stated by another respondent as:

> "I think it makes children more likely to learn permanently, and I think, for example, that they will understand their science, technology and mathematics courses better by appreciating how a 1/0 system works through using Arduino. With this, they can see what resistance is, I mean, not its emergence or formulation, but they realise that resistance is something against the current, and they get to know that the system requires electrical energy to run.” (R07 – on how robots empower Learning)

According to the view of the respondent, using robotic systems may empower learning by using electronic components in the system such as, resistors, that can cause necessary conceptual relations in the student's mind between the subjects of science, technology, and math. Basic understanding of electronics such as, resistors, required voltage to light up a led is also related to the further topics which will be instructed to students at their higher grades. Project-based learning is offering several opportunities to students to understand abstract concepts and relate the notions of science and math in real life settings. Another respondent, when asked about the benefits of robots [04], said:

> “Even simply getting two engines together for the robot to walk is something, after all, the pieces must be assembled correctly, the motor has to be put in its proper place. When one of the steps does not work, the child realises that there is a problem and tries to solve it.There are apparently two issues with today's children: The first is problem-solving skills and the second is concentration of attention. I was told that today's children are having problems with concentrating on the task... but, I can see here that a child can intensely focus on a robot for two hours. It develops the ability to focus, problem-solving skills, and it enhances perception, both visual and audio.” (R02 – on developing motor skills, problem solving, concentration, and perception of students)

Due to respondent’s view, nature of doing an educational robotics project is based on constant problem solving for students. The respondent is using a commercially available robotic platform for projects and has experienced significant benefits for the students such as developing problem-solving skills, improving motor skills and improved concentration of students regarding developing personal skills. Students use various skills and ways of thinking to identify issues on the robotic system, problem-solving skill becomes a part of the systems thinking as well as critical thinking while building robots require manual dexterity [05]. Further on the benefits of robots to enhance 21st-century skills, one respondent commented:

> "It's definitely contributing to the development of intelligence... and secondly, it is beneficial in terms of algorithm development. Thirdly, seeing that the abstract concepts which they cannot model in their mind is realised in the physical world has always been a pleasure for humans. In this respect, the student progresses at a faster pace since she can always question herself by asking what is next. Thus, it becomes possible to develop a certain skill of a student in one year which could otherwise take four years.” (R15 - on cognitive and algorithmic thinking skills)

Three aspects of the benefits of educational robots is emphasized by the respondent, two of them is in regard to development of student skills such as, mathematical intelligence, algorithmic thinking, and the other one is related to student motivation which is referred as witnessing the dream that comes true or in other words sense of accomplishment. In addition to benefits on cognitive skills of students, as specified by the respondent using educational robots accelerates the overall skill development of students when compared with the traditional methods. Unlike traditional learning environments where students sit listen and take notes, robotic activities provide a suitable ground for active learning environments that students are allowed to use their knowledge in one practical application [06]. As one respondent put it:

> “Using different aspects of the mind helps with the development of intelligence since the child is doing something physically, by touching; at any rate, the smaller children want to touch everything for that is how we learn. As the robot enhances motor skills, it also helps with intellectual development. The child uses her skills in a calculative design-oriented space.” (R10 – on learning by doing and how robots aid to develop student skills)

Respondent highlights the importance of learning by doing for the young age group which referred here as middle school students. Learning by doing is accelerating learning of students by enabling them to touch and try things which they might want to see. In line with the statement of the respondent, motor skills and cognitive skills are improved through designing and building a robotic system which requires design skills to adjust dimensions and make calculations to make it work properly. Building a robotic system is found beneficial for the improvement of motor skills of middle school students for the respondent [07]. As another respondent state that:

> "Well, this is already a process where the child comes without knowing anything at first, but afterwards, you see how the problem-solving skills of the child are improved and I can see very easily that her hand-made skills are enhanced as well. We see a significant improvement at the end of the term." (R09 – on problem solving)

Majority of the robotic activities are conducted as extra-curricular activities for a significant number of respondents. As stated above, respondent observed the students for a school term and make a favorable inference on the development of motor skills obtained by using robotic construction kits for middle school and elementary school students. Problem-solving is one another developed skill throughout the use of robotic construction kit. Unexperienced students with robotic kits are getting used to parts, and the way components work by using their problem-solving skills which are desired by the educator. Educational robots are commonly stated as beneficial for new ways of thinking and cognitive abilities of students. Regarding educational robotics for students' competencies as well as their benefits on the personal attributes of students [08], as one respondent put it:

> "I believe that thinking evolves towards multi-frontal thinking in many avenues of life. There are so many variables, so many pieces. The child will do something by combining them. She will create something. First of all, her self-confidence will increase. She's very happy when she does something. When the thing moves, when she does what she wants, her self-confidence gets restored and her fine motor skills are improved. She improves her motor skills. I think that these are nice experiences for a child of twelve-thirteen years old." (R04-on motor skills and self-confidence)

The diversity of parts that is provided by robotic construction systems allows students to build and design their robot in their way. Thus, using of a variety of parts within the robotic construction system improve their motor skills and by creating a tangible artefact through student's ideas boost their self-confidence. Benefits of using robots for education not only addresses the skills needed for science, technology, engineering and math and also promotes students social and personal attributes which lead to encouragement for following robotic activities [09]. One respondent explicitly referred to benefits of the use educational robotics followed by rise in self-confidence on students as:

> "The benefits that they provide to students improve their self-reliance. So, when you the child makes something and sees it working, her self-confidence increases. Here is the thing, when I was a child, you would see on television all those movies, devices, so on, and you would not have the slightest idea how these works. You would wonder, but you could not figure it out, but now when the child switches on a light there, it is enough for him. At the same time, by doing this, she revises the topic of electricity or numbers from her science and mathematics classes. In this way, she has the chance to apply what she learns or to dream and design them in a competitive atmosphere with her peers." (R06 – on technology fluency, creativity, and confidence)

In line with the point of view stated by the respondent, using educational robotics also contributes to students in the ways of learning about their surrounding technologies and attaining them with technology fluency among the other communication and information technologies. Raised self-confidence by the sense of accomplishment from a robotic project may lead students to further learning activities. Accomplishing a robotic project may create opportunities for other subject domains that is mentioned by the respondent. Moreover, confident students may motivate each other and may create a suitable ground to lead new challenges such as participation in robotic competitions [10]. As another respondent remarked the benefits of educational robotics on STEM-related subjects and social skills when preparing for a robotics competition as:

> "... She can observe the cause and effect relationship and see other options ... that's a good thing. She does not do these activities alone, for she is insufficient on her own. She is involved in teamwork, and that way, her social behaviours are changing and developing. In a process that cannot be limited to school time, these students use their free time outside of school time efficiently. They recognise that the systems they know, see and recognise can be used differently than they are. These STEM activities

help them to gain an affinity towards the fields of technology, engineering, and mathematics, and improve them generally. (R08 – on student thinking skills)

Robotic competitions provide various challenges for students, and by covering various STEM-related subjects, students feel more comfortable with STEM-related concepts. According to respondent significant benefits acquired from participating a robotic competition for students is critical thinking, social skills which are acquired through teamwork leads to positive behaviour change [11]. Designating social skill benefits as one of robotic project goal, another respondent said that:

"I provide the robots and their programs separately to them but putting them together is not the whole thing. The child herself needs to learn something on her own, without guidance. She needs to solve problems on her own. When she engages in these sorts of activities, her problem-solving skills and research skills improve, and finally, she understands the logic of production... ... Not only research but also entrepreneurial skills improve as well. When they cannot solve the problem in a certain way, the students can make contact with the members of the robot maker company or with other people who know the matter... they know how to ask for information when they need to." (R12 – on problem solving, and communication skills of students)

Project-based activities for robots in learning out-of-school learning environment needs extra effort from students to build successful projects as well as communication between teammates and other stakeholders of the project. The respondent was pre-defined a design process for the robotics project, but students were free to decide on a project which they want to work. During project's research phase students talked to people to gather design requirements and further information for the use of the project outcome also after the project has done, students strive for entrepreneurship. The journey that students have passed through for a robotic project is nourished by their communication capabilities with other people who sponsored their project or involved in their focus group. In this way, use of educational robotics in out-of-school activities has empowered social skills of the students. Improving social skills for students are also crucial for collaboration between teammates especially for their future career choices or for their current activities, such as participating in a robotics competition to win against another team [12]. The comment below illustrates the link between student's social skills and personal attributes, such as, emotional control or being patient.

> "The robot is only expected to perform certain tasks on the desk, but on the other hand the child develops a project. Thereby she understands the process of developing better. She gains valuable experiences at such an early age by managing a project, starting it, research... She understands how correct information is obtained within the guidance of certain ethical principles etc... At the beginning, our aim was to teach them programming with robots. But we saw that the student had much more different achievements. Such as overcoming her anxiety... or dealing with failure..." (R11 –on developing teamwork, and social skills through robot competitions)

The respondent has stated the benefits of robotic competitions as an inspiration for recognising different learning goals than teaching programming for students in learning environments. All along a robotic competition student gains a variety of 21st-century skills, some of them mentioned by the respondent, such as, on how to do research towards goals, accessing to actual knowledge, time and project management. Alongside the directions given by the competition to develop 21st-century skills for the students, respondent values the personal development of students regarding emotional control caused by failures and loses during the competition. Talking about the personal benefits [12] of educational robotics a respondent said:

> "...for example, the student sometimes places the wrong part, this contributes to improving their patients even in hyperactive children. Think about it for a moment: She can shred the part into pieces because she made it wrong. But she says, no. I will find the mistake... even showing this kind of patience improves the development of her character. She says, "I did something wrong here, I will remove the parts and put them in their proper place." She does not make it a problem, she takes care of her own." (R04 – on personal skill and emotional control)

As mentioned in the statement, respondent shares an experience of the building phase of a robotic construction system based on a conducted workshop happened as an extracurricular activity. All students have different characters; some might be patient while building robot some might get bored quickly. The shared memory of the respondent demonstrates the benefit of using an educational robot to increase engagement of a hyperactive student. Therefore, student improving motor skills while learning how to be patient and responsible by controlling emotions in the building phase of the robot.

4.1.2 Benefits on Student Motivation

Providing student motivation is an essential aspect of education for the quality of learning experience. Learning becomes more fun and desired by students if educators or themselves well motivate them. Educators faced by multifacet challenges to sustain student motivation in learning environments, considering classroom management challenges can be created by students, for instance, interruption of the educator’s speech by students who are not interested in the lesson. Also, students that are highly motivated more likely to go with the flow in the classroom managed by an educator. Educational robots are promising tools to raise interest and motivation of students to aid educators in learning environments [13]. As one respondent stated that:

> "So it makes the lessons fun. The child learns and participates if she has fun. She becomes more active. Accordingly, the educator no longer needs to make an effort to pull her to the class. Educator's efforts are then naturally spent towards lecturing and making learning persistent. In the traditional educator-centric approaches, we struggle to create the optimal class or school environment. But when you employ these sorts of activities, since the child is getting fun anyways, she gets interested in the subject and the educator finds the chance to draw upon the most important parts of the story.”
> (R03 – on fun aspect and student motivation)

Educational robots are fun in nature for students because robots are offering a different kind of approach to learning and seem to be more appealing from other educator aiding tools in the learning environments. As pointed out by the respondent, unlike traditional educator centred approaches using robots for learning provides benefits to an educator regarding personal resources, such as the transition of time from efforts to provide student motivation in the classroom to elaborate crucial aspects of the subject. Depending on the comment, educational robotics supports found beneficial for active learning environments; to provide student motivation while saving educator’s energy and open pathways to empower learning. Commenting benefits of educational robots to student motivation [14], one of the respondents said:

> "In physics, chemistry and biology classes, as the educators, we set the contents of what is to make, provided the students with some models, and waited for them to finish. We usually did this on a project basis. ... In the process, they understood better the contents, purposes and gains of the classes and had pleasure in making the products. The biggest contribution of this process was that students did what they did with a lot more fun. Since it did not feel like a lecture, they saw it as a kind of entertainment, and they learned while they enjoyed." (R12 – on learning by doing and student motivation)

Some of the respondents support other educators in their institutions for the use of robotic activities for their subjects. They are collaboratively creating an activity plan with learning outcomes for biology, chemistry and physics subjects and relate those subjects with the use of robots to provide an active learning environment for students. Students enjoy designing robots, and fun aspect of robots keep students active on the whole process while they are learning the goals that are predefined by the educators. Integration of robots to educational goals of educators aid them regarding student motivation which is highlighted as a significant benefit by the respondent. Use of robots for the better explanation of abstract concepts in science subjects may also increase students' academic performance [15]. As one respondent put it:

> "In terms of self-confidence, it is indeed very important ... a child whose academic achievement is not high is becoming a child who finds himself in the robot-making and starts to lead everyone in and around ... and thus the contribution to her personality becomes self-confidence and happiness. She asks "why is this class only two hours?" You can transfer some of the work-time from such and such a class and we can continue doing this. She likes the fact that she enjoys a class this much and wishes that all the classes are like this. (R04 – on self-confidence and student motivation)

Benefits that have been provided to educators by robotic activities delivers additional knowledge-based, skill based, and motivational based perks for students. As one of the most stated benefits of educational robotics, raising student's self-confidence elicits student motivation which is followed by an increase in overall academic performance in school. In this case, use of educational robots shows significant value to attract low-performing students to other subjects by raising their self-confidence in robotic activities. All that is provided by the fun nature of robotics which is attracting students by changing the context of the traditional learning environment. Using educational robots seemed to have a positive effect on the student development from the perspective of the respondent which also increases student engagement in the activity and influence other students [16]. Talking about this issue, a respondent said that:

> "This is a bit like a drop of water: When the children see a positive development in themselves, others are positively influenced by it and involved in the positive communication or development. When they get afraid, they all get afraid; but they see that they can do it, the believe what you show them. It is easier to shape a human's understanding when she believes in the subject." (R08 – on student motivation)

Positive development of student's skills and on their attributes that are provided by the use of educational robotics is influential amongst students. Other students motivate students who are not participating in such activities by seeing their increased competencies and positive change. However, the substantial effect of using educational robotics might have some negative effects amongst students because of the fear of failure and believed as not capable of programming and designing a robot is also stated as an influential affect by the respondent. To sustain student motivation in a positive manner, educator's plays a significant role in robotic activities. Planning robotic activities based on real-life examples is one of the key points to overcome student bias on educational robotics [17]. As one respondent put it:

> "I conducted the classes rather with examples from the real life. When I opened the boxes of the circuits and showed them, the children were afraid at first and they said: "what would we do?"As a matter of fact, I showed them a variety of sensors. I thought about the light sensors in the cars and temperature sensors in air conditioners which blows air as it gets hot; similar principles. Or, you know, the material in the Playstation controller and the joystick are the same. Since these are the things that the children know from their own daily lives... when we tell them will be working on these... it becomes very motivating for them. (P07 –on real-life examples in learning)

Relating the robotic activities with real-life products that we use in our everyday life seemed like a proper solution for the respondent to overcome fears of the students on using microcontrollers with various sensors. Given the example of the respondent, attract students by analysing existing products and lead to unique project ideas amongst students after they understand the basics of programming and electronic components especially sensors. By relating real-life examples in the learning environment, respondent builds up technology fluency and confidence for students to design a unique project for the exhibition which is accompanied by student motivation. Therefore, educators play a vital role in the robotic activities to attain most of the benefits offered by educational robotics. Role of the educator is crucial for both taking all advantages of educational robotics and developing student's skill with robotic activities [18]. As one respondent put it:

> "Students can discover a lot of things, too. Educators should be open to the things that students themselves discover; so, it is better not to have an overly didactic style but to approach the students as if they are comrades. This is so, for, in the end, there is no complicated work to combine many parts; there is not so much need for an authority of knowledge. I can say that the Lego bricks make students and educators equal in a way. These are not sophisticated parts; therefore, the student can have a better idea, and the educator should be open to this. Each new idea should be presented to everyone with an appreciation to everyone. The educator, in this regard, should be a unifying force. (R01 – on learning together)

Unlike traditional ways of teaching, students are more active during the workshop hours of robotic clubs or in other extracurricular robotic activities. Moreover, as stated by the respondent, using educational robotics sometimes may bring educators and students to common ground and equalise them regarding skills required to design a robot. In such cases, educators also continue to play a vital role by being open to new ideas from student and supporting the exchange of ideas between teams or students. Being open to new ideas, allowing students to explore on their own and guiding students with a comprehensive attitude are important aspects of educator's role in the active learning environments.

4.1.3 Learning Opportunities

Learning based used of educational robotics vary due to educational approach of the educator. Mostly educational robots are used to address needs of the educators in learning environments under the activity plan of the workshops or robotic clubs function as tools. Using educational robots as an educational tool is showing similarities with another tool that have been used in education [19]. As one respondent put it:

> "I regard the robot as a tool... if we look at the tools we use in training, there are visual tools and these visual tools often are two-dimensional, or three-dimensional. The whiteboard, for instance, is a visual tool; you write on it. Television is a visual tool, you can show images on it. A 3D model, a skeleton model, for example, is a visual tool. The robot, however, is much more than all of this for it is functional. It can be fitted into the curriculum of natural sciences as experimenting tools that the children program. She makes it herself and sees the result. Making and experiencing are the two key terms in education in this era.... In all the other tools, either we make the children watch or listen to, nevertheless, robot-making is experienced by the children. I believe that experiencing is the most important thing here. (R02 – on robots role)

Benefits obtained from educational robots as a learning tool offers experimentation and first-hand experience on abstract concepts in science. Learning by doing is highlighted by the respondent and embraced as a pedagogical approach for conducting robotic activities with students. Educational robots are providing students with a tangible platform to further develop their understandings of science concepts by experimentation. According to respondent, physical nature of robots offers rich experiences for students when compared to other educational tools. Working with a physical object in a learning environment is commonly used approach by educators throughout the history of education, for instance, beads, wooden blocks and so on. Moreover, educational robots may play an essential role in the understanding of abstract concepts and internalisation of the knowledge given by the educator as a tool to think with (Papert, 1983). As one respondent put it [20]:

> "The purposes of using robots in the training process are not so different. Normally, the purpose is to conduct the classes and to present the learning outcomes of that class

> within our curriculum in a robust way. This is so, for it is more difficult for the students to understand abstract notions. When we combine these outcomes with robots in a concrete way, for instance, when you make the student carry and deliver some item via a robot, that serves better. We often use robots to apply the theoretical knowledge into practice and that is very helpful for us." (R12 – on the understanding of abstract concepts

Some of the respondents were concerned about the curriculum that they have their ways to use educational robots to further instruction of the abstract concepts. Understanding of abstract concepts in science and math is often regarded as a problematic issue from the perspective of students. Designing or building educational robots to seize abstract concepts, reflects the internal knowledge of the students by the given subject and offer chances to educators to notice student's knowledge. This act of transferring knowledge from theory to practice may also bring additional challenges to robot design because of the constraints brought by working in the real world. However, robots may provide a combination of a variety of tools and skills which is required for the better learning experience and may lead to radical changes in learning environments [21]. As one respondent stated that:

> "As we discussed, the child works individually and one on one, so she transfers her own creativity to a direct object; and secondly she learns to work with the team if she is doing teamwork. Thirdly, it addresses more than one kind of intelligence. As we mentioned, we are working in a multidisciplinary way, and these are developing the child and contributing to her education. Fourthly, the traditional concept of the educational environment comprised of tables and chairs is replaced. You can provide for any kind of educational environment with robots: You can make one like a drone and fly it on the street or you can use another as a submarine in the water... You thereby diversify the educational environment, there are no traditional class environments anymore, you design a platform wherein the child will make products." (R10 -on creativity, teamwork, and changing learning environments)

Educational robots provide opportunities to educators further build communication and collaboration skills amongst students. Working in a robotic activity is an active process regardless of the aim which may also require guidance or suggestions from different fields. To build robots students usually move from one point to another to try their designs or to get appropriate tools or parts to work on their robots. Active roles that have been played during the robotic activity offers improvement of a variety of skill sets to students. Educators also gain benefits from the possible variations of robot designs, and if desired they can work with flying or swimming robots instead of walking ones to diversify learning activity as stated by the respondent. Educational robots offer plentiful opportunities to the diversity of learning activities, and various skillsets might be acquired for students such as communication and collaboration skills and cognitive skills. Based on educator's preference for implementing robotic activities such as, building robots from scratch or using a commercially available robotic system may require different tools to work [22]. For example, one respondent said:

> "There is a software that *AutoDesk* provides. *TinkerCad* is a version of this made for kids. With this software, all you have to do is to cut and combine from the wide range of available objects which are triangles, squares, circles. By doing this, the child creates a design and actually learns how geometric shapes are seen in three-dimensions. We seem to build robots here, but if fact, we are doing geometry here when seen from an educational perspective. I give the students a sensor and when it is used for growing a plant by adjusting the temperature and the light, then the whole experience is tied to natural sciences. From there, you move onto social sciences where there is a topic about drought and you accordingly add it inn. You can use this in art classes as well; you can make the students draw or have them make the drawings via the robots. In other words, there are so many fields into which you can integrate technology, there is no end to this. I actually think that you can integrate this into any field." (R13- on multidisciplinary aspect of robotic activities)

According to the statement, by using educational robots, educators are supported to address wide range of subjects in education. Respondent prefers to build robots from scratch by using microcontrollers and electronic components and benefits from the other educational tools such as, 3D modelling software to relate the robotic activity with geometry concepts. Therefore, educators play a vital role in the robotic activities to attain most of the benefits offered by educational robotics. Role of the educator is crucial for both for guiding students and developing student’s skill with robotic activities.

4.2 Challenges of Using Educational Robots

Besides their benefits, using new technologies such as educational robots in learning environments comes with additional challenges for their users as well as for the integration of the ongoing educational system. Challenges based on the stakeholders are extracted from the insights of the respondents considering the usage of educational robotics, educator’s role in robotic activities and difficulties faced by students. However, except few respondents, most of them mentioned on challenges from the student perspective rather than their own experiences on using educational robotics. Concerns were expressed about using educational robotics in school and out-of-school learning environments. Challenges that related to the overall aim of the study are classified according to stakeholders such as, *student-based,* and *educator based* while challenges which cannot be affected by design are categorised as *external challenges*.

External challenges are often including high-cost, institutional support and maintaining academic materials to support educators. Considering issues emerged from external challenges, a common remark amongst respondents was the high cost of the educational robotics [23]. One respondent stated that:

> "Expensive! It must get cheaper. Students at private schools are more advantageous in this regard, but these must be available for every group in society. Therefore, there is a problem in this regard. In terms of time, there is a certain National Curriculum that we must follow, and there are classes to be given under this curriculum. We have to factor that in concerning the time allotted to the robot club's activities. Sometimes, we can give these classes before the start of the term, after it, or on the weekends. Naturally, it may not be sufficient. Curricula and educational programs could also be designable in a more flexible framework and reasonably priced so that all schools could implement them. (R03- Cost and curriculum related issues)

Accessing educational robots for every student is a challenging issue because of the high cost and low-level funding spared from the institution where educators belong. In the next few years with the development in the mass production of robotic technologies may decrease the costs. Some educators can overcome this issue by using third-party sensors and microcontrollers to build robots from scratch with the aid of 3d printers or other fast prototyping machines such as laser cutters. Another critical challenge according to respondent is time; limitations of school hours need strict lesson plans that are required to fulfil curriculum adopted from the ministry of education. Also, robotic clubs are in need of activity plan from educators too which is added to the workload of an educator. Providing enough robots for students in the learning hours is needed for effective learning [24]. As one respondent put it:

> "For example, if you have twenty-four students, you need to have twenty-four kits in a class so that we can do proper work, we cannot make two students properly work on a single kit, for instance. However, buying one for each student increases the costs a lot and no parent wants to pay for that amount. Accordingly, we have to make significant reductions from the contents of the package, and this is not in line with our interests. Therefore, I am in favour of buying for the class rather than having reduced kits." (R14 – on student robot ratio in classrooms)

According to the statement, the high cost of educational robots is creating financial difficulties to parents, and if purchased it will degrade the number of components that might have been included within electronics bundle which is not desired by the respondent. To overcome the challenges possessed by the high cost, the strategy implemented by the respondent is to buy electronics bundle according to student number of the classroom to have at least one robotic system for each student. Keeping robot and student ratio on one on one is a matter of preference for the educator and desired to learning outcomes. Student robot ratio is vital for the interaction between students and the robotic system [25]. As one respondent stated that:

> "When we look from the point of view of the students, we can see that there are three kits eighteen students in each class. This means that there will be six students in each group. The problem here is that while some students get very interested in the work, some others, for example, may remain isolated and pass the time without even

> touching to the robots. We have seen this happening." (R09 – on relationship between number of robots and student interest)

Schools which are unable to provide students with a suitable number of robots are more likely to separate students into groups. However, the number of groups is crucial for student engagement in the robotic activity. The interaction between student and the robotic construction kit is essential to keep students engaged during the workshop hours. Otherwise, students might not want to participate further activities. Constraints based on the tools such as, computers and design of a robotic construction kit may limit the number of students can work together for a robotic activity that is the critical issue to consider for the educators.

4.2.1 Challenges of Educators

Educational robotics as a new context of learning for students, educators may also be in need of computational and design skills to implement robotic activities as intracurricular or extracurricular. Educational robots combine programming, design and engineering skills to create a tangible artefact which is relevantly new tool and skills for some educators. Within a great workload upon educator's shoulders sparing time for unconventional use of new educational technologies out of their comfort zone can be challenging which is why educators need to be supported in various ways throughout their use of educational robots. Commenting on challenges faced by educators [26], one of the respondents said:

> If you from the educator's perspective, it gets difficult for the educator will need extra time to design the class. The design capacity of the educator enhances the benefit of the robots in education in a way. If the educator does not have great design skills, then she will need some prepared designs. This means that there is a need for documentation in this aspect. The educator may need to be supported heavily so as to enhance the benefits of these activities and tools in education. Alternatively, there must be some reward mechanism for the educators to ensure that she is more motivated to provide for these creative activities." (R01 – on lack of resources of educators)

Regarding achieving learning goals educators trying to provide student motivation, however, to offer students effective learning opportunities educator's motivation is seemed to be one the critical issue. To provide external motivation to educators, supporting them with ready-made academic materials for robotic activities, robotic activity curriculums and documentation of robot designs is crucial. Some of the commercially available educational robots have these kinds of options for educators to support them in their creative activities. However, it seems not enough for some of the respondents. The comment below illustrates the needs of a respondent regarding support through educational materials [27].

> "We cannot find enough sample models. For example, I ask if there is an example of colour-reading for disabled people? It turns out that there is none in Turkey. There are some international sources, of course, such as one video in Japanese that I saw. I do not know Japanese, but we tried to figure out the instructions in the video out by trial and error. Once or twice some of the cables were burned... sensors are not reading correctly and you do not know who to consult... So, the product is being sold but there is no one to get some after-sale support." (R15 – on lack of resources of educators)

Lack of resources and support in the native language is defined as a challenge by the respondent. Building robotic projects through tutorials from the internet videos and selecting the proper tutorial or example for the intended project in the one's mind is another challenging issue. While trials and errors happening through building a prototype from an example project found from the internet respondent sought support for consultation about sensor reading. However, the respondent could not find any answers to troubleshoot problems. Personal competencies are equally mattered as supporting educators for the use of educational robotics. Comprehensive training for educators on how to use educational robotics is essential to reduce faced challenges by the educators. Furthermore, proper training on educational robotics may increase the effectiveness of robotic activities [28]. By addressing these issues, a respondent said:

> "If robots or electronic will be included, then the educators must really be educated and they themselves need to be aware of how they can be within the activity together

with children and how the children can internalise these activities. This is so, because you need to be much more enthusiastic than the children so that she can always motivate the children, increase their curiosity, and teach them new information. Motivation is needed for this job. The educator should feel sufficient to motivate the children, to give them the answers that they may need, to direct them, to make them think differently. This is the essence, and it cannot be done with anything material. This has to be something that the educator should feel in herself." (R07 – on educator's motivation)

Considering the given statement, student motivation and quality of learning experience are affected by the educator's training also, benefits that are provided by robotic technologies to students is in direct proportion with the educator's competencies. Educators may expand opportunities for students if they feel comfortable their technical skills with the tools they use. However, motivating educators is another issue for the training of educational technologies that might have been used in both in and out classroom environments [29]. As one respondent put it:

"... Educators are the ones that resist us the most, in particular, computing educators. The reason for this is that they have already been accustomed to programs like Word, Excel and other programs of this sort for years... they are not open to learning new things. To learn something new, the educator must make preparations and planning in advance. She must be able to teach that new information to the children. This can only be done, of course, if educators learn it themselves first, but this feels too burdensome for most of the educators. I think that these problems must be overcome. The biggest obstacle here before us is educators for student can never learn unless the educator learns first. The educator should direct the student so that the student can achieve more."(R13 – on educator's pedagogical beliefs)

Respondent is conducting workshops for students also provides training for educators on how to use educational technologies for education. Due to comment of the respondent, motivating educators for training is challenging. Some respondents argued that lack of time and financial issues are the reasons for not attending educator training for educational robotics. On the other hand, a small number of those interviewed suggested that training for educators should be free to extend the use of educational robotics amongst educators. Some of the institutions are providing training on educational robotics for their educators [30]. As one respondent said:

> "The first and the most basic of the serious problems is the lack of educated educators. Here, it is usually the computing and informatics educators who take care of these activities. These educators generally work on computer skills, and their understanding of these activities are limited. We try to overcome this by educating them by providing seminars ourselves. Sometimes, we come across people who educated themselves. This is how things are." (R14 – on educator training)

Lack of experience in educational robotics is stated as the weak point of ICT educators. Due to the statement, this problem can be solved through specialised lectures for educators in their college years. To provide a simple solution to this problem, respondent's institution supported in-house training to fill their educator's deficiencies in the use of educational robotics. However, the challenge that stated by the respondent might be solved by political directions and cannot be solved through with design of a robotic system.

4.2.1.1 Robots Based Challenges of Educators

Preferences of educators for the appropriate educational robot is dependent on the spared activity times and student number who participate in robotics clubs or workshops. Some students who participate in robotic activities may limit the work can be done within the activity hours which is generally 2 hours per week. To support educators to reduce their workload within the time constraints of robotic activities, using educational robots which is easy to use regarding assembly and ease of learning is crucial [31]. As one respondent said:

> "There is a burden of learning that this will create. You will have to learn more. I can say that it can take too long an amount of time to make the robot better. It particularly takes a long time to reassemble the body parts. All these parts can be problematic, their cables can be disconnected, etc. It may require a good deal of electronics knowledge. Sometimes you cannot solve the problem, the settings, cables, and resistances can be malfunctioning. It may accordingly require director expertise." (R01- on commenting mBot)

Complex robotic construction kits may oppose additional difficulties to users, but it depends on the educator's goal to select appropriate robots or robotic kits between various educational robots. Based on previous research, different types of use are defined, and educators can decide upon which kind of use of robots provide benefits in the light of their goals. Alongside the selection of appropriate educational robot, planning and managing students in robotic workshops is another issue [32] which is highlighted by another respondent as:

> "You have to put sufficient material before each child and put up a very good system or else the whole place could turn into a chaotic atelier full of small robot parts. This is usually the biggest problem. Let me think for another. I come across two kinds of children: Some of them are interested in the design aspects while the others are much more interested in the programming aspects. The balance here must be fine for a single child may not be interested in programming. If you bring together two children who are interested in designing and doing two teamwork, you will find useful things." (R02- LN45 – on messy workshop and division of labour in student teams.)

To preserve order in the workshop space for robotic activities, respondent suggests that bringing limitations to given robotic construction materials for students helps educators to keep workshop space in order. Otherwise, workshop space for robotic activities can quickly turn into a mess if students are allowed to access irrelevant materials. In addition, a collaboration between student teams is another challenging issue which is stated. Regarding dynamic student teams for robotic activities, the strategy of the respondent to overcome the challenge is to match students with different personal interests in the same team. The challenge stated by the respondent is concerned with the social aspect of the using educational robotics. However, there are other examples of challenges faced by educators that are caused by the robot itself; most of all based on using sensors [33]. As one respondent put it:

> Learning through the program duration is important. We ourselves study each week before the students come. Of course, sometimes problems arise, even though you can arrange everything to its minute detail. I test it before students come, but still, sometimes problems happen during the class. These problems could arise for both the

> students and the educators. For example, while I am doing exercises with colour sensors, even the light from the environment can affect the the colour due to its reflection. (R09 – commenting on technical diffuculties.)

Majority of the respondents stated that they are making preparations for their next robotic activity and also testing the robotic systems before the activity hours to disregard possible errors to take advantage of time. However, despite preparations and tests of educators, they still faced problems based on sensor readings due to the unpredictability of real-world environment. The reason for the occurring problems while using sensors is because of not conducting robotic activities in laboratory environment which are specifically designed to provide stable values for sensor readings. There are possible solutions to adapt robotic systems by calibrating sensors, but it may require advanced programming skills which may be inappropriate for students. Using sensors are commonly stated as a challenging issue amongst respondents [34]. As one respondent said:

> You'll be using a new sensor, for example, and you need to know how it works. More than that, as we discussed just now, you need to make the system work in a rapid way. Therefore, you need to know how the sensor works completely so that you can code it in its proper way. This takes a long time, sometimes, weeks depending on the sensor. (R05 – on unpredictability of a system and reliability issues.)

According to statement, challenges that are generated by using sensors or teaching about sensors is interrelated with the time spent for the activity. Building robots from scratch is often stated as more time consuming than other types of robotic activities (Vandevelde & Vanderborght, 2013). Therefore, absence of compatible sensors with main controller of a robotic system which is designed for ease of use generate multifacet challenges and requires additional effort from educators. To understand how sensors work, datasheet examinations and experimentations may needed which also cause loss of time. To use educational robotics in schools or in spared time for afterschool robotic clubs wasting time on technical side of sensors might not be desired if the learning goal of the educator is not teaching robot itself.

4.2.2 Challenges of Students

New context of learning as educational robots, brings different challenges than classroom lessons might oppose for students. Sometimes challenges that offered from using educational robots can be welcomed or provoke negative feelings for students yet, the student motivation and interest on robots are dependent on effects of the faced problems [35]. As one respondent put it:

> "That is to say, learning the robot itself becomes an issue in itself. Therefore, students cannot be completely independent. While some enjoy this a lot, others do not appreciate it in the same way and at the same level. It can create a cognitive load for some students. For some students, it does not create such a great load in that sense, actually, it would be great if the use of robots could be in the form of a study in which the student is active." (R01- on cognitive load and learning robotics)

According to the statement, learning about robots regarding electronics, sensor reading, and programming is a new context of learning for students so, using robots may bring cognitive load for students which may limit their creativity until they are feeling comfortable on the context knowledge. Moreover, engagement of students depends on the motivation and personal areas of interest upon educational robots. Addressing students personal interest is a crucial aspect of sustaining student participation in robotic activities. In line with the personal area of interests of students, external factors such as, parental support is another challenge that students faced. Talking about this issue [36], a respondent said:

> "If the student does not have the special interest, he cannot think algorithmically; he runs away from it, leaves it, drops it, does not get into troublesome work. In others it's mechanic, for instance, their computer is insufficient, the child's family does not buy a new computer, and the computers in the school are accessible to a certain degree because we do not allow them to take the school computers home. Naturally, when the machine in the hand of the learner is left inadequate, he drops it feeling enervated, thinking he can't do it." (R08- on student's personal interest and lack of parental support)

Considering the statement, educator-based and institution-based support cannot be enough for student's motivation; parents also play a vital role to support their children according to their interest morally and financially. Since the time spared for robotic activities is not enough to build and programme a robot, motivated students are working in their free times for their robotic projects. Providing students tools that are needed to build and programme a robot is an important issue which is addressed by some private institutions under the name of robotic clubs, however, personally in their free times not all students can access these kinds of opportunities. Lack of numbers of educational robots for large groups is decreasing the interaction between student and robots thus, resulting in the loss of student's interest from robotic activities [37]. As one respondent put it:

> "When we look from the students' perspective, there are three groups in each class, and if we assume that there are about 18 students in each class, there are six students in each group. While some are wholly interested, others don't do anything; they stand apart favoring only to observe, some students spend their time without touching a robot, we have had this; for example, some students do not get into any interaction with the robot. Often these are mostly female students, there happen to be students who do not have it in the area of their interest, some of them are really not interested, they also think that such things as robotics won't be useful to them in the future, they are not interested and they prefer to stay a little back."(R09- on student lack of interest)

From the perspective of the respondent, one of the most critical issues derives. Considering students, providing robotic activities for increasing participation is of the significant challenges in the field of educational robotics. Student's lack of interest may overcome by creating gender-neutral, broad themes that all students can find projects according to their interest is one of a critical aspect to conduct robotic activities (Rusk et al., 2008). Educator's role is essential to provide student motivation and enhance engagement of students by selecting themes that offer freedom of choice for the robotic project. However, age-group that the educator deals with is another aspect and may require additional time and effort to provide student motivation. Talking about the student's interest based on their developmental stage [38], one of the respondents said:

> "Another thing is that the sections we work with, especially the middle school children, children in adolescence, from 12 to 13, bring out different problems on

> various issues, and this causes a distraction for them, their interest shifts to utterly different things.” (R06 – on developmental issues of students)

Respondent states that being in adolescence also may bring challenges for student’s interest and concentration in robotic activities. However, the developmental stages the students are going through is temporary, and educators may take precautions for environmental distraction or develop strategies to attract them into more engaging robotic activities. Afterall, educators are the experts on the field to work with diverse age groups and specialised on communication according to students age. Elementary school students are more likely to challenge by developmental issues regarding motor skills while building robots from the robotic construction kit [39]. As one respondent said:

> “Because their manual dexterity has not fully developed yet, meaning, not having control over those muscles, and because it is not an age group that can achieve complete control... You know, not having much body muscle coordination. But by trying repeatedly and working hard on it, as I said, we've managed to overcome their over activity. A child who can't stop moving during class stops moving when it's time to interact with the robot. Which means this not a problem, that is to say, it's entirely related to the child's interest.” (R04 - on motor skills)

According to the statement, lack of manual dexterity depends on the student’s age. Also, respondent states that building robots from a robotic construction kit have developmental benefits for motor skills of the students. A robotic activity that is conducted by the respondent caused behavioural changes on students who are defined by the respondent as “hyperactive” during the formal education hours. However, building process of educational robots is based on student experience and familiarity with robotic components and may develop through practice [40]. Another respondent, when asked about the challenges faced by students while using educational robots, said:

> “these exercises are generally in English, our kids are not bad, they are well developed in terms of teamwork but they struggle with English. I don't have problems in the foreign language (English), but even though our students take eight hours of English per week, none of them know English. They do not know English well enough to read

> and understand an article, I am not referring to their speaking, I am talking about understanding what you read at a basic level. Actually, they do not understand what they read in Turkish either, we have such a trouble." (R10 – on language barriers for programming)

Language problem can be both sided challenge for educators and students. According to the statement, most of the programming interfaces and open-source documents are in a foreign language to students, and they have difficulties to understand and interpret the information given. Being able to make research on the internet to reach valid resources and understanding programming interface or errors caused by the system is based on student's language competencies if the student is beyond the educator's guide. Being able to have language skills to communicate and interpret knowledge is one of the goals to achieve for 21st-century skillset (Binkley et al., 2012). Beyond technical skills that are required for educational robotics, other skills such as collaboration, communication are equally important to raise interests of students.

4.2.2.1 Robot Based Challenges of Students

Students that are unfamiliar with robots before are having robot images in mind which is based on media representations of robots from the movies, comic books or video games. This representational image of robots may deceive students for their work and create barriers to robotic activities in learning environments. Educators also having challenges to understand how students perceive the robots they are using; this perception differs between age groups, and below high-school level, younger students are more likely to attribute characteristics of a living thing to a robot. From elementary school to high school common use of educational robots are as a tool for learning or learning robot itself which is lack of advanced intelligence to attribute character. Therefore, anthropomorphism may cause barriers to the learning experience of students [41]. As one respondent put it:

> "The biggest problem with robots is to see them through the eyes of the learner and to check how the learner perceives the robots; it is not easy to explain that there is no consciousness in the robot. To be able to tell that robots communicate with the outside world using the commands we give and sensors, an introduction course may be required. Students cannot learn the concept of sensor easily; it's a numeric value. That is to say, you show a color, and the student needs to perceive its numeric response,

> not that it's a color nor the meaning of the phenomenon, this is a kind of mental transformation." (R01- on anthropomorphism issues)

According to respondent, teaching how robots perceive worlds, is essential for the use of sensors within the system. However, robot perception of students that is influenced by high-intelligent robots in movies makes students think robots have similar perception with humans which is followed by failures in programming while using sensors. Explaining how sensors work is related to the conversion of real-world perception of humans into computational representations. Therefore, the anthropomorphisation becomes an obstacle for the understanding of computational concepts and the suggestion of the respondent to overcome this challenge is to give students an introductory course on robots [42]. Another respondent alluded the notion of anthropomorphism as:

> "Children have extraordinary dreams; for example, they say 'I am going to go inside this mirror and teleport to another dimension.' They come up with these unrealistic projects, and you have to make sure that they come back to earth. Same is true of robotics; they fantasize a cyborg that talks and get a bit disappointed when they see the sets. Well, our sets are not very advanced, firstly the child is having trouble here. Secondly, the child has no notion of what a robot is, get it? he considers even remote controllers as robots or thinks only of cyborgs when she hears the word robot." (R10 – on anthropomorphism and media effects)

According to the statement, the educator was guiding students to more realistic projects when students are demanding inapplicable robotic projects from the educator. Respondent persuades the students for a feasible robotic project to recover disappointment of students derived from the mismatch between the imaginary robot in the student's mind and actual robotic construction kit. Moreover, respondent agreed with statement that suggest introductory course on robots for better understanding of students about how robots work. Beyond the robot perception of students, familiarity of students to robotic components is another challenging issue mentioned by educators [43]. As one respondent put it:

> "For example, sometimes you encounter a child who's never built a Lego set before,

they come, and they just do not want to be here, that becomes our biggest issue sometimes, but as they build it independently, they like it and began doing it, well, that's the only situation I encounter, other than that there are many students who are very interested." (R09 – on familarity with robots)

Depending on the experiences of the respondent some students that participated to robotic activities can be unfamiliar to construction elements or inexperienced on how to assemble parts of a robotic system such as, wiring, using memory sticks and so on. Lack of experience of students may decrease the motivation of students upon failures. However, it is a skill that can be mastered if practised enough. Given memory of the respondent was based on students who built robotic construction kit. Building robots from scratch may bring different challenges to students for the use of unfamiliar tools such as, soldering iron, screwdriver, wrench, 3D printer and more depending on the educator's choice [44]. Similar to shared experience of the respondent, another respondent said:

"Some of the children are afraid, for example, the female students, you know, because we firmly believe that stereotype in our culture, boys can hold a screwdriver, but girls can't. So, the child may not have ever held a screwdriver or have built Lego and can get frightened thinking she won't be able to do because it is something entirely new, but we overcome these issues, that's how problems occur." (R10 – on familiarity with tools and robots)

Students are experiencing and mastering a variety of tools which they are not able to experience in traditional learning environments. Robotic activities are providing a suitable ground for students to know the unknown in diverse ways and with the aid of the educator raise their confidence in the use of different tools. While some respondents are focusing their goals on the programming aspect of the educational robots, others are choosing to combine different skills of students to design a robotic system [45]. As one respondent said:

"Because we do not use a ready-to use robotic kits, we need to combine them from scratch. In this part, in terms of required strength or because the tools used are sharp objects, we come across some obstacles, some students can cut themselves. This is a rare situation, but it is one that I see as an obstacle to design, and like I said if some design subjects are taken priorly, for example, 3D design course to improve kid's 3D

> thinking skills, I believe we can overcome that obstacle." (R13 – on design skills and tools to work with)

Instead of using robotic construction kit respondent prefers to build robots from scratch with students. As stated by the respondent, most faced challenge by students while building robots from scratch is a design-based challenge. Together with the design of a robotic system, assembly of custom parts is more challenging for students than assembling a robot by using robotic construction kit. Custom built robots by students can have poorly designed body parts and connections which can extend the time of building phase of the robot. To avoid such challenges, respondent suggested that 3D modelling courses can be beneficial on student's design skills. Moreover, because of using real-life tools such as razor blade knife, students may have injured during the process. However, Injuries during robotic activity is not frequently encountered a problem for most of the respondents because students are using such tools that hold injury potential under the supervisory of the educators.

Students gain mastery over educational robotics by failures and failures provide learning opportunities for educators. Students are biased over robotic technologies and avoiding themselves from trying or even to touch. Maybe it is the fear of the unknown because one of the respondents stated that students are not even touching to microcontroller because of the fear of electrocuted by it [46]. For example, as one respondent said:

> "Children are unfamiliar with electric and electronic devices, they pre-judge, thinking it's complicated, they get frightened, and they initially don't want to work on it, but you overcome this, they connect a few wires, see that things start working and they proceed. It is all new to them, so at times they confuse the wires, they attach them to wrong places, and things do not work, but in time things speed up." (R06-on fear of making mistakes and lack of experience with micro-boards)

Microcontrollers seemed to have a negative first impression on students which evoke feelings that is complicated. However, students raise confidence after their first successful examples that guided by the respondent. User-based errors happen during wiring process respondent's projects because of the microcontroller's pin sockets are tiny and hard to see which number is written on the side so, it ends up with a short circuit with a cost of few components and programming failures. False wiring while using microcontrollers is commonly faced challenges by the educators [47]. By pointing out this issue, another respondent said:

> "Children sometimes misconnect the circuit, causing a short circuit; they don't even notice because they act very fussy when wiring. It is necessary to install the cables to the ports on the border very carefully, for example, at times, the student supplies electricity to one of the holes but wires the cable to a different hole. When we check we realize that the short-circuit is caused because cables are reversed wired, or the cable is connected from another place. We come across small problems such as these, not any big ones." (R07 – on false wiring and lack of electronics knowledge)

Respondent mentioned about student behaviours during their project as being hasty to wire components and causing short-circuit because of not paying attention to connection points on the microcontroller. Students demoralise upon their failures, but with the guidance of the educator, some of them troubleshoot together to solve problems occurred. Younger age groups are growing impatient to see the results of what they are doing and sometimes can have difficulties with problem solving. According to provide efficient learning opportunities for students in learning environments, educators should guide students and explore rather than giving direct instructions (Glen, Suciu, & Baughn, 2014). Respondent only guided students to solve problems by themselves and boosted their confidence. Another respondent remarked the issues based on problem solving skills as relating their existing knowledge from other subjects to solve problems. In addition, respondent remarked the challenges that students faced on using sensors [48]. Commenting on this issue one respondent said:

> "They are having a lot of trouble with the sensors. As I said, when looked at the logic of the robot's program and the algorithm, it is expected that the program works correctly, however, due to parts students use affecting the design, the robot can not fulfill the task in the given time. You see, it is critical where the student starts the work from, for example, let's say there is a piece that needs to be put in on the right of the robot to do the job, it is a heavy piece, and it causes the robot to slide slightly to the right. They need to think about ergonomics, laws of physics. These are the most significant problems encountered." (R11 – on sensor based problems of students and knowledge)

While programme code which designed by students is without error, a robot built from a robotic construction kit still not working as wanted. Due to the statement of the respondent, the leading cause of not seeing the necessary action from the robot is based on its design because students did not consider the laws of physics while designing the robot. Relating the written programme with other factors that are connected with robot's physical components is highlighted as a huge challenge faced by the students.

4.2.2.2 Challenges of Working Together Among Students

In 21st-century skills collaboration and communication skills are mentioned as essential skills to attained for students which are entwined with various provided skills from the framework. Providing benefits to students on social skills alongside with the technical ones is one of the most significant advantages of using educational robots in learning environments. Educational robots may play the role of a valuable tool to improve communication and collaboration between students. However, improving social skills for students, it seems as another challenging issue for the respondents [49]. As one respondent put it:

> "Problems I have experienced in general are ... well ... I believe that children should do their own design. I give kids the design principles and expect them to design according to them, but when designing each student wants to work on the design by themselves. Instead of collaborating to achieve the goal, everyone tries to impose their own design on the others, so we struggle to conduct this matter as a group work, individual ideas clash." (R02 – on working together)

According to the statement, students are not open for collaboration, and they prefer to behave self-centred during the robotic activities. On brainstorming phase of the project, students are not showing respect to each other's' ideas and prefer to stick to their proposals which are creating challenges for the respondent to move on the robotic project [50]. Further discussing the challenges of the collaboration, respondent said:

> "some children act selfishly, trying to program by themselves. The kid always wants only himself to program, we try to change things up by saying 'let your friend work on it too' or ' have Ahmet work on it as well.' Some children can show off-task behavior, and when they do, we call the kid over and give him the '1, 2, 3, start' task,

> that is how we redirect off-task behavior." (R02 – on team working and student motivation)

Respondent adopted a strategy to tackle challenges of collaboration amongst students. By changing the roles of the student teams, respondent preserved the overall student motivation also students equally share the effort throughout the project. Changing student's role in teams is also provides a chance to exploring other aspects of educational robots. In fact, solely focusing on programming or building robots for students may limit their perspectives to see the big picture. However, students prefer to work individually, and collaboration amongst students remains a challenge [51]. As one respondent said:

> "The thing we struggle with regularly is that our students actually are not suitable for working in teams, they usually prefer to work individually, so, as the number of group members increases, potential problems increase as well. Normally, it should be the opposite of what we have, things should go smoother as group attendance increase. You will see that the smaller the group, the faster the project finishes. This is one of our biggest problems, students affect each other badly. Apart from that, to minimize the problems we are taking the following measures. We have students who are very good at 3D modeling, we assign one of them to each group, there are students who are good at problem-solving and can think critically, we assign one of them to each group, and we have kids who are good at programming, we assign one of them to each group as well. Once these conditions are met our problem are solved. Of course, then there are also kids who have good hand skills, they significantly accelerate the work during the assembly stage. There needs to be a student with these different specialties in each group, because, if not, the troubles begin there, when these students are restricted they drain each other's time. This the biggest problem we experience." (R14 – on division of labour in student teams and challenges of working together)

According to the statement, as the number of students increase in teams the challenge of providing collaboration amongst students is gradually getting harder. Also, despite accelerating the progress student teams with large numbers are slower on the progress. Not using robotic construction kit may provide extra roles for students who work in teams because students need 3d printed or handcrafted components for their project. The strategy adopted to overcome the challenges of student collaboration is different from the previous example. Respondent is placing students with different abilities to different teams to accelerate the progress of the project and to sustain social relations in student teams. According to experiences of the respondent, teaming up students with same interests such as, a student who likes programming or student who likes to assemble parts, may create disagreement amongst students.

4.3 Exploration of Design Requirements for Robots in Education

This theme embraces the design requirements of a robotic system for K-12 education from the perspective of the educators. Design requirements are specified from the expectations and needs of the educators in line with their criticisms and comparisons between commercially available robots.

Regarding design requirements for educational robots, responses gathered from the educators led to eight categories considering the expectations of educators from a robotic system which is specially designed for the learning environment. From the most stated to less, sub-themes will be presented hierarchically according to the emphasis of the educator’s statements. During the interview respondents mentioned about design requirements in a disordered way but requirements mainly found on the robot comparisons and process-based questions part.

4.3.1 Adaptability

Adaptability of a robotic system is widely mentioned the concern of the respondents. As a design requirement, adaptability resulted from the analysis in two-folds: first as *adapting to the learning environment*; and second as *adapting to student age group*. Fourteen (14) out of fifteen (15) educators have criticised and stated their needs related to the adaptability of a robotic system.

Adaptability term used by the respondents to address a wide range of needs and expectations for robots in education. Considering the statements of respondents, adaptability of a robotic system is required to widen the spectrum of application domains (science, math, social sciences, art) in K-12 education; provide flexibility to educator’s goals; adapt student’s cognitive and physical abilities and, to extend robot’s physical capabilities such as: construction parts, material, input/output ports. In line with the significance rate from data analysed, adaptability has three distinct features namely; *modularity*; *adapting to age*; and *compatibility*.

4.3.1.1 Modularity

Modularity of a robotic system provides students and educators wide range of opportunities for a designed system in many ways. Regarding statements of the respondents, modularity term is commonly used to refer design variation of a robotic system by the flexible use of body (construction) parts and sensors. The design variation of a robotic system or robotic construction kit is one of the first preference for an educator to adopt one system to a variety of subjects in the learning environment [52]. To illustrate the importance of design variation preference of an educator, one respondent said:

> "At various times, various toys become popular. For example, there were toys that you could spin like peg-tops, they were popular. That toy gets purchased, and so do different variations of it, then, after a certain period, the toy is no longer attractive, why? The design becomes outdated. You bought it for the child, the child has consumed it, and now she doesn't have a chance to do anything else with it. But with models such as 'Lego' or 'Rex,' you can make something different each time, create a construction machine today, a cube solver the next. Possibilities are endless, I would prefer for it to be modular. (R02 – on comparison between pre-assembled robot and construction kit)

Concerns were expressed about modularity during the comparison phase of the interview between construction kits and pre-built robot. Educator prefers to do various projects with a construction kit rather than a pre-built robot with no alternative design options. Modularity of robot components provides diversity to robot design which also contributes to educator’s goal to raise students interest for an extended period by offering diverse robotic projects in the learning environment [53]. Considering raising interest of student by providing customisation through robot design same respondent stated that:

> “I can say that when children create their own robot designs, their interaction with the robot is more powerful. You are having them built a task robot. What is in a task robot? Two wheels at the bottom, two engines, and a controller on the top. But when you ask the child to make a bumper for it, and when he adds two colored lights to the back of it, then that interaction is higher, the child sees it as his own. When he sees it just as a task robot, the interaction is lower. But when the child customizes it with his own design, this interaction becomes more powerful. Let’s call it ‘customizing with own design’ (R02- on relationship between modularity, customisation and likeability)

Providing diverse projects for learning is another aspect for educators which can be affected by the flexibility of a modular robotic system because, in formal education, student robot ratio may not be enough because of external challenges such as; high-cost of robotic platforms, funding spared to buy robots for school and so on. Therefore, according to available robotic platforms in formal education institute, students may work in a small or large number of teams on different projects with different educators. In this case, modularity feature of a robotic system which allows ease of assembly/disassembly with easily removable components (sensors, battery, body parts) gain importance [54]. Commenting on ease of assembly aspect of modularity, one respondent said:"Must be modular, sensors should be easily removable so that it is ready for the next lesson. It's unrealistic that every student can have his/her own, it is more feasible to have one for the whole class. Therefore, in class, there must be a design that is composed of quite rich sensor packages and can easily be broken down." (R14 – on modularity and reusability)

Regarding learning with robots in formal education, educators can possess everchanging concerns according to their pedagogical beliefs. Moreover, the choice of an educational robot and robotic activity shapes due to the approach of the educator. In the frame of this interview educator’s approach to learning with robots can vary on design skills, programming skills or combination of both. While built-in robots are found beneficial for students to focus on more advanced programming skills, robotic construction kits are found beneficial for creative thinking and innovation by the respondents [55]. As one respondent put it:

> "These are like DIY computers, I'll have this processor, this case, and this big of a hard disk. You can just design it according to your desires, it's more creative in my

opinion. Of course, bringing things together is more creative and more practical. After all, you can compose what you want to create by buying specific products. This adds a bit of freedom, I think this is important, and as I said, it also looks adorable." (R03 – on mBOT)

Nevertheless, commercially available modular robotic systems are not found beneficial for proving freedom of design to students by some respondents. Respondents who prefer to build robots from scratch instead of purchasing robots or robotic construction kits are often criticised that the construction kits with unique components regarding construction parts and sensors may cause limitations for creative thinking as well as for the spectrum of the learning opportunities within the robotic project [56]. Talking about this issue, a respondent said:

"It can be beneficial in terms of education, other than that, everything else is within boundaries that they (the manufacturer) have pre-determined and you can't leave them. This is because the sensor used is specific and all the structures you can use are limited, but if created from scratch, you can integrate different sensors and have the children do creative projects that they come up with. There are about a thousand different sensors available on the market today. Here you are just limiting their imagination." (R13 – on how ready-made components limiting creativity)

Educator's goal to build robots from scratch seemed to be more creative and open-ended than being attached to a robotic construction kit or a built-in robot. A significant number of respondents believes that usable wide range of sensors and robot body parts may open pathways to more creative robotic projects for the learning activities. Without ready-made construction parts to build a robot, students may face new challenges to design a robot which may require to attain different skills such as; learning 3D modelling programs for the use of 3D printers or how to use various materials like clay, cardboard, plastic wastes etc. to design robot's body with hands-on modelling tools such as: razorblade knife, soldering iron, hot glue gun and more [57]. Commenting on why building robotic projects from scratch instead of using a robotic construction kit, one of the respondents said:

"What we want is for them to create things and discover, improving their imagination and creative thinking. We are limiting this in a way, it becomes as if it's only a toy

> that can perform certain operations. We want the child to be able to see certain operations and be able to execute them. Like this, it's like solving a puzzle, but in the other one, you are designing a product from scratch. "So cardboard is used here in this, maybe it doesn't look as nice as the other one. As you can see he made that from cardboard, and over there he made something entirely different from cardboard, you know how they question whether or not absence help trigger creativity, right? So, even him being able to solve that, or problems alike, is important for us. It's important for us to use Arduino in this way. " (R06 – on the use of different materials and providing explorative learning experience

Required time to building robots from scratch is more extensive than designing robots with a robotic construction kit. Building robots from scratch offer a wide range of materials by reducing the quality of the final product, whereas construction kits offer robust designs because of their material quality. Some respondents argued that robotic construction kits limit the creativity of students because of the constraints brought by pre-made components, while others found construction kits beneficial to raise the interest of students with easily generated design options for robots.

4.3.1.2 Adapting to Age

Adaptation of educational robots as a learning tool for a specific student age group is a second most mentioned issue of the respondents. Adapting to student's age varies from physical parts of the robot to software complexity within the frame of learning goals of educators. Since the learning capability and physical abilities differ according to age, a robot in a learning environment should be able to correspond to the physical and cognitive capabilities of different age groups. From elementary school to high-school respondents are working with wide range of age groups which may require changes to the robotic system for a specific age range. These changes may vary from physical attributes of the robot, such as the size of the parts to software complexity of the programming interface [58]. During the robot comparison part in the interview, by referring a robotic construction kit, one respondent stated that:

> "If the pieces are too small they can lose it easily. The school environment is such a setting that kids forget everything immediately. The small size of the pieces is a disadvantage. Finding those parts and rebuying them are costly expenses. So, maybe the robots used in the education system would be made of bigger pieces, maybe

> something like that. Or the pieces can grow and shrink related to the ages of children." (R03- on the physical constraints of components in robotic kit)

Educator thought that robotic systems with smaller parts as a disadvantage in a learning environment which can be easily lost, and because of the required dexterity to join parts the robotic system may be difficult to use for younger age groups. Parts are commonly linked with developing motor skills of students. Some respondents attributed developing motor skills to construction part dimensions of robots [59]. As one respondent put it:

> "As I said they [lego pieces] really develop their handicraft skills. While they can complete only a little piece of the work at the beginning of the year, they can do faster at the end of the year, or they can complete the work that they were not able to do in a limited course hour. It improves their handicraft skills." (R02 – on developing student motor skills through constructing robots)

Adaptation of the size of the robot components is found necessary regarding ease of assembly, and the overall size of the completed robotic product. For instance, an educator who works with middle school age range, states that students sometimes have difficulties during the design phase of the robot and removal of the parts [60]. During the process-based questions in the interview, one respondent referred to difficulty caused by the dimensions of the parts as:

> "He needs to both hold the pieces on the top and at the bottom and assemble another piece on edge. The child cannot use his hand correctly enough. Though, he needs two more hands. But, there is someone who does it on its own. During that time, he makes a reverse move; the other piece falls, he cannot attach the pieces. But, this changes in different situations related to the robot he makes. If he makes something easy, he's already making it proceedingly." (R04 – on building experience through practice)

Ease of assembly is related to dimensions of robot parts for below high-school level students because of their lack of dexterity on practical appliances. However, sometimes it can be a desired limitation for educators to improve motor skills of students by challenging them to assemble hard fitting parts and mechanisms [61]. As one respondent commented on this situation as:

> “the piece is growing by using it. It is about spending time with the robot. If the robots are designed with pieces that can be attached easily, he doesn’t experience it. But I think it has a positive effect. He needs to try harder when the work is difficult. Otherwise, he needs to click two pieces, and he is done. He needs to understand the mechanism. There is a situation that he needs to question why he has to complete the tasks in order, what he expects from it and what he does.” (R04 – on gaining familiarity with robotic components)

To address different levels in the learning environment, an adaptation of a robotic system to different age groups remained unclear between the comparison of robots in the interview. The desired robotic system is overlapping with the goals of learning of educators to suit needs of students from different levels of education since the learning is incremental in educational environments [62], one of the respondents stated that:

> “Makeblock is superior to all. The Makeblock has the advantage that one of the products that appeal to very young age groups, and after you have made the necessary upgrades and used Arduino's resources, you can also use the same kit for high school groups. This is a great deal of flexibility because when you look at other brands, they are always targeted separately. We do not generally see a product for children from primary school to high school in other kits. Makeblock provides this flexibility. " (R14 – on flexibility)

According to respondents view sustaining robot itself through the education of students from elementary school to high-school is crucial. Learning content in education also incrementally changes through the education life of students, so an adaptable robot or robotic construction kit which is used in diverse learning activities is preferred by educators rather than purchasing new robots for each age groups. A robotic system that allows further development be essential to fulfil educator’s goals for different age groups of learners. In line with the robots used in education, an adaptation of programming software to various levels of learners is another critical issue [63]. One respondent state that issue as:

> "There are interface troubles. Some interfaces are very complicated; some faces are very simple. The child says: "I will put the scratch codes, but after I put the codes, I want to do that." That interface will be straightforward, it not improve him. It must be a level between intermediate and very difficult. There should be proposals for

every project directed at the child. We have experienced them. Also, possibilities for programming are limited in general. Robots have limited capacities. You can not reflect the command you gave every time, the algorithm you thought you gave each time to the robot. Because they are not very advanced systems. You can not do a lot of programming on mid-level robots. They give errors, do not get the commands, reset themselves, or they're resetting while you are coding. " (R10 – on adaptability of robots to diverse age groups)

In line with the robot's physical attributes, adaptability of programming software due to different learner levels is regarding robots for education as a unified system with skills required to use computers. To implement and guide doable robotic projects, educators play a vital role in the learning environment. Therefore, an adaptable robotic system which can be used to support educators in terms of designing activities related to variety of skills and subjects become an important issue.

4.3.1.3 Compatibility

Considering robotic system design compatibility is another mentioned category by respondents. The respondents refer compatibility involves two distinct perspectives; firstly, from learning perspective as compatibility of robotic activities to learning environments and secondly as design perspective that concerned about features of a robotic system.

From the learning perspective, application of robotic activities desired to fulfil expectations derived from the school curriculum. Linking robotic project-based activities with school curriculum is preferred by some respondents and seemed to be a compatibility issue between schools and robots for education. Affecting factors about the compatibility of robots in learning environments mainly concerned about, the time required to build robots, supporting educators with academic materials, lesson plans and intra-curricular activities [64]. Commenting on the strength and weaknesses of robots for education one of the respondents said:

"Fundamentally, the curriculum to be applicable. If you can explain the Pythagorean theory by using a robot, that's fine, but, if you cannot, then, it seems as if that robot exceeds its area of use. Or, let me put it this way, if you can show germination in a science class using a robot, that's fine. However, training programs have to be very well structured utilizing robots. Maybe they will be at a higher level because they can not be done in class but rather in tournaments such as First Lego Leauge, sumo, or ping-pong, which its work continues." (R08 - on curriculum related robotic activities)

However, integrating robotic activities as an intra-curricular activity in formal education settings is still a challenging issue for the field of educational robotics. Similar to other technological tools for learning in schools such as computers, tablets and smart boards; robots also require an additional effort for practical use. Lack of well-defined curriculum to integrate robots in formal education made robotic activities inapplicable for the current exam-based assessment system because of the time required for setups and activities for a variety of lessons. So, the educators prefer to join robotic competitions with extra-curricular activity groups of students instead of using robots in classrooms during the lesson hours. To overcome some difficulties faced to integrate robotic applications into formal education, educators may come up with different strategies by choosing familiar programming languages for students [65]. For instance, one respondent said:

> "In the information Technologies Software course, in 5th and 6th grade, we teach Scratch in the coding section. Because we teach Scratch, the student uses the logic of ardunioda, other than that you don't need to explain anything extra. There are only a few extra blocks in the arduino-related parts, we show those and continue with the process. You don't need to explain the editor (program) from scratch or say things like, 'this is what blocks are for,' 'this how you use this.' That's the first step, and we are able to continue right from the second step immediately, so, we don't have to deal with the training of coding again." (R06 – on how to integrate robots into the curriculum)

From the design perspective, it allows for further development of robot by enabling the use of wide range of sensors, body parts, mechanisms which some previous researchers on educational robots referred as third-party components. Integration of third-party components to purchased robotic construction kit or built-in robot for education is not usually supported by many commercially available robots, and that may create barriers for educators to address a wide range of learning activities with robotic projects [66]. For example, one respondent said:

> "If I am going to work with a construction kit, I usually work with the Arduino platform, and I prefer robot kits that support this platform. I usually try to stay away from finished products. On the contrary, I am concentrating on more customizable platforms. Frankly, I don't lean towards finished single-piece products, and besides, it is also important that it is an open source. Its hardware compatibility is also important to me. For example, If I cannot connect the sensor of a different brand; to me, this is a negative aspect. So I would like to use this even if I have the change to change the pin structure of the cabling." (R14- on compatibility)

The comment of the respondent illustrates the importance of compatibility regarding the use of compatible components, open-source documents and customizable platforms for learning activities instead of built-in robotic platforms. Using a combination of various robots or platforms from different brands is a desired feature for the use in learning environments. Freedom of design, standardised connections, open-source documents and an upgradable robotic platform is pointed out as the most suitable robotic platform among others [67], as the respondent put it:

> "This is the most investible product amongst the once you named. I studied mbot with this and bought mbotu. There are many sensor connections on the board, when I get the necessary budget, I can them and develop it further. Apart from this, its mechanical part is a standard mechanical part; it supports Metric4 screw design. I can connect any Metric4 screw or a piece I designed from a 3D printer directly to this because it does not have its own rivet structure. They do not force you to buy their products. Also, they share 3D models of their original parts free of charge. You can extract the same from a 3D printer. For example, you do not need to buy its wheel, or you do not need a gear structure, you can produce that gear from your 3D printer. Another attraction is its compatible with Lego pieces." (R14 – on compatibility issues with other components)

Alongside with preferences on customizable and compatible components such as sensors, 3D printed body parts and mechanisms, compatibility of several programming languages are seemed to be found beneficial for diverse learners with different backgrounds. By considering students existing knowledge, challenges offered from programming software may also suit to educator's goal [68]. Another respondent, when asked about their programming language software preferences, said:

"Generally, all robots come in with their own interfaces. As you know, we use these, but if there are gifted children I show them Arduino, directly. I don't have them do drag and drop programming, instead, I show them the common programming logic, Arduino. I slightly go into C or Python fundament because it is needed. Ultimately, I need to understand the basis of the programme running afore so I can help the child. Other than that, I used the programs own software." (R10 – on programming related skills and issues)

As provided by the statement, respondent adapts learning goals based on students competencies. Since the students may vary regarding knowledge background and skills also programming languages for robotic systems may adapt their difficulty levels to make valuable contributions to students learning [69]. On the following question in the interview as a reason for programming languages preferences, the respondent said that:

"Why did I choose this? We automatically prefer ready-made interfaces because they are easier for children to use and they cause less problems and work in a more stable way anyway. I don't know the set either, it's a new set for me as well, you start with its own interface and its own program. Other than that, why did I prefer arduino? You know how arduino is, it can work with almost any device. So 0:06:12 is an easy interface, you do not have to know so much about synthax. My fundemantal knowlegde is on C and pascal, and in high school I dealth with C and more or less with Java. So, in order to improve them I chose these." (R10 – on preferences on programming interfaces)

Planning and implementing robotic activities require continuous dedication from educators. However, there can be compatibility problems between different robotic systems caused by programming language which affects the performance of the action expected from the robot. As another respondent mentioned, unique programming interfaces designed for robots sometimes may cause compatibility problems with other text-based programming languages [70]. Talking about this issue, a respondent said:

"Now, the biggest problem we experienced was the interface of the robot itself in the overall robot application itself. Or the software to be used with the robot worked best with the programming language C, Piton. It doesn't matter which one you use, the problem occurs when the robot is not compatible with these programming languages.

> Maybe I have used all types of robots but I can confidently say that I haven't seen a single robot that worked with a hundred percent, or even a forty percent compatibility. A problem is bound to occur at some point. I mean the problems between the software and the robot's own physical program or the one that we made for it. What we need to work on is the flexibility of the programs." (R12 – on reliability issues with sensors and programming environments)

Together these results provide valuable insights into adaptability feature of a robotic system for learning environments. Adaptability feature of a robotic system is required to provide flexibility for educational goals of respondents to build skills for students; clarify abstract concepts by making demonstrations and experiments to empower unique benefits attained from robots in learning environments. From the perspective of the respondents, adaptability referred to variety of categories that merged under three sub-themes namely: *modularity*; *adapting to age*; and *compatibility*.

Modularity involves features for robotic systems such as being flexible enough to provide a wide range of robot designs; ease of assembly to provide reusability for another purpose. Respondents also highlighted the importance of modularity to enhance creative thinking for students. Modularity is also related to compatibility issues that addressed under adaptability can be extended as, use of third-party components in various robotic systems, use of different materials for design and supporting educators by providing wide range of application areas between the subjects. Some respondents argued that robotic construction kits provide enough freedom of design regarding components to enhance creative thinking while others thought that robotic construction kits limit the creativity of students and it is more beneficial to build robots from scratch to enhance creative thinking.

Adapting to age is found as a valuable feature for both physical and digital aspects of a robotic system. The overwhelming majority of respondents thought that suitable robotic system for education as a modular system which can be used across all levels in K-12. Considering student age groups, interaction design requirements for physical components are based on the dimensions that are suitable for the use of different age groups with different motor skills. Given adapting to age, physical features of robots are related to safety and usability aspects of design requirements. Digital aspects of robotic systems for adapting to age are based on software complexity and level of difficulty. Since the information given from elementary school to high school is adapting to student's age, the programming language and interface of robotic systems is required to do so to provide acceptable challenges to improve students. Linking robots with the curriculum is another concern of some respondents to increase academic performance of students because most of the robotic activities are extra-curricular activities and attended by only students with a particular interest in robots.

Compatibility is commonly related to curriculum, components and software features of robotic systems. Compatible robot components such as sensors and construction parts are one of the needs of educators to use more than one or more different robotic systems for the learning environment. Specific to robotic construction kits, some respondents mentioned their concerns about the incompatibility of third party components to robotic construction kits in line with the performance issues caused by the use of different programming languages. Majority of the respondents shared their views on their preferences for a robotic system which offers a wide range of design variations while supporting the use of third-party components and other programming languages.

4.3.2 Usability

Usability characteristics of robotic systems are broad, so in the scope of this study mentioned issues based on respondents comments, usability characteristics are examined under three categories namely: *usefulness*, *ease of use*, and *learnability*. Although, there are many intervened statements of respondents which can be related to usability but to relate user statements to usability, gathering under three categories found beneficial to express design requirements for educational robots. The usability section of design requirements may also enlighten issues that underlined by the adaptability section. Afterall, all the mentionings of respondents are somehow interconnected with each other as a part of a system.

4.3.2.1 Usefulness

Usefulness on a subjective basis might not have a constant definition for any human being; it can change due to our emotional state, environmental condition and many other factors at that very moment of using a product or system. In the same way, respondents mentioned about the usability characteristics of robotic systems in various ways. While robotic systems that can adapt to their physical and digital properties according to the pedagogical aim of the educator (including their programming environment) found beneficial and useful. Other factors may also affect the use educational robots in learning environments, such as cost and institutional support [71]. As one respondent stated:

> "It's called usefulness. For it to be better both in terms of effort spent and in terms of costs… When we purchase a material or a product, let's say we bought it for Science class… That's why interfaces can be preferred when they are higher in number or when we can include them in the curriculum. For example, if they have five or seven versions, I would like to choose the one with seven versions to do an event with the children. So instead of one, multiple purposes will create more difference in education." (R03 -on perceived usefulness of robots)

In this case, expectations of the educator are linking robotic activities with the curriculum to provide educational benefits for a variety of lessons. The choice is indicated on modularity to use diverse robot designs and compatibility to use a variety of programming languages to offer a rich learning experience for students. Educators perspective on usefulness is affected by the usability characteristics such as compatibility and modularity as well as external factors such as cost and time. To gain more insights about design requirements for educational robots, when asked about the opinions of the respondent on a robotic construction kit [72], one respondent said:

> "When you see that it is more compatible with Lego and that it can be used in exact compatibility with Lego, you can clearly see that it is more suitable for open sources. For example Arduino can be used in different environments and in different ways, and therefore it is more different. It is more useful for the user in terms of the lesson or the multiple users or maybe becayse it protects the user more." (R12 – on usefulness of mBot)

As a robotic system, offering rich design variations, compatibility with other robotic platforms and third-party components while having an open-source community enables the educator to widen activity area of robotics for students. Thus, opportunities and features offered by the specified robotic construction kit make educator feel like, something positive coming from the providers of the robotic system which is defined as protection, being loved, and sincere from the point of usability. Supporting educators with open-source academic materials and activity guidelines are increasing the quality of the user experience according to some respondents [73]. From this point of view, the relationship between open-source and usefulness of a robotic system is alluded by the same respondent as:

> "These are more in terms of the resource groups…. Because you can use softwares, the more programming languages you know, the more uses you can have for the robot, as you probably agree. The more open sources you find if it's not closed, the more chances for use you have. At least these are my assessments." (R12- on the relationship between usefulness and compatibility)

Preferences highlighted by the respondent are associated with the use environment supported by the adaptability of a robotic system. The more open-source support, programming software compatibility the robotic system offers, it creates more applicable areas in the learning environment for students. Overall satisfaction resulted from the use of the robotic system is based on educator's goals and compatibility of both software and components. In addition to that prediction made by educators upon the use time of a robotic system may cause disappointments that end up with the never using the same robotic system again. Usage time of a robotic system is dependent on its energy consumption and battery life which is constrained by the current state of the technology to execute tasks in a more energy-saving way [74]. By pointing out these issues, disappointment caused by a mismatch between expectations of the educator and the educational robot, one respondent stated that:

> "Now, in the engine, there is the iron component, there is the screw, when you can't get the whole tour right, then the engine does not work properly. And there is the battery. The battery runs out too quickly, which I forgot to mention. For example, in EV3 the battery lasts shorter for some reason; I don't remember how many batteries we used, it was 6 or 9. It didn't even last for half an hour, ran out quickly. The batteries are not cheap after all, it increases the costs and then you leave it somewhere." (R15- on reliability and battery problems of robots)

Battery consumption of the educational robot is seemed to be at high level for the respondent and affected the use time during the robotic activity. The educational robot stays on for half an hour with a full battery which is not enough as understand from the statement. Moreover, replacement of the batteries cost too much to end up the project, so the respondent is dissatisfied by the educational robot and decided to not using it again. User experience provided by the educational robot regardless of its other features is failed to satisfy the respondent because of its low lifetime with batteries. The respondent did not find the educational robot as useful because of the energy consumption with alkaline batteries. However, most of the educational robots include rechargeable lithium-ion batteries which may provide more extended time for usage, but it also requires time to recharge and having additional rechargeable batteries in stock might be costly

4.3.2.2 Ease of Use

The definition and explanations for ease of use differ between respondents. From the perspective of the respondents, statements on the ease of use of educational robots are based on their programming interface, an assembly such as body parts, sensors. In addition, some respondents use the ease of use to refer how easily tasks given to students can be done by using educational robotics [75]. The diversity of functions of educational robotics is also linked with the ease of use by some respondents. Commenting on these issues, one respondent said:

> "… it's easy to use because as I remember it can only perform single tasks. It follows a line and you can choose colours and it carries them and does nothing else. Therefore, it is easier to find a product for a single purpose." (R06 – on minimal design and simple tasks)

According to the view of the respondent when functions that provided from the educational robot is limited with few options to do one task such as, following line and recognising colours seemed to be easy to use. Without offering additional functionalities beyond line following and recognising colours, it perceived as dull and doing only a few tasks. However, there can be possibilities to enrich activities by limiting functions and components of a robotic system, and it can be useful to enhance creative solutions of student. It depends on the educator's imagination to support students with creative projects. Embodiment of robots effects ease of use of educational robots regarding ease of assembly and provide flexibility to allow design variations to support educators [76]. As one respondent said:

> "I used similar kits before but I have not used this particular one. I can see the visual here, to use this kit you mantle, mount the screw; it is easy to use because you don't have to deal with sources and stuff. As I said, I have used similar ones but the problem here is that those parts are too small. The thing with Lego parts is that you spend a lot of time trying to decide which part goes where" (R15 – on ease of use of the consturction parts of robots.)

Assembling robots that have friction-based snapping parts is assumed as much easier to use over using tools such as, screws, nuts and bolts and welding machines for the assembly of robotic components or body parts. Respondent stated that the educational robots which are built by using friction-based snapping parts usually have small parts that cause loss of time to distinguish between parts and their characteristics. Some respondents also mentioned their concerns on fluctuating for finding correct parts which fit each other or serve to their purpose on design as a loss of time during the building phase of the robot. Quite a few commercially available robotic construction kits are providing design manuals for their users to reduce affordances of educators to build robots. For instance, providing design manuals and academic materials such as, activity plans and robotic activitiy curriculums for diverse uses of robots for educators is one of the services that offered by educational robotic manufacturers. Educators may also benefit from open-source platforms that creates oppurtinities to sharing projects on internet from other users of the same robotic construction kit. However, using ready-made academic materials or replicating another one's robotic activity is dependent to educator's choice [77]. Commenting on the ease of use provided by design manuals, one respondet said:

> "It should be easy but not as easy as Lego. We can talk about it in terms of assembling the parts or in terms of installing the kit so we can talk about the set-up. It is not a nice thing to put a thick catalogue in front of the kid and tell him to assemble some things and make a model based on a schema. It must be flexible in terms of difficulty." (R10 – on providing diverse difficulty levels)

According to the statement, building robots through design manuals is perceived as an easy way and not unapproved to conduct robotic activities. Respondent suggested that there is a need for appropriate difficulty level for the ease of use of educational robotics building and setup phase. Likewise, the difficulty level of the programming interface may create barriers for students or can be too easy to provide enough challenge for further improvement on student's programming skills [78]. As one respondent said:

> "…For example there was Adobe Flash, which was used to developed games. It had a difficult language and you had to type this text-based language on a keyboard one by one. When I tried to explain it in class, I could get the attention of maybe 3 students in a class of 20 who were able to understand it. Now we have something called "Scratch", which is amazing or Google has a block infrastructure called "blockly" where you can drag the codes and make it work. We have actually had a breakthrough, now instead of typing the codes on a keyboard, kids can now just drag it and bring them together like a pieces of a puzzle and see how the software works." (R07 – on comparison between text and block based programming interfaces)

With the advancements in the educational technologies which are designed explicitly for non-adult use is maintain student motivation by enabling them to create projects easily without facing technical obstacles. Relying on the respondent's teaching programming to students related experiences, the transformation of text-based programming interfaces to drag and drop block-based programming interfaces seem to have a revolutionary effect in learning environments. Before block-based programming interfaces, respondent was using text-based programming interfaces to let students design their games which implied as challenging issue for the understanding of the computational concepts of text-based programming interfaces in the learning environment [79]. As another respondent referred to ease of use provided by drag and drop based programming interfaces, said:

> "For it to be child user-friendly, it has to be engaging, and shouldn't get stuck in syntax or spelling rules. Children in this generation in the last five years or so want to go for the result right away. Like adults, they want to see the result of what they have done right away and they do not want to get stuck because of a semi colon, if you know what I mean. Therefore, things like drag and paste that exist in Scratch make it easy

> and you can’t teach these kids anything without making it into a game.” (R10 – on ease of use of programming environments)

Discarding syntax-based errors for the use of more natural programming interfaces for students, using drag and drop based programming, supporting educators to provide student motivation in the ways of quick demonstration of designed programme codes. According to respondent, students are impatient to see results of their efforts so, the quick feedback possibility and ease of error correction of using drag and drop based programming reduce affordances of both students and educators. Despite the ease of use provided from drag and drop programming interfaces, raising student interest remain as a challenge to be overcome by the respondent as a gamifying learning experience. Drag and drop programming interfaces promote student motivation by enabling them to see quick feedback from designed behaviours of the robot. Text-based programming interfaces require additional effort from students and educator guidance through robotic activities which may extend the time spent on debugging caused by punctuation errors [80]. As one respondent stated:

> “This is the software part. As far as I understand, it requires a bit of an effort and it’s not something everybody can easily do because everybody has different skills. It requires patience because you can forget a comma or a semi colon. Robots that work with drag and paste mentality are more attractive because people actually want to see the effect of what they have designed in the robot. They do not want to deal with the writing part of the code but still what do they do when there is a whole block of codes? When you drag and paste, you can see the final product easily hence getting rid of a long and arduous method. This is the reason why I prefer it.”(R15 – on both visual appeal and ease of use of programming interfaces)

To address students with different abilities is seemed to be a should as an educational robot feature. Respondent related the likeability of an educational robot with the ease of programming. From the perspective of the respondent, programming on text-based interfaces require patience and skill from students who may not attract each student in the learning environment. Students are motivated when they are provided with features that grant quick feedback on robot’s behaviours instead of spending hours on debugging syntax errors. As mentioned by the majority of the respondents in variety of ways, granting student motivation is an important issue to deal with for the use of educational robots as well as for learning outcomes. Programming physical robots may lead to distinct challenges beside programming on virtual environments. However, respondents are adapted to situation of facing errors from robots during robotic activities which sometimes wanted by some respondents to create additional learning opportunities for students. Learning opportunities for educators may arise from failures but sometimes it may also prevent novice students to attain fundamental skills from the use educational robots. Most of educators regarded algorithmic thinking as one of the fundamental skills for the use of educational robots [81]. For the attainment of such skills, ease of use of robots plays a significant role, as one respondent put it:

> "Here we conduct production-aimed education. That will support these and make interfaces easier. Children won't be scared when they first see it. The interfaces should be easy so that they can learn the algorithm rationale first and then work on it. They can learn new things later. Of course we can go forward in one way or another with robots that do not create any problems but when we have frequent problems, we can't progress easily. There are almost no robots that do not create any problems, we have problems in almost all of them."(R12 – on complexity of programming interfaces)

Providing programming interfaces that have the minimal and straightforward appearance to attract students instead of giving complex and challenging impressions is an essential aspect for the respondent. Giving the impression of ease of use might be a motivating aspect for students to overcome their drawbacks upon robot programming which can be provided by reducing the sophisticated view of the components on the user interface and may provide faster learning of programming concepts. Using physical robots to attain learning outcomes is causing challenges for programming because in real-world environments there can be design based problems robot's performance which may require slight arrangements in programme code such as, mechanisms of the robot, friction between moving parts and so on [82]. As another respondent, commenting on this issue with additional programming interface-based difficulties, said:

> "… and the child has to calculate this: for example, in the tournament the child completes the tasks in her robot on the table successfully but when she goes there,

> even if she applies a bit of extra pressue when pressing on the start button, the robot maybe starts a millisecond late. The child has to go through this because she writes the code taking into account all the possibilities and risks. This is not different from the real life. You can come across different risks in life at any time and it teaches them this. But somethimes we face software-related problems, which we can say are the most challenging ones: the problems with the software interface. It is important for the children to use user-friendly interfaces; also it takes time for them to understand programming and when they also have problems with the interface, it becomes even more difficult.” (R11 – on user error on lack of user-friendly interfaces)

Giving a start to the robot by executing programme code have various options provided by the commercially available robotic construction kit which is used by the respondent. Either programme code can be executed by pressing buttons or giving commands from the programming interface via wireless communication, or it can be executed by a programming code itself by using sensors or other commands depending on the programming skills of the user. However, while showing similarities with some respondent’s comments on this issue, students are preferred to execute the programming code with physical interaction by pressing buttons which may cause misalignment of robot’s starting position and ends with the unwanted outcome. Misalignment caused by pushing buttons is related with the force that have been used by students as well as robot’s overall weight. Because of new context of learning programming with educational robots, students are learning new concepts that are distant to their prior experiences which creates a further challenge for students. To support students for in their new learning context, providing ease of use for physical interfaces also, from the respondent’s statement; user-friendly programming interfaces may reduce the affordances of the educators and students.

4.3.2.3 Learnability and Understandability

Learnability and understandability modalities directly and allusively referred by respondents to address educational robot’s physical components and programming interface. Understandability has a variety of aspects for respondents, using simplified language to define programming concepts to students in the programming interface is crucial to saving from affordances lost during the robotic activity. According to diverse users around the world translations of programming, commands can be confusing and lose meaning when translated into another language [83]. By pointing out this issue, as one respondent said:

> "There is this matter in the interaction interface of the robots, it is similar to how children have a hard time when the interfaces they use have English words. They end up having a hard time using the program, however when using coding softwares Turkish equilavant of words become absurd and while child tries to corelate concepts, his own basis for language is very different from context of English which can cause problems. Alongside words and keywords, what I could want for these interfaces is understandability and usability." (R13 – on software learnability and language-based problems)

Language-based problems are mostly experienced in elementary school level as mentioned by another respondent on elementary school student's abilities on programming; they are novices at reading and writing abilities even in their native language. On the use of programming interface, students use different language than their native one to create programme codes. Thus, for the better understanding of students, translation of the programming terminology to student's native language should be made carefully to not to create false relations about concepts in the student's mind. Without any professional support, the definition of given programming concept by the educator may be irrelevant from the original one or lose meaning. From the viewpoint of the respondent's use of language is an essential aspect for learnability of programming interface of robots. Programming interface complexity by covering icons and texts, is also equally important to teach students efficiently about programming concepts [83]. As one respondent said:

> "People who create these software training programs know software and imagine their audience to be able to conceptualize as people who know topics. This is while for people who don't know software imagining concepts is a really hard task to do, there is a difference in teaching someone with knowledge grounds for a creation and someone who doesn't have any idea about these topics. This is where I think the biggest problem of these training softwares is…"(R11- on learning how to use the software)

Criticism of the respondent has been given to a locally produced robotic construction kit which is currently in development. According to the statement, programming interface should be designed to support users who are unfamiliar and without experience with the concepts of programming. As users, students and educators, programming interfaces for educational robots should have understandable identifications of programming commands which are designed to suit users without an engineering background. Adjusting the intensity of the given information according to user's knowledge level may provide ease of use of programming interface while enabling progressive advancement through learning activities. Easy to learn programming interface is crucial for students and educators to manage robotic activities regarding time. Because of the loss of time generated by the lack of understandability of a programming interface creates barriers to meaningful learning of students as well as educator's motivation. To empower student's understanding of computational thinking concepts and for the transition of the use of educational robots, use of same programming interface which is previously experienced by students is preferred by some respondents [84]. As one respondent said:

> "When we look at Code.org, it gives applied training books to instructors while its' content is free and works online without any need for installation. It also allows the instructor to open his account and track students easily which makes this a successful first step for training. The visual basis of this makes it easy for us during the transfer to robotics. When you have to start working on a completely stranger interface waste of time becomes a concern which is why scratch data interfaces makes more sense for the first step." (R14 – on software and compatibility)

The respondent prefers non-profit educational platforms such as, (https://code.org) that support educators in various ways by providing advantages on the track of student progressions, releasing the burden of installing software and offering learning activities for teaching computational concepts. Transition to use of educational robots benefits from the prior experiences of the students with programming concepts which they have learned earlier by using drag and drop based programming interfaces. Regarding time limitations spared for robotic activities in the school environment, using familiar programming interface parries the adaptation phase of students and saves time. Despite learnability and understandability issues of programming interfaces of educational robots, students and educators may also need time to understand and be able to manipulate physical components of the robots. Understanding how sensors work was a learning-based challenge for students which is mentioned by the respondents. Teaching students about how sensors work and doing projects by using sensors may create additional challenges for students learning [85]. As one respondent put it:

> "It was not such a big problem to find its plus or minus or to see if there are any, we only needed to look loser. At the beginning we have problems; for example, for some two legged sensors we know its plus and minus but with four-legged and five-legged sensora we have to look up from the internet to see which legs are positive and which ones are negative and what the other legs do. In some cases, for example it says it is a heat sensor." (R07 – on learning components)

When compared to building robots from construction kits, building robots from scratch as more challenging for students because designing robots without using ready-made compatible parts require more problem-solving and content knowledge on robotics. The connection of the electronic components such as, sensor pins, requires knowledge about how sensors work and how should be connected through pins accurately to correctly work, which may also require additional research and tutorial watching for the use. Building robots from scratch are offering more learning opportunities but require more affordance to conduct robotic activities. Understandability of sensors and other components by merely touching or examining is not helping novice users about how to use them or connect them. Additional efforts must have done on the internet or another platform of research to access datasheet how to make things right. Some respondents choosing to watch tutorials while others are obtained information of explanatory materials from other resources such as few electronic component providers put datasheets with on-sale components in their web-based sale platforms. Supporting educators with learning materials and provide easy access to another kind of resources such as sensor datasheets is a critical issue because in learning environments they should reflect on the educator's needs according to their goals in learning. To support educators, provided learning materials should be easy to understand and learn both for students and educators [86]. As one respondent commented on this issue, said:

> "As I mentioned, the visuals not being very clear influences them (students) and makes it hard for them to find the right piece. There are times that pieces look a lot like each other and when in the software it doesn't look clear, it makes it confusing and hard for students to identify."(R09 – on provided design manual)

Designing robots through design manual require explicit recognition between components from students. However, representative images of the shown components are sometimes confused because some of them showing similarities regarding appearance. The distinction was made with colours and geometry of the components helps students to locate wanted part within the robotic construction kit but, having too many pieces like puzzles consumes time while searching. Design manuals are stated by the respondent as not having clear comprehension for building robots. Likewise, within the robotic construction kit, some components are commonly confused by the students during the building process. Design manuals which are provided by educational robotics producers are to support educators in their learning activities, however; sometimes it is sometimes desired it is not found beneficial and mentioned by some respondents as limiting student's creativity. Nevertheless, design manuals are beneficial to improvise familiarity for novice users, and they can be remixed with students' ideas on robot design to lead unique solutions. Using robotic construction kits instead of built-in robots have a higher learning curve because they may have numerous tiny parts, connection elements and electronic components to provide freedom to users to allow unique creations [87]. Regarding time spent to attain familiarity on a robotic construction kit, as one respondent said:

> "This is completely related to time spenditure by the student. I had the same problem becayse when I bought my first robotic set, it took me three hours to create the first robot, I didn't know the components. For example, right now if it is not really complicated we can assemble a robot in 45 to 50 minutes, it has become a hand skill, the more you do the more you own the processes. It wasn't a problem with the set we bought…" (R04- on getting familiar with the system)

Some of the respondents linked the learnability and understandability issues of educational robotics with time-spent to get familiar with provided construction parts and electronic components. However, designing an educational robot and expecting adaptation from educators and students or any other users is inappropriate to design user-centred products (Hartson & Pyla, 2012). Respondent's experience with the mentioned educational robot is two (2) years, and they are preferred to design robots from design manuals which are provided by the purchased robot's company. The respondent notes progression as, on the first use of robotic construction kit while it took three (3) hours to build one robot, later on with attained familiarity to mechanisms and others, the building time reduced around two (2) hours. However, to support educators for their use of educational robots, time consideration is a crucial aspect in and out-of-school robotic activities. By covering all aspects that mentioned by the respondents, educational robots that are easy to learn are promoting learning opportunities by reducing the time required for users to adapt and build robots.

4.3.3 Likeability

Along with the goal-oriented use of educational robotics to attain cognitive and meta-cognitive skills, likeability of educational robotics is an important aspect of sustaining the use of educational robots in learning environments by providing aesthetically pleasing designs to address both students and educators. *Likeability* term is used to address attractiveness and visual appeal of an educational robot by considering various aspects such as, colour, shape, size, appealingness of design manuals, and materials that used for the components. From the perspective of the users, likeability has a direct influence on the perceived usability of a product or system which seems crucial for the integration of the technologies such as, educational robotics in learning environments (Sonderegger & Sauer, 2010). Likeability aspects mostly derived from the prior experiences of the respondents and the media shown in the interview. In line with their subjective views on the attractiveness of an educational robot, respondents also remarked the likeability aspects of educational robotics for students too [88]. As one respondent said:

> "By its' appearance I think it could be a set impressive as "LEGO". There are no colors available here, I'm picking on colors again, but it is important for children." (R02 – on likeability regarding colour choice of design)

According to the comment of the respondent on a single coloured robotic construction kit, the physical appearance of the robotic construction kit seemed to be failed to give an impression of a useful educational tool. As a cause for not being a useful learning tool, respondent remarked that customisation of robot's design by students as an essential aspect which may affect the use of colours on components. Students may want to design their robots with their favourite colours or add a non-functional accessory to create aesthetic values on their designs. Due to the respondent, student engagement on customisation or building robots is deeply related to the use of colours and their choice of colours on components. Student's choice of colour and preferences on components within the robotic construction kit are associated with their personal interests and characters [89]. Highlighting the interrelation between student's personal interest and likeability and reflections of these aspects on the student behaviours in a robotic activity, as one respondent put it:

> "It is about habits, one might like wheels and somebody else might like things that cover their head. As these are indivual factors, personal preferences become more important. Even colors can be important, kids might ask from the beginning that they want a piece which is red." (R01 – on likeability aspects of robots)

Selection of materials and collaboration in teams while working on a robotic project, students are making decisions on which parts they want to build based on components attractiveness. Personal interests of students are reflecting their robotic activity as, selecting components with specific colours and features such as mechanism or wheels. Offering colour choices to students seemed like an important aspect to attain student interest in using educational robotics in learning environments. However, colours may be used as an indicator of specific features to create a distinction between components, and usually, robotic construction kits include a limited number of components. So in large groups of students, students who are attached and insisting on the use of one specific colour to build a robot may generate barriers for the educators to provide enough materials for all students.

4.3.3.1 Visual Appeal

Just as how visually appealing products have effects on perceived usability of a product. Additionally, design manuals also evoke emotions of students and educators on the difficulty level of presented robot design. These emotions may create positive starting boost for a robotic activity however it has some drawbacks if the design manual is not transparently communicating with users. Design manuals provide design examples to create robot designs from a scheme which sometimes might deceive students and educators about the difficulties of the robot design. Difficulties faced during the building phase of the robot may lead unwanted outcomes such as, losing students who participated and excited for the robotic activity [90]. Commenting on this issue, one respondent said:

> "I first asked our students what to do since they were bored of making cars. Then I used a source with Lego designs and discussed a design I chose with students to see if they are interested. The students got excited as the appearance was different. They decided to start the project for because of its' interesting appearance, but then those who had a hard time in making it separated from their groups." (R01 –on visual appeal of robot from a design manual)

According to the statement, respondent considered the past robotic activities with students and realised their boredom on building car-like robots then tried to select a different model than before which may seem like a visually appealing robot design for students. From the design manual, (in this case, I do not know if it is hardcopy or digital) robot design attracted students to build the robot and gain competencies that respondent planned to provide. However, the thrill that evokes from the attractive robot design that is offered was not enough to maintain student motivation; it was temporary. Moreover, design directions given from the design manual are not clear and caused students to ignore big picture while building a robot. To maintain student motivation using educational robots in learning environments is mostly dependent on educator's pedagogic approach and role in the robotic activity, at the same time, educational robots may only support educators to realise their ideas. Supporting educators with educational robots contribute to student's learning experience in various ways. As a free to touch a physical artefact in a learning environment, educational robotics open pathways for educators to balance between instruction and fun. Some educators have remarked the fun aspects of robots, and some of them linked the fun aspect of robots with the physical appearance of the robot design [91]. As one respondent put it:

"External design of the robot should be appealing to them, at least I think so since robots that look like cars get students bored. They expect robots to be looking good and be attractive to buy. " (R15-on visual appeal)

By a majority of the respondents, fun aspect of robots keeps students active during robotic activities and prevent the boredom of students by offering ongoing engagement through activity hours. The decision mechanism to purchase educational robotics for students is not based entirely on students view because they are not adults with financial income. However, student view on the purchase or making of an educational robot is vital for their better engagement in robotic activities. Regarding different age groups in education, educational robots which are found visually appealing to students may generate positive effects in learning on different as groups [92], [93]. As one respondent said:

> "I think the face of the robot looks a bit cold, the color versions look much more attractive in terms of use in training. For example, female students usually stay far, a good appearance could raise interest for them as it could seem more sympathic and warm." (R03 – commenting on mBOT)

> "Honeslty, this is the first time I see this robot, similar to how it looks in the photograph it seems like it can attract little children. I think this robot does a good job in attracting and keeping the interest of children. For example you can give mBOT to preschool students or ROBOTIS. What I mean is that I like the approach of introducing software and its' capabilities in this robot, it is possible to start small and develop a basis." (P04 – commenting on Romibo)

Teaching programming to elementary school level students is have unique challenges because they are not familiar with mathematical concepts as other levels do. The complexity of a design system may generate various interaction possibilities. However, students are interacting with educational robots based on the educator's teaching goals and educational robot's flexibility and allowance on the use of components. Robot's morphology is one of the most useful aspects of likeability on first sight, in this case, a social robot which interacts with users differently than others such as, using language and conversation and have a cute fluffy animal-like appearance which also attracts students for further interaction such as, touch. According to the statement, using similar robots in elementary school to aid educators in teaching programming for novice students can be useful, and the appearance of a robot is playing the dominant role to raise student's interest [94]. Commenting on likeability and its effect on the interaction between student and robot, another respondent said:

> "Regarding OZOBOT, it is highly interactive for children because it has visuals. I think young groups make good interactions with this robot but are limited in things they can do. The robot offers color selection and games inside itself, I think it finishes after a while since children have a way of consuming a game." (R02 – on boredom caused by lack of variation and appealingness)

Educational robots with minimalistic appearance such as having a single body, perceived by some of the respondents as having fewer capabilities when compared with robots with complex appearances such as robots with no component casings and exposed wires. While remarked built-in robot found beneficial and appropriate to attract students for programming activities, respondent does not find the built-in robot useful for long-term interaction with students because of its non-customizable and non-flexible components. Respondents generally perceive built-in robots as non-flexible and restrictive for a wide range of robotic activities which are usually preferred to use for inexperienced robot users such as, elementary school level students or below because of the simplicity of tasks and robot design. Adaptation of robot's design to specific age groups all along elementary school to high-school may require changes in robot's physical appearance to address students with different interests. For some respondents, visual appeal of an educational robot plays a vital role to address students in different education levels [95]. As one respondent put it:

> "Designs of the robotic systems are commonly look like too industrial or too cute there is no appearance option between these two. Even when we consider their forms they can give an impression of a toy. Considering robots for education, they can be

> designed in a way to give an impression between toy-like serious designs." (R10 – on physical appereance and programming language preference)

The physical appearance of educational robots also gives clues about which age group it refers for educators. The toy-like appearance of robots is seemed to be appropriate for younger students below high-school level while more machine-like, serious looking educational robots are perceived as more appropriate for high-school level students. According to the statement, respondent exposes their needs by considering student's attraction on robot's physical appearance; there is a need to keep a balance between toy-like and machine-like robot appearance. Adaptation regarding physical aspects of robot design, such as, colour, material, and size affect the likeability of the targeted age-group interest and engagement in robotic activities which highlights the importance of likeability of educational robots for the learning experience.

4.3.4 Maintainability

Maintainability term referred to identify educational robots, maintenance including repairing of robots by providers or users themselves and accommodation of components. Maintainability of educational robots is another crucial aspect for overall robot design while this aspect already provided by the companies, except built-in robots' students, may also show additional effort on their robot design to provide maintainability for their robots, for instance, replacing a low battery during the competition.

Educational robots are used by few educators when we compared to a number of students who interact with them. Therefore, when we consider the use scenarios of students between ages of 7 to 17, it can be unpredictable and if an educational robot is not durable enough for the use of children it may require more maintenance than other products or it can not work at all. Moreover, sending broken robots to technical service may cost time and prevent robotic activities for a considerable time length which is not a wanted situation for most of the respondents because educators always have limited time to conduct such activities [96]. Commenting on the maintainability issues of educational robots, one respondent stated that:

> "Here, child can learn the basics laws of motions (in physics), but this doesn't become a long-term work. Additionally, they use digital which can transfer data and this pump

> up the prices when maintanence is needed while the possibility of them getting broken is high. Since we are using these robots in school, more rigid designs are required and ones that we can fix ourselves." (R14 – on durable and replaceable components)

Because of the high cost of educational robots, most of the respondents are showing additional care and provide additional instruction for students to keep robots secure to extend educational robot's lifetime for other students. Sometimes students can be reckless when interacting with robots and give damage to components so, regarding various harming situations for educational robots in learning environments, producers may provide instructions or make it easy for personal maintenance by the user themselves. Regarding consumer electronics, most of the damaged products are replaced instead of repaired which is also acceptable for educational robot's components, such as, microcontrollers, sensors and other electronically sensitive parts. However, construction parts or body parts of educational robots when damaged or broken may lose their functionality in that case replacement of parts or another solution may be required [97]. As one respondent said:

> "Some problem happens regarding the robot, for example a component gets broken from a simple part of it and when it becomes hard to find it or we lack budget for it, we immidietly change the topic there. Imagine, we change the training because they don't change the robot and we can't find components." (R10 – on changing activity plans according to avaiable components)

Not having additional fabrication potential except low-fidelity prototyping methods in learning environments such as 3D printers and laser cutters, may bring additional challenges for maintainability of the used educational robot. Replacement of body parts of robots can be difficult for educators in a short period because of the time required for shipping from the producers. To solve faced problems during the robotic activities due to broken components, respondent uses a strategy as changing the task given to students by discarding the requirement of using a specific component/s; in this case, the broken was discarded from the use in the robotic activity task for students. The viability of educational robotics components, for instance, body parts from diverse materials, electronics, and connection parts is often stated by the respondents as a locally problematic issue. Besides, robot design that made by students and educators also should be designed by considering maintenance to enable replacement of batteries and making changes on robot design due to faced problems [98]. As one respondent commented on this issue, said:

> "For it to be strong and stable, we tell them that it needs to be in form of a rectangular prisms. Cables need to be organized, they should be gathered in a way that doesn't get caught around and be stabilized in its' place. Batteries need to be replacable, accessible in design, this is something we think about. We pay attention to the remot being directed towards us, it is important in "Lego". We assemble the wheel according to the panel, we use wide wheels, to cover more area in smaller amount of time. We arrange the front wheels in a way that prevents undesired movements." (R02- on the student design of robots and maintainability of designed robots)

According to the statement, just as the designers who thought about the maintainability of a product that is sold on the market, students are designing their robots to allow ease of maintenance and adaptable to changes on the main design. Constraints when designing the robot was given by the respondent to guide students for suitable robot design for the robotic competition. There are many aforementioned challenges of robotic competitions, one of them is the replacement of batteries during the competition the battery level effects the overall performance of the designed robot which may result in unwanted behaviours from the robot. Thus, from the view of the respondent, designing robots to allow ease of assembly and disassembly is important for students to keep in mind for further improvement of robot design and granting success in robotic competitions. The battery is almost most remarked problematic issue for educational robotics, including energy consumption and other issues caused by the high-level energy consumption of robots such as replacement of batteries both rechargeable and non-rechargeable [99]. As another respondent put it:

> "After design phase, usually the problem we face is that robots energy can finish really fast. We are continuously changing battereies, this is the biggest problem, when the battery finishes the work gets half done and become meaningless." (R15 – on replacement problem of batteries)

During the robotic activities, custom designed robot by the collaboration between the respondent and students has high-level energy consumption which can depend on various factors from optimisation of programme code to used motors in the system. However, designing robots from scratch may bring additional challenges for the robotic activity. Unlike well-optimised components for energy consumption of robotic construction kits that serves for direct use of students and educators, students are free to purchase several motors, sensors and microcontrollers from different producers who may bring additional technical challenges while building robots from scratch. For educators with limited time spared to robotic activities building robots from scratch is the long way to reach goals but in long-term, students gain more profound insights and understanding of technical issues of robotics.

4.3.5 Reliability

Reliability term refers to effectiveness on the use by considering technical and functional features of educational robotics that used in learning environments. Educational robots as a relatively new learning tool in learning environments, complexity of robot design may create uncertainty and chaos in robotic activities for educators. The complexity of robot design or designing robots to fulfil tasks in learning environments derives from the mixture of knowledge required from different areas such as, mechanical engineering, computer science, physics and design which is simplified to be appropriate for non-expert users. Students and educators often blame themselves when they are failed to accomplish a goal in their mind by using educational robotics. However, the interaction between the robot and the students is weak regarding providing opportunities for further exploration of robotics without external support from educators or experts from the field of robotics.

Regarding reliability aspects of educational robotics, the effectiveness of educational robots is interrelated with the prior knowledge of the user amongst the disciplines in robotics to design a functional robot. Educational robots that are used below the undergraduate level of education specifically designed to make things easier for the use of inexperienced users. However, they may face various challenges to fulfil their expectations in the light of educator's goals on learning activity or to design a robotic project to provide learning goals. Some of the respondents stated their frustrations on reliability issues about battery when using educational robots [100], [101]. As two different respondents commenting on the same issue, said:

> “While ineracting with the ronot they first write the program. The design of the robot can be reversed or straight according to thus. They sometimes can place the robot reverse and command as if it is straight, which causes them problems sometimes. While programming children might use the robot with a low battery and get a result, the same program can give a really different result with a full battery.” (R02- on mismatch between users input and robots output)

> “Our biggest problem is battery usage, for the battery being usable for one hour, two hours or just a minute makes huge difference. These are problems that are not being optimally addressed and we are having too many problems. For example, in competitions, whenever there is a surge in battery or change of functioning, robot can malfunction and cause problem or do nothing at all.” (R12 – on functional properties of robots)

Errors that have been made while programming such as, putting wrong inputs and outputs in the programming code may cause false expectations on the actions of the robot to do the desired task and may end up with frustrations. Some of the educational robots are not some purchase and directly use end products such as, televisions or computers it is desired to create challenges for learning outcomes that lead students for debugging activities to attain them various experiences on robotics. However, a step by step debugging of programme code or checking the connections and assembly between components is not offered as a strict guideline such as curriculums and improved with experience or by the guidance of more experienced users such as, educators and open-source communities. The performance of the educational robot is also affected by the battery level and may create different outcomes on low and high battery levels as stated by the respondent. Reliability on programme code is related to various factors such as battery level, environment, and physical aspects on robot’s design. Respondent stated the battery-based problems caused to a mismatch between the desired action of the robot and the programming code as a problem and may desire a robot which can act same while the battery is fully depleted. Besides battery-based effects on robot’s behaviour, students may also affect the action of robots while pushing starting buttons and cause small displacements from the starting point [102]. As one respondent said:

> “Robot works really well here, we go there and when their power source gets affected their starting mode gets influenced or it doesn’t start from the line. Even tiniest amount of disturbance can prevent the robot from reaching its’ goal. In the meanwhile, children learn how to deal with these emotions.” (R11 – on executing the robots program)

Students can be hasty and to provide an excellent collaboration between student teams as aforementioned earlier in a student at benefits of educational robots, educators may assign specific roles to students in robotic activities such as starting up the robot’s programme code manually by pressing buttons. Usually starting point of robots that used in learning environments is important because they are not fully autonomous systems to adjust themselves. Student’s one pushing touch on the robot may cause undesired effects on robot’s expected action. Moreover, as educators, respondents are having unexpected outcomes caused by the environmental changes such as, light intensity, while using an educational robot which is tested and approved for the desired action [103]. As one respondent put it:

> “Before students come, you arrange the robots to every bit of it but then during class you face problems, this affects both students and the educator. For example, when I’m working with color sensors the environmental light itself can affect it or reflections.” (R09- on ways of starting programme code and sensor reliability)

Use environment of educational robots is a significant issue to consider because the real-world environment is everchanging and providing a stable laboratory environment for physical robots might demand space and additional cost for most of the learning environments. As new learners, students are not capable of creating advanced programmes as well as educators because advance programming skills may require specific content knowledge on robotics and effort which may not be feasible for most of the educators regarding required time to build skills. Thus, supporting educators on the use of educational robots by providing ease of use on programming interface and offering open-source solutions to commonly faced problems may elevate their skills to create advanced solutions in learning context with less effort on learning advanced programming. Some respondents are using virtual environments to ignore environmental effects on physical robot programming to advance on teaching programming concepts to students by saving time from happening errors and debugging during the robotic activity. However, while using same programme codes in the real-world environment, there can be slight changes in the programming code to adjust robot behaviour to its environment [104]. As one respondent commenting on these issues, said:

> "Children want to see results of the program they have written, but sometimes we tell them its' not possible or the robot doesn't work as expected. For example, in O-bot they ask you to rotate the robot 360 degrees, the kid decides to rotate the robot four times 90degrees in a minute but it doesn't become complete 90 degrees because there can be various complcations. Lookin a these deviations, robot doesn't reach where it should, these can compare to a lot of topics in the real world." (R11 – on test of tasks between virtual vs real world)

Values that have been used in the programme the robot is crucial for students to make calculations or predictions about how the robot is going to behave and act. According to the statement, respondent had some difficulties which are caused by the simulation software and programming language about adjusting values for robot's motor control such as, activation of a motor for the desired period. The conversation of given numeric values to another for motor control is causing non-desired actions for the robot, and the respondent stated that it might because of the not accurate calculation of the software. Assigned values were changing from second to minutes on the used programming software, and it confuses both respondent and students during the robotic activity. In addition, mismatch of the programme code in virtual environment and physical one is not aiding knowledge-based mistakes of the users by providing appropriate feedback or an advice to reconsider the differences between real and virtual world. Programming interface and physical components of robots' act as two different aspects of educational robotics for interaction, making connections between two and provide appropriate feedback to enhance learning experience is remarked as an important issue by respondents. Compatibility of educational robot with different programming languages and components is another aspect for reliable use of educational robots for diverse learning environments [105]. Remarking this issue, as one respondent said:

> "Not every robot is usable for every project, this kind of a robot doesn't exist and its' not expected either. The most repeating problem I have had is that we can have difficulty in relation between the interface and the robots, robots don't really work coordinated with normal programming interfaces..." (R12 –on mismatch between interface and robots)

According to the statement, use of educational robots with different programming interfaces may generate compatibility problems during the robotic activities. Problems that derived from the incompatibility between the owned robot and programming language may negatively affect the flow of the learning activity by causing frustrations and uncertainty for both students and educators. Use of different programming interfaces on robots is crucial to support educators for enabling them to address diverse applications with educational robots and conduct various projects to offer rich learning experiences for students. Also, compatibility of an educational robot may offer freedom of component and appropriate programming interface choice for educators who work on different levels in education. Majority of the statements did not cover the reliability problems in detail; anyhow they might lead to insights on mistakes made or frustrations while using educational robotics based on the user's perspective.

4.3.6 Durability

Durability term refers to the physical durability of overall educational robots and components that been and will be used in learning environments. Educational robots in schools and out of school environments such as, robotic summer schools and workshops are used by numerous students and educators which may wear down the components and construction materials if they are reusable. Thus, alongside with the maintainability aspects such as, maintenance, the durability of educational robots is remarked as an essential aspect for sustaining the robot itself to enable wider audience of students to use them in learning activities. More durable the educational robots may create less demand for maintenance and replacement of components. Commonly electronics which take place in robotic construction kits or components that purchased such as, sensors and motors, perceived as fragile and sensitive products from the viewpoint of the respondents. Some commercially available educational robots are designed by considering the usage scenarios for students who can damage, throw or harm the components and create durable components. However, educators who build robots from scratch may not be able to provide durable components just as commercially available products because most of the components they attained does not have protective casings or durable shells to provide more freedom which are also used by professionals [106]. Commenting on the durability aspects of a commercially available robotic construction kit's durability, one respondent said:

> "What Highschool students do under the name of workshop session in four hours, can turn into much better work in six. When middle school students enjoy using robot components it becomes sensitive. We don't have a problem with our Robotis sets, even when the processor board drops on the ground which it does as the students do throw it, or they decide to fight with the robots on the ground. Which is why I decided to not use it myself, not to have such problems." (R04 – on age based concerns to damage robotic platform)

Students often want to play with their designed educational robots in various ways so, the durability of the components and robot's overall design is become important to endure diverse situations caused by students. Respondent stated that the currently used construction kit is durable enough to endure falling to the ground and play activities of the students but also highlighted that it is risky. The material of the educational robots plays a significant role to imply durability of the product to users. Moreover, for a long-term use of educational robots and their components, durability of parts is essential. However, it may not be possible in learning environments with lots of students who are curious, discovering and experimenting about almost anything, for instance, students may want to see how durable the parts are or for black-box components they might want to see what is inside of the component and open by breaking it. For some respondents, sensitive components such as sensors and other electronics are not durable for students when exposed or provided the freedom of soldering [107]. By considering electronic components and durability, another respondent said:

> "We are really scared of electric circuit components getting harmed because just as we are doing the circuit some elements come off, break or malfunctions. When these happen, we try to cover it for the students at the end of the sessions or during the next

> classes, but the student needs to get the training during that session." (R07 – on the durability of electronic components)

Considering building robots from scratch, students without prior experience with electronic components may not be aware of the sensitivity and fragility of them so, because of the nature of being a child, they can act recklessly without warnings of the educator or experience of their own by damaging or breaking a component. While building robots from scratch or learning electronics students learning by mistakes and those mistakes can be transformed into learning opportunities by educators. So, according to the rarity of the sensors or microcontrollers that have been used, backup supply might be needed which can increase the cost of robotic activities for the institutions. To avoid such instances, educators play a vital role to instruct students on fundamentals of electronics and may demonstrate the commonly faced failures while conducting robotic activities.

4.3.7 Safety

Safety of educational robotics is covering large are when we consider the physical interaction between autonomous robots and humans. However, the term safety which is used in here is considering the use of tools to create high and low fidelity prototypes and possible injuries that may happen based on the use of educational robots.

Robotic construction kits may include a variety of different sized construction parts to offer rich design variation to enable students to build a robot as they want. Construction parts of the kit may assemble in various ways such as, by snapping together or using nuts and bolts or many others. Usually, most of the robotic construction kits do not require additional tools to assemble to provide ease of use in various contexts but sometimes assembled parts may require aiding tools to remove connected parts in avoiding minor injuries [108]. As one respondent said:

> "Since I work with young children I get concerned. Accidents such as swallowing the components doesn't happen but sometimes while separating small pieces from eachother they don't use separator. They use their hand and as their hand are small, their nails get in the middle of the pieces. If the components were slightly larger, these wouldn't happen but these are completely relevant to the students age groups in terms of to what extend they harm themselves." (R04 – on safety concerns

Respondent remarked the safety issues based on minor injuries on the use of robotic construction kit but also stated that after gaining enough experience on how to assemble and disassemble parts of the robot, students are not hurting themselves. Learnability of the robotic construction kit decreases the time required to be familiar with robotic components regarding how parts are connected, and which ones have physical constraints to only fit with specific parts. Hence, the more learnable the educational robot, it may decrease the possible minor injuries caused during the assembly of robot parts during the building phase of the robot. Besides using plug and play based components of some robotic construction kits for learning activities, using electronics which require soldering for the use which may also create possibilities for injuries because of the hot part of the soldering iron [109]. As one respondent put it:

> "Generally, children get concerned on how to connect some pieces and we give the training like soldering the pieces. During the training however, since they don't have any experience with the materials they might burn themselves." (R05 – on safety issues of soldering)

According to statement goal of the respondent it to teach students about how to solder electronic components and basics of wiring. However, as novice users with little or no experience with tools like soldering iron, minor injuries happen. Respondent stated that students are sometimes hesitating to use soldering iron because they are afraid of getting hurt again. Because of safety concerns, most of the robotic construction kits are not using components which require soldering. Alongside with the possibility of hurting themselves, proper ventilation in the learning environment is another thing to consider because of the harmful gases released when soldering components. To attain students with various skills from the use of educational robots respondents following diverse strategies based on their goals and their choice of robotic activity shapes according to their pedagogical approach. Some of them believe that use of real-life tools (screwdriver, wrench, soldering iron and more) is more beneficial for students while some of them focus on programming skills rather than building robots [110]. Commenting on the safety issues considering soldering and other tools to create models, one respondent said:

> "Children don't want to solder electronic components, you can do it with middle school children but since personaly safe envrionments and personal safety measures are not available, it is better not to do it. There was a set which children would learn electronic components and their roles and connect them with magnets. They would teach how to make circuits but students could only make the available designs, developing more projects or researching wouldn't be possible because of the default templates." (R10 – on soldering issues and learning electronics)

Due to the comments of the respondent, let students solder components and use of hazardous materials for their robot designs which are used in industrial settings is not recommended for robotic activities because of the safety concerns. Moreover, in the robotic activity safety precautions are required while students are designing their robotic projects by using various modelling tools these precautions are predominantly dependent on the educator's attitude such as instructing the student on how to use razor cutters and hot glue guns before making models. With sufficient financial support from institutions, educators may provide diverse workshop materials for robotic activities to empower student projects which are also may encourage students for creative solutions for the overall robotic activity.

All in all, according to comments of the respondents, safety issues regarding educational robotics are mostly dependent on student's experience on electronics and design tools with external issues considering learning environment which can be examined under the two folds: firstly, taking safety precautions by considering environment which takes place for the robotic activity and secondly, for the use design tools to create models including surrounding objects around the robot and robot itself. Safety precautions can make for the environment by providing suitable space to work which also includes first-aid equipment. Tools for modelling and soldering can select by educators according to age-groups of students by providing them age-appropriate materials and tools that specially designed for the use of children. The classroom is not seemed to have suitable physical space to work on robotic projects additionally, not corresponding safety considerations of the respondents.

4.4 Discussion of the Findings

4.4.1 Discussions on Benefits of Educational Robots

The vast majority of the results outcome on the benefits of robots are based on PBL robotic activities. PBL approach of using robots provides a suitable ground for the development of 21st-century skills by encapsulating technical challenges that require diverse thinking skills, social interaction, and use of a variety of tools to solve real-life problems (Stephanie Bell, 2010). Since robotic activities are occurring as an indirect transfer of knowledge and mostly based on self-directed learning of students. Exploration of unknown territories of multi-facet knowledge is providing rich learning opportunities for students to develop a variety of skill sets.

Diverse student age groups from kindergarten to the high-school level required to develop different skills than each other. Different levels of education have their constraints based on knowledge and skills due to the developmental needs of the students. Thus, STEM-related robotic activities adjusted by experts to fit specific age-group needs and interests to motivate to continue learning activities by designing robots. Regarding different education levels, from kindergarten to 5th-grade robots used for engaging interest in robotic activities by tangible programming, direct control (remote control) of robots while above 5th grade participating to competitions and developing skills become a priority (Barker, Nugent, Grandgenett, & Adamchuk, 2012). Critical thinking, problem-solving, and communication skills are highly observed acquisitions when using robots for educational purposes.

The diversity of tools to work with robots develop student’s cognitive skills by providing ill-structured real-life problems to solve. These tools may vary from programming languages, real-life assembly tools such as, screwdrivers, bolts, nuts, and digital manufacturing equipment that require 3D modelling skills by using CAD (computer-aided modelling) programmes. Educator’s goals differed from each other according to the type of robot they used for activities. Thus, educators who prefer to build robots from scratch needed more manufacturing equipment when compared to a pre-assembled robot or robotic construction kit user. Moreover, a multidisciplinary aspect of robots requires teamwork in order to overcome multifaceted challenges that offered by programming, mechanical design and task-based analysis of robots. Working on a robotic project requires technical background knowledge as well as social interaction between teammates and other people such as mentors or experts from various fields. Based on the theme of the robotic projects students may need to get in contact with experts in doing interviews and collecting information from diverse sources. Therefore, their social skills develop through interaction with their teammates and other humans who may provide potential help.

Robots provide a variety of tools to work on both design, construction and programme code to students; therefore, offers plentiful opportunities for innovative solutions. Iterative nature of designing robots leads students to creative solutions through trial and error and lessons learned from made mistakes. To overcome the frustration of failure working in teams and social interaction between project members (including mentors, facilitators and experts) may aid self-regulating strategies of students. In the long term, self-control and self-criticism on occurred mistakes help students to improve their self-regulation strategies to move on to project without external motivating factors (Dweck, Walton, & Cohen, 2011). Results based on the benefits of robots, commonly addressed the development of student self-confidence, participation in other subjects and emotional control are also related to the previous studies.

Benefits of robots are widely taken into consideration to aid future career choices of students and for the acquisition of 21st-century skill sets. In the previous studies, student motivation is profoundly affected by the use of robots in the learning activities to attract students to STEM-related career choices or subject as well as to develop self-regulation strategies of students (Leonard et al., 2016; Lye et al., 2013). Also, amongst the three roles of educational robots in a learning context, the robot's role as a learning tool and learning subject is most preferred by educators. However, using robots as a learning subject is more commonly adopted role when compared to using robots to teach subjects or science concepts in Turkey's educational context.

4.4.2 Discussions on Challenges of Using Educational Robots

Challenges of using educational robotics for learning purposes are based on the context of use, stakeholders, and external factors such as affordability of robots, institutional support and politics. Most of the robotic activities with learning outcomes occur as out-of-school programmes, private workshops, and competitions. For the implementation of robots as learning tools in school curriculums, challenges opposed to the design of the educational robotics as a system and stakeholders involved in learning environments. Regarding results related to the challenges of both educators and students. Using robots for learning activities are required time investment for planning activities, design and test of robots, and prepare classes or workshops from educators.

Moreover, educators have some personal challenges because of using relevantly new tool for teaching by adopting alternative instruction strategies when compared to traditional ways of teaching through direct instruction. Personal challenges of educators are matches with the findings of the previous studies that are investigated educator-based challenges (Sullivan & Moriarty, 2009). Training of educators is crucial for the acceptance of robots for learning activities in school settings. Training of educators regarding programming, mechatronics and general knowledge background on robotics field can make them more confident about using robots. Other concerns that matched with the previous studies are based on lack of availability of lesson materials and physical space provided by the school authorities (Mataric et al., 2007).

Also, educators mentioned the student-based challenges as lack of familiarity with robots, lack of design skills, and lack of teamworking abilities in school environments. There are implications found on current difficulties of using robotic construction kits in school environments regarding losing unique parts in the box and creativity limitation caused by the provided lesson materials and design manuals. However, to enable students to design unique robot ideas is related to educator's expertise on robots as well as to provide possible design advice in an open-minded way. Design skills of students are supported by providing design manuals or open-source communities to solve faced problems during the process. Considering the use of Lego Mindstorms in robotic activities, a student who is familiar with Lego parts are more easily adapted to the design process of robots when assembling or disassembling the robot (Strautmann, 2011).

Also, robotic kits may limit student behaviours during the design process and prevent their transformation of ideas into physical artefacts because of the physical constraints of the parts that are contained in the kit. Possibilities to do with construction kit is limited to physical constraints of the designed connectors, gears, beams and other structural elements additionally with the provided compatible sensors and actuators. Building robots from scratch leave the all design decisions to users by allowing the use of a variety of construction materials, manufacturing techniques, and physical and digital tools (Vandevelde & Vanderborght, 2013). However, building robots from scratch requires much more time than designing robots by using construction kits. The complexity of the design is also essential for the interaction of students with the connection modules such as plugging/wiring sensor/actuator input and outputs (Blikstein & Sipitakiat, 2011). The complicated and messy appearance of the micro-computer board caused a bias towards building robots and students afraid to make mistakes while plugging electronics.

Most of the respondent’s robotic projects are worked in student teams with educators acting as mentors or facilitators. Used tools for robotic activities are computers, robot’s programmable micro-computer, construction parts and other electronics such as sensors and actuators. However, some schools may not have enough funding or laboratories to provide one computer and robot for every student; thus, students with the same interests become unable to work together. Previous studies provided solutions to support educators during robotic activities to preserve their role as facilitator or mentor of the project. Distributing students to teams according to their role of interest is crucial to provide the useful division of labour and communication between teammates (Bers et al., 2002). Otherwise, one student dominates the computer (especially mouse and keyboard) and not allow others to work on the programming code or construction materials to build the robot (Hourcade, 2007). Other challenges stated by educators are depended on the external factors such as the availability of low-cost robotic platforms which is also a global challenge for the implementation of robotics in learning settings.

4.4.3 Discussion on Design Requirements of Educational Robots

Extracting design requirements based on the educator's needs is required an overall understanding of the school environment, different age groups of students as users, and other tools that are used in robotic activities. Shared use experiences of educators with different brands of robotic construction kits and toy robots provided a general understanding of the educator's needs from robotic construction kits. In general, school authorities are deciding which robot type to use in extra-curricular robotic activities or for the preparation of robotic competitions. In schools with a small number of budgets, educators prefer to use micro-board sets with a wide range of options to balance the number of the kits with students. Therefore, building robots with micro-boards and sensor kits requires more technical knowledge than other robotic construction kits because non-optimised sensors and actuators can be unreliable even for a simple task like following a line. So, students required to solve more technical problems and design unique mechanisms to externalise their ideas which extends the time required for the robotic activities. Rapidly realising ideas is a critical issue for constructionist learning activities to attain further knowledge through feedback of educator and the physical artefact itself (Stager, 2005).

Educators choose robotic construction kits as a learning tool to provide students with a wide range of design possibilities and practical reasons for designing robots more quickly than building robots from scratch. Moreover, designing robots without ready-made compatible sensors, actuators and structural elements require more tools such as 3D printers, soldering irons, jumper wires and so forth. Thus, building robots from scratch can be more expensive rather than using robotic construction kits. Most school budgets are not high enough to purchase every newly released robot so, educators need robots that can adapt their utilities, size, and complexity according to incremental levels of education also to student age-groups. Age-appropriate design of robots is vital to develop abilities based on physical and cognitive capabilities according to age-group. Also, using one robot which can adapt to diverse age-groups by reducing the complexity of design is preferred by respondents. Resnick et al., (2007) maintained design principles which cover adaptability aspects of robotic construction kits by using low floor, high ceiling, and wide walls analogy to enable novice users to quickly realise ideas while providing further access for experienced users to work on complex projects. Modularity of the system it deemed to be a real need of respondents to provide them flexibility in learning settings. Modularity and flexibility issue is provided by previous studies as an essential design consideration for educational robotic toys (Robins et al., 2010; Zuckerman et al., 2005).

Usability aspects derived from the results are found related to perceived usefulness of the educational robots with different roles, ease of use, understandability of the interfaces and components, and learnability of the system (Bartneck et al., 2009; Hassenzahl, 2001; Yanco, Drury, & Scholtz, 2004). Comparison of different types and roles of robots with each other also provided implications for the factors that affect educator's preferences on educational robotics. While some respondents only prefer using robots as a tool for learning, others welcomed the robot's role as a tutor for teaching language in small age groups. Robots with a variety of construction parts perceived by respondent as flexible robotic construction kits that provide a full range of design variation to use in robotic activities. Pre-assembled robots such as Ozobot and Romibo attributed with limited capabilities for learning in school environments. Being capable of using robots for more than one subject and age-group is commonly referred to as useful. From the perspective of the respondents, usefulness is highly related to the flexibility of using compatible programmes and third-party components as well as the modularity of the robot.

As a learning tool, robots encourage physical interaction between students and tangible learning materials from programmable micro-computers to electronic components. Also, there are other materials that aid learners such as RFID tags and cards act as a communication medium (or act as a semantic representation) (Juarez, Bartneck, & Feijs, 2011). Conceptual understanding of interaction interfaces is crucial to empower learning activities. Design of the system required to provide student's understanding of what things mean in representational forms and how things behave through cause and effect. Moreover, to provide a clear understanding of the physical and digital aspects of the system, student's need to understand the relationship between how things appear and respond (Antle, 2007). However, regarding students from different age groups, their cognitive, perceptual and physical abilities differ; so, designed affordances for the robotic system can have limitations to communicate relationships between digital and physical aspects of the design (Hartson, 2003).

Other design-related aspects that are expressed for educational robots are concerned about both functional and non-functional requirements. Functional requirements are based on the operational capacity of micro-computers, input and output ports, the reliability of the system, and durability of components. Most of the respondent has more experience with Lego Mindstorms. Some respondents criticised Lego Mindstorms by not having enough input and output ports also for its incompatibility with third-party sensors and actuators. Reliability issues are expressed mostly considering the compatibility of purchased robots with third-party components and programming interfaces. Previous studies that are used Lego Mindstorms for rapid prototyping expressed similar issues for limited processing speed and memory and a limited number of input/output ports of sensors and actuators (Bartneck & Hu, 2004). However, Lego Mindstorms is a popular robotic construction kit, a large number of respondents are using Lego Mindstorms in their robotic activities because of ready-made lesson materials and chance to participate in world-wide robotic tournaments. Benefits of the popularity are enabling worldwide users to access open-source resources and community of other users to ask questions. Respondents prefer to use robotic platforms/construction kits that offer prosperous open-source community and resources for the robotic activities. Aesthetics of the robots is found pleasing by respondents mainly on the first impression and affected by colour and form. Likeability aspect of robots by students seemed to be a significant determining factor for the use of respondents. Cute appearance of robots and exciting options are preferred over single tones of colours to address the diverse interests of students. Also, likeability aspects are affected by the personal customisation; people tend to like more personalised products/robots over standard ones (Sonderegger & Sauer, 2010; Syrdal et al., 2007).

Respondents frequently state external factors regarding cost, supporting educators in various ways, and as safety issues. Safety issues related to robots are concerned about the physical safety of students in the learning environment. Robotic construction kits used for learning activities are designed by keeping children use of the product in mind. Hence, except for extreme use scenarios, robotic construction kits do not pose a danger for students under the educator supervision. However, building robots from scratch requires more tools to work with such as soldering iron, craft knife, screwdrivers, hot glue guns and so forth. If precaution is not taken such as ventilation, first aid kits, and so forth students may harm themselves in the short term or long term based on various factors.

CHAPTER 5

5. CONCLUSIONS

This chapter summarises the overall study of the thesis and presents the reflections from the findings to generate a set of design requirements for programmable educational robotics. First, research questions are revisited to provide information about how they are answered at the end of this study. Then, regarding challenges have been faced through the research limitations of the study is discussed. Finally, future implications of the study are presented to provide a better starting point for the future studies.

5.1 Reflections on Findings to Extract Design Requirements

Use of robotic tools in formal and informal learning contexts is a relevantly new trend and offer promises for the development of 21st-century skills. Robotic applications that are suitable for student use, design and learning activities are found beneficial to build future work environment abilities as well as to provide a fundamental understanding of technologies. Robots that are used in learning environments differ regarding preferences of the educators and policymakers based on their benefits for learning of students. There are diverse types of educational robots to aid learning such as language, science concepts, social sciences, robotics, design education and so forth. However, due to availability and cost-related issues of intelligent robots, educators prefer cheaper robotic construction kits or building robots from scratch by gathering components from different providers. Also, a comparison of different types of robots provided valuable information about the perception of educators in different robotic activities, robot types and requirements of the design. For an overall reflection on the findings of the study, conclusions are made by revisiting research questions.

The primary research question is:

- What are the requirements of user and robot interaction to support learning in educational robotic activities from the educator's perspective?

Sub-questions to support the primary research question are:

- In which ways the interaction between the user and the robot can be improved to better support the learning experience? What are the expectations and needs of educators regarding educational robots?

Regarding exploration of diverse robotic activities of the respondents, suggestions and use experiences of diverse users provided broad information for design requirements under functional and non-functional requirements. These requirements are commonly based on respondents' prior experiences with robotic construction kits and shown informative usage videos of different types of educational robots in the study. The literature on designing robotic construction kits and robotic toys for educational purposes provided a suitable ground for the overall investigation on design requirements. Also, understanding of student's interaction with robotic systems regarding age-groups with different needs and requirements on design. According to significant findings of the study, design requirements for educational robots as a tool for learning are concerned about the adaptability of the robots, usability aspects, likeability, maintainability, reliability, durability, and safety considerations of robotic learning tools. These requirements are further expanded as follows:

- *Designing an Adaptable Tool* – Adaptability is based on modularity, compatibility utilities of robotic construction kits that provide suitable use scenarios and constraints for age-appropriate robot designs, programming activities and projects. These features of robots also cover other aspects of the overall system (programming environment, construction parts, and electronic components)
  - *Providing Modularity/Compatibility* – Providing modular construction parts which enable users to create various design variations is crucial to expanding learning activities with one construction kit. Modularity of the physical components have a direct effect on ease of assembly,

reusability of the designed robot, and making improvements on the designed system. Ease of assembly is mainly affected by the connections between the construction parts of the embodiment. These connections can differ based on the design decision such as magnets, friction-based connections, or connecting parts by using traditional fastening elements (bolts, screws, nuts and so forth). Compatibility aspect is to support the use of a wide range of digital and physical tools. Robotic platforms that are compatible with third-party sensors, actuators and electronics as well as with other programming languages expanding the possible project space for the educators. To support educators on highly mentioned cost-related issues designing modular and compatible robotic platforms are a crucial priority for the design.

  - *Adapting to Age* – Corresponding to cognitive, perceptual and motor skills of diverse student age groups with single construction kit is another crucial issue when designing robotic learning tools. Educators in this study are often concerned about not being able to use one adjustable robotic construction kit for different age groups regarding the size of the embodiment elements, input/output connections. Visual representations on programming environment, size of the construction parts of the embodiment, and signifiers that communicates the relationship between connection ports with electronic components can be adjustable on size, and information complexity to address students with different motor skills and perceptual abilities.

- *Designing Easily Learnable Tools* – Learnability of the elements that form robotic construction kits provides natural progress in robotic activities to expand learning domains. Learnability of programming environment can be empowered by identification of user's behaviour during use by an additional system operation that keeps track of the interactions and provides suggestions according to user intentions. Passive helpers for learnability of programming interfaces sometimes unnoticed by users. Robotic construction kits commonly learned by users through demonstrations of necessary applications by trainers of the purchased companies or tutorials. To overcome these difficulties providing visibility for the simple application guides and help desk is crucial. Providing further information within the interface through feedback, the language of the programme, visual representations of programming commands, and testing programming command virtually or physically also significant factors related to learnability. Offering a wide range of language options enable world-wide users to contribute to design improvements as well as to the open-source community for further collaboration between users.

- Supporting users to quickly realise their ideas by combining parts, connecting sensors and actuators or building an embodiment for the robot is related to ease of use of programming interface and physical components. Providing simple interaction for the construction and programming can reduce the cognitive load of the user and further accelerates the adaptation to assembling robots and programming robot tasks. In most school, students learn programming concepts with the aid of internet-based programming games by using drag-and-drop programming blocks specified with basic actions such as, move forward, turn left/right, and so forth (Resnick, 2013). By using computer-based applications students are develop algorithmic thinking skills with programming activities in digital learning environments; thus, gaining familiarity with the programming commands that are similar to control robot movements and actions in real-life. Since students are familiar with the block-based programming commands, using their existing conceptual understanding to increase understandability of programming interfaces is beneficial for both tangible and digital tools for computing. Perception of ease of use by respondents is strongly related to modularity and ease of assembly of the components. Apparent understanding of physical constraints of the parts also plays a vital role for the ease of assembly and to communicate on how parts are fitting together or how far users can manipulate the design.

- *Designing for Likeability* – Likeability aspect of robot design explored by respondent’s comments regarding their experiences with students in robotic activities. Visually appealing robots are attributed to rising interest amongst young students aged between 7 and 15. Providing colourful options for construction parts enable students to personalise their robot design; thus, empower the active engagement of students in robotic activities. Also, customisation of the robot design is found related to likeability and engagement of the students in robotic activities. Visually appealing robots' designs are linked to attracting young students for programming activities to build a fundamental understanding of computing and robotics by respondents. On the other hand, for high school student's likeability of robotic construction kits or pre-assembled robots are from a more functional perspective and rely on the interaction capabilities of the robotic system.

- *Designing a Durable System* – Maintaining or repurchasing different sensors or actuators to build robots can be difficult during school hours if we consider shipping time to school or lack of backup robotic kits. Therefore, durability is considered as a significant concern for educational environments while large numbers of students use the same robotic construction kits or electronic components. Compared to educators, students can be reckless when using electronic products or toy-like parts to construct the robot; hence the physical durability of the components that contains sensitive electronics is crucial to preserve materials for the next activities.

To support educators teaching by using robots in the first place. Robotic construction kits offering a wide range of design options to implement on different subjects; educators believe that they are limited within the constraints of the provided construction parts, mechanisms, sensors and actuators when compared to building robots from scratch by using easily accessible components for lower prices. However, to realise robotic projects from scratch demands more resources regarding time, cognitive and physical effort and sometimes related to the complexity of the robot design requires more financial investment. To implement robots as a learning tool in educational environments, a clear understanding of national curriculum goals and relating robotic activities with the appropriate robotic kits is a crucial issue. Considering the use environment of the robots, designing such systems plays a vital role in addressing major challenging issues. For instance, by providing ease of assembly and disassembly, robotic activities can be made in lecture hours or to use same construction kit with different age groups modularity aspect of design can allow the use of bigger parts, less input/output ports or tangible programming interfaces. Also, compatibility of robot's components with other programming environments and components that are unique to robotic construction kits from different brands can provide freedom for students to create remix projects from different communities of robotic construction kit users. Creating a common ground for educational robots regarding the programming environment and compatible components can empower learning and collaboration among students, educators and other users by making the transfer of knowledge easier through open-source communities.

In the context of education in Turkey, most of the educators are preferred to use DIY robots, micro-controller kits or robotic construction kits with students in order to cover various subject areas with one tool. According to respondents, pre-assembled robots are seemed to be found beneficial for teaching programming concepts for young students who have no experience with robots while DIY robots are found beneficial for all levels in education. Educators prefer DIY robot kits as learning tools over pre-assembled robots because DIY robots can be easily used for various purposes according to educator's goal. Considering all aspects of the challenges that educators faced while using robots as a learning tool in educational settings issues above can be addressed through several design interventions. Table 10 provides some solutions for the significant challenges and needs of the educators in the context of Turkey.

Table 10 - Challenges and Possible Solutions

Need	Requirement	Solution
Affordable tools/robot	Maintainability	Use of low-fidelity prototyping materials such as clay, cardboard, paper
Flexibility to use in various subjects	Modularity and 3rd Party Component Integration	Designing modular system which allows for the use of various components
Adapting tools to student age group	Modularity and Compatibility	Designing parts that allows for changes in size and connection style
Addressing wide range of users	Explorable Components and Understandability	Providing incremental challenges from novice to expert users by increasing complexity of design and programming interface
Likeable tools and robots by students	Visual Appeal and Customisation	Offering wide range of customisation options, designers might allow users to customise their own components and robots
Durable robots throughout K-12 education	Physical Durability and Reusability	Desigining components to endure physical stress and unpredictable behaviours of students. Also, using easily replaceable or repairable components can be another option.

5.2 Limitations of the Study

In the first place, finding respondents that use robots as educators were challenging. Majority of the educators work in schools are not able to meet for the interview except for holidays because of heavy work-load. Regarding finding contacts and arranging interview meetings with the respondents from different schools took between six-seven months. Only half of the contacted educators positively returned while some of them did not even give any response to invitations. Interviewed educators are not selected according to their expertise or occupation in the K-12 level of education. Educators who teach elementary, middle, and high schoolers are contacted randomly through phone calls to school managers. It may take more time or decrease the number of respondents if the specific level of education is addressed in the study because the use of robots by educators is not well established in Turkey.

Secondly, for the comparison part of robots in the interview made by using video footages and printouts of programming interfaces to criticise their design and possible use scenarios in learning environments. Using videos and printouts of robots instead of real ones also remained limited to provide enough information about robots. Some respondents had hard times understanding the real capabilities of the robots also there is a possibility that they might imagine non-existing additional features on robots. Using physical robots for the comparison would be more beneficial to stimulate respondents by providing the experience of robots in the first hand. However, it was not possible to purchase four different educational robots personally without external financial support.

Finally, the study was concerned about understanding the use of robots from educator's perspective by excluding student users. Respondents evaluated robotic systems from the perspective of the student as educators which can be misleading. Educators who work in private schools are more occupied and have more workload because the use of robots occurs as extra-curricular activities; thus, requires educators to devote their free time after work. Majority of the respondents are educators from private schools this can also be a limitation of the study. Since, a private school can adopt additional curriculums and learning activities, exploring how robots can implement into schools from governmental school educators can maintain different needs and requirements for robots.

5.3 Future Implications of the Study

This study was concerned about exploring various factors which might support by design of educational robots in a learning context. Media used in the interviews are limited to provide real experience of robots. Also, the context of learning with robots usually occurs in the classroom or out of school settings and actual use of perceived robots by respondents may create additional challenges in a real context. Using physical robots with educators will allow them to experience in the first hand which can maintain more reliable outcomes for the design requirements. Also, using different types of robots through the same tasks with incremental difficulties may provide valuable information about the actual use of robots from an educator's perspective.

Respondents in the study are commented about how students use robots, how students overcome challenges, and how robots can be designed to address student needs. However, information provided by the educators can be unreliable and biased. For the future studies, educators and students can be involved together in the real context of robotic activities for the design-based evaluation of different robotic products. Involving students in further studies can provide a more general understanding of how products can be designed for the joint use of both adult and child users. Investigating collaboration within the robotic activities can be another option, robotic products are commonly used for collaborative tasks, and students collaborate when designing robots for a common goal. Design related issues can be examined through observations or testing of prototypes to support collaboration between users on the same product.

There is a tendency to train educators for the practical use of robots in educational settings by school authorities and other private companies. Regarding educator's training on robots, workshops aimed to make educators more comfortable and confident while using robots. Simultaneously design based evaluations of the robots might examine through qualitative research methods by design researchers. Multidisciplinary nature of robotics requires work from different fields, and designers can remain insufficient to think about all aspects of the educational robotics individually. Therefore, when designing a study to extract design requirements in collaboration with other disciplines such as developmental psychology, education, and engineering through a design process can be crucial as well as beneficial. Regarding education, design and social aspects, educational robotics field offering multi-facet challenges and there are numerous issues to explore

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ABBREVETIONS

HRI: Human-robot interaction

cHRI: Child-robot interaction

HCI: Human-computer interaction

AI: Artificial intelligence

PR: Personal robots

PSR: Professional service robots

IR: Industrial Robots

UCV: Uncrewed vehicles

STEM: Science, technology, engineering, mathemetics

STEAM: Science, technology, engineering, arts, mathematics

ER4STEM: Educational robotics for STEM education

APPENDIX A

[001] “Eğitimsel faydaları dediğim gibi 21.yüzyıl becerilerinin geliştirilmesi noktasında önemli bir yerde görüyorum ben bunu yani bu becerileri geliştirmek bizim asıl amacımız olmalı, çünkü gelecek bundan ibaret olacak hatta bugün bile bu ihtiyaçlara bu becerilere ihtiyaç duyuyoruz… analitik düşünebilen ve sorun çözebilen insanlar yetiştirmek açısından bunu önemli bir yerde görüyorum. Ayrıca psiko motor becerilerinin geliştirilmesinde de önemli bir yer ediniyor, çünkü [öğrencilerin, robotun] parçalarını takıp dengeye alıp sıkıştırmaları gerekiyor ve burada da yine tasarım gücü önemli. Biz genelde hazır mekanik parçalar kullanmayız, 3 boyutlu yazıcıdan kendimiz çıkartıyoruz. Bunların çoğunu öğrencilerimiz kendileri tasarlıyor, bir bölümünü de biz ekip olarak kendimiz onlara sunuyoruz”

[002] “Robotlar yardımıyla aynen bir hesap makinasını kullanırken nasıl bir rahatlık varsa belli görevlerin robotlara yükleniyor olması öğrencilerin daha yaratıcı faaliyetlerde zihinlerini kullanmalarını kolaylaştırır. Bu açıdan sınıf içerisinde tamamen bilişsel bir faaliyete yoğunlaşmış bir beyin artık sosyal bir faaliyete ve aynı zamanda yaratıcılığa yönelik bir faaliyete de yoğunlaşacak hale gelir. Çünkü Robot onun yerine belli sıradan yapılması gereken fakat zihni yorabilecek işleri üstlenmiş olur. Bunu hesap makinası kullanımıyla özdeşleştirebiliriz. Hesap makinası nasıl bize bir grafik çiziminde yardımcı oluyorsa nasıl belirli istatistik hesaplarını hızlı yapmamızı sağlıyorsa bundan kazanılan zamanı öğrenciler öğretmenlerin yönlendirmesiyle daha üst seviye becerileri geliştirmek için kullanabilirler.”

[003] Bence çocuklarda kalıcı öğrenmeyi daha çok sağlıyor ve ben mesela hep öyle düşünüyorum özellikle arduinoyu kullanırken elektrik var yok sistemini yani bir sıfır bir sistemini kullanarak çocuklardaki ileride görecekleri Fen ve Teknoloji ve Matematik dersindeki elektronik kısımlarını daha iyi anlayacaklarını düşünüyorum. Bunula Dirençin ne olduğunu görebiliyorlar hani evet direncin nasıl bir formüle edilip ortaya çıktığını bilemiyorlar ama direncin akıma karşı koymak olduğunun farkındalar bir sistemin çalışabilmesi için bir enerjiye bu enerjinin de elektrik enerjisi olduğunun farkına varıyorlar”

[004] “Sadece iki motoru takıp da bir robotu yürür hale getirmek bile bir iş sonuçta parçaları doğru birleştirmesi lazım motoru doğru yere takması lazım bunların her birini yapamadığında çocuk hatayı görüp problemi önce tespit edip sonra çözmeye çalışıyor. Birinci olarak problem çözme becerisi, ikinicisi dikkat yoğunlaşması. günümüzdeki çocukların çoğunda dikkat yoğunlaşmasıyla ilgili sorunlar olduğu söylenirken … Ben 2 saat bir çocuğun bir robotun üzerine yoğunlaştığını gözlemleyebiliyorum. Dikkati toplama özelliğini geliştiriyor, problem çözme becerisini geliştiriyor, algıyı geliştiriyor hem görsel(estetiksel) algıyı hem işitsel algıyı geliştiriyor”

[005] “sayısal zeka olarak gelişimine katkısı var o kesin… ikincisi de algoritma geliştirme açısından faydası var. Üçüncüsüde tasavvur edemediği (abstract concepts), hayalini kuramadığı şeylerin gerçekleştiğini görebilme hissi insanlara her zaman bir zevk vermiştir. Bu açıdan öğrencilerde bir sonraki aşamada neler yapabilirim sorgusunu sorgulayabildiği için gelişimi biraz daha hızlı oluyor. Yani çocuklar açısından 4 yılda geliştirebileceğiniz bir yeteneği bir bakıyorsunuz ki 1 yılda geliştirebiliyorsunuz.”

[006] “Farklı zeka yönlerini kullandığı için zeka gelişimini artırıyor fiziksel olarak, dokunarak bir şeyler yaptığı için. … ne kadar çok dokunuyorsak o kadar hızlı öğreniriz ki zaten küçük yaş grubu mutlaka dokunmak istiyor deneyimlemek istiyor, deneyimlemek de geliştiriyor. Robot motor yeteneklerini geliştirdiği gibi entelektüel olarak da çocuğu geliştiriyor. Motor yeteneklerini hesaplamalı tasarımlı bir alanda kullanıyor çocuk”

“Hani bu zaten bu bir süreç başlangıçta bir şey bilmeden geliyor çocuk ama sonrasında bakıyorsunuz artık problem çözme becerileri geliştiğinden hani el şeylerinin becerilerinin de geliştiğini de çok rahat hissedebiliyorum yani hani dönem sonuna baktığımızda ciddi bir gelişim gösteriyor”

[007] “zihinsel olarak düşünmenin hayatın pek çok yerinde çok boyutlu düşünmeye gittiğini düşünüyorum. Yani bir sürü değişken var bir sürü parça var. Onları birleştirerek bir şeyler yapacak. Bir şey koyacak ortaya. Her şeyden önce kendi özgüveni artacak. Bir şey yaptığı zaman çok mutlu oluyor. Hareket ettiği zaman, istediğini yaptığı zaman hem özgüveni yerine geliyor hem de ince kasları (fine motor skills) çok gelişmiş oluyor. Motor becerisi artmış oluyor. Bunlar da on-iki, on-üç yaşındaki çocuklar için bence hoş tecrübeler diye düşünüyorum”

[008] “Öğrencilere sağladığı faydalar bir kere çocuklar da özgüven gelişiyor. Yani bir şeyi orda yapıp çalıştığını gördüğü zaman çocuğun özgüveni gelişiyor mesela ben çocukken işte televizyonda görüyorsunuz işte o filimler de falan cihazlar nasıl gidiyor geliyor en ufak fikrimiz yok merak ediyorsun çözemiyorsunuz ama şimdi çocuk orada bir ışığı yaktığı zaman o ona yetiyor bununla beraber Fen dersinde öğrendiği sayılar ile ilgili veya elektrik ile ilgili öğrendiği konuyu tekrar etmiş oluyor veya işte demin söylediğim gibi matematik de olan konuları tekrar etmiş oluyor onların uygulama imkanı olmuş oluyor veya hayal kuruyor yeni şeyler keşfetmek için hayal kuruyor onları sunuyor birbirleri ile yarış içerisine giriyorlar”

[009] “… Sebep-sonuç ilişkisini gözetleyebiliyor diğer seçenekleri görebiliyor… bu güzel bir şey. Tek başına yapmıyor, yetersiz kalıyor bir takım çalışmasının içine giriyor sosyal davranışları değişiyor, gelişiyor. okul zamanı ile sınırlanamayan bir süreçte bunlar okul zamanı dışındaki serbest zamanlarını verimli bir şekilde değerlendiriyor tanıdığı gördüğü bildiği farklı sistemlerin daha

değişik kullanılabilir olduğunu görüyor bunlar onun biraz daha STEM etkinlikleri dediğimiz size teknoloji, mühendislik, matematik alanlarına yakınlaşmasının ve bunun sonucunda da iyi bir noktaya gelmesini sağlıyor.”

[010] “ben robotu verip atıyorum yanına da programı verip atıyorum bütün desteği yapıp çocuğun sadece onları bir araya getirmesi de değil. Rehberlik edip rehberliğiniz dışında çocuğun kendisinin bazı şeyleri öğrenmesi lazım. Çözmesi gerek bunları yaptırdığınız zaman çok faydalı bir şekilde problem çözme mantığı(skill), araştırma mantığı (skill), ve en sonunda da üretim mantığı kavramış oluyor. … Araştırmadan da sonrasında girişimcilik yönleri de artıyor. Belli bir şekilde çözemedikleri zaman ya robotun kendi firmasındaki elemanlarla veya bunu bilen başka insanlarla birebir iletişime geçebiliyor … birisinden bir bilgi alacakları zaman nasıl alacaklarını bilebiliyorlar.”

[011] “Robotun sadece masada belli görevleri yapması bekleniyor ama diğer tarafta proje geliştiriyor çocuk o projenin gelişim sürecini iyi tanıyor böyle bu yaşta bir projeyi yönetmek, başlatmak araştırma, bölme yapmak işte etik bir takım ilkeler doğrultusunda ilerlemek bilgiye ulaşmak doğru bilgiyi seçmek vs. … başlarken amacımız robotla programlama yapmasıydı. Öğrencinin çok daha farklı kazanımları olduğun gördük. Heyecanını yenmesi… o yenilgi duygusuyla baş etmesini öğrenmesi gibi…”

[012] “…atıyorum yanlış parça takmış o arada/ sabır konusunda çok hiper-aktif olan çocuklarda bunu bile aştık yani şu an. Mesela parçalayıp atabilir yani yanlış yaptığı için. Hayır diyor bulacağım yanlışı / hani o sabrı göstermesi bile bence karakter olarak gelişimini de etkileyen bir şey. Ben diyor burada yanlış yapmışım, bunu sökeceğim, takacağım. Hiç arıza çıkarmıyor yani o konuda kendi işini kendisi hallediyor”

[013] “Yani dersi eğlenceli hale getiriyor. Eğlenirse öğrenir çocuk derse katılır. Daha aktif olur. Öğretmen de kendi enerjisini çocuğu derse çekerek harcamaz. Ordaki konuyu anlatıma ya da oradaki konunun çocukta kalıcı olması üzerine kendi enerjisini harcar. Ama diğer türlü öğretmen merkezli anlayışlar ile gittiğinizde bu sefer sınıf atmosferi okul atmosferi veya o sürecin belirtilmesiyle ilgili sıkıntılar yaşıyoruz. Ama bu tip uygulamalar yaptığınız zaman çocuk keyif aldığı için zaten öğrenci ilgileniyor ve öğretmen konunun önemli kısmına daha çok kafayı yoruyor.”

[014] “özgüven açısından hakikaten çok önemli … akademik başarısı yüksek olmayan bir çocuk robotta kendini bulup bir anda herkese yol göstermeye başlayan bir çocuk oluyor ve etrafına topluyor… Kişilik olarak katkısı o anlamda özgüven, mutlu oluyor. Hocam neden iki saat diyor bu ders? Haftada mesela bizi diyor şu dersten alabilirsiniz tekrar devam etsek gibi falan/ hem keyif aldığı hem

de bir ders yani bir dersten bu kadar keyif alması onun da hoşuna gidiyor yani keşke diyor hep böyle olsa”

[015] “Fizik, Kimya, Biyoloji dallarındaki derslerde yapacakları içerikleri öğretmenlere belirleyip bizde onlara uygun bazı modeller ortaya koyup onları kendilerinin bitirmesini bekledik. Genelde proje bazında yaptık. … Süreçte hem derslerin içeriklerini onların amaçlarını kazanımlarını aldılar ve o kazanımları aldıktan sonra kendileri de zevkli bir şekilde bir ürün elde ettiler. Buradaki öğrencilerden gelen en büyük artı daha isteyerek daha zevkli yaptılar. Bir ders gibi olmadığı için daha çok bir eğlence gibi gördükleri için eğlenerek daha zevkli bir şekilde dersi öğrenmiş oldular”

[016] “Bu birazda su damlası misali çocuklar kendisinde olumlu bir gelişme gördüğü zaman da diğerleri de ondan etkilenerek olumlu görüşmeyi veya olumlu gelişmenin içerisine dahil oluyor yoksa korktu mu hepsi korkuyor ama yapabilir olduğunu gördüğünde birçok şeye inandırıyorsunuz. Bir insanı da bir konuya inandırdığınız zamanda onu şekillendirmek daha kolay hale geliyor”

[017] “Ben daha çok gerçek hayattan örneklerle dersi yaptım. … devrelerin kutusunu açıp gösterdiğim zaman çocuklar ilk başta korktular, ne yapacağız falan dediler. Aslında orada çocuklara ben bir kaç çeşit sensör gösterdim. Işık sensörü arabalardaki far olayı, ısı sensörü otomatik çalışan klima sistemlerini düşündüm sıcaklık arttıkça hava üflemeye başlıyor. Veya işte joistikte bildiğimiz işte playstation kolundaki malzeme aynı aslında mantık olarak aynı. Bunları düşündükçe çocuklar ve gerçek hayatta bildiklerinden dolayı … biz buna benzer bir çalışma yapacağız dediğimizde çocuklar için … en büyük şey motive edici şey oluyor”

[018] “Öğrencilerde çok şey keşfedebiliyorlar öğrencilerin keşfettikleri şeylere de açık olması lazım yani çok aşırı didaktik bir tarz değil de biraz daha böyle yoldaş gibi arkadaş gibi olması daha uygun olur. Çünkü neticede çok parça birleştirmede karmaşık bir iş yapılmıyor burada bir otoriteye bilgi otoritesine çok gerek yok. Bir nevi Lego parçaları öğretmen ve öğrenciyi eşitliyor diyebilirim* Daha böyle alt seviyede parçalar o açıdan o an öğrencinin aklına daha iyi bir fikir gelebilir buna açık olmak lazım ve bunun paylaşımını desteklemek gerekiyor. Her yeni fikrin bir şekilde herkese anlayışla sunulması gerekiyor. Öğretmenin o anlamda bir bütünleştirici güç olması lazım.”

[019] “Ben robota araç gözüyle bakıyorum… eğitimde kullandığımız araçlara bakarsak; görsel araçlar var bu görsel araçlar genellikle iki boyutlu olabiliyor 3 Boyutlu olabiliyor, tahta bir görsel araç yazıyorsunuz görsel araç, televizyon bir görsel araç görüntü gösterebiliyorsunuz yada 3 boyutlu bir model mesela bir iskelet modeli görsel bir araç bunların hepsinden daha fazlası bence robotik etkinlik çünkü neden fonksiyon var üzerinde. Fen bilimlerinde müfredatı var deney aracı olarak kullanabiliyor çocuklar

programlayabiliyor. Kendisi yapıyor sonucunu görüyor. Eğitimde yaparak yaşayarak şu dönemde eğitimdeki en önemli anahtar kelime… Diğer bütün araçlarda çocuğa biz ya izletiyoruz ya dinlettiriyoruz ama bunu çocuk deneyimliyor burada en önemli şey deneyimlemek diye düşünüyorum…"

[020] "Eğitim sürecinde robotları kullanmamızın amaçları çok farklı değil normalde bizim müfredatlarımız da bulunan derslerin işlenmesi ve derslerdeki yapılan herhangi bir dersin kazanımlarının bir şekilde görsel olarak elle tutulur şekilde öğrencileri gösterilmesi çünkü soyut olan şeyleri öğrencilerin anlaması çok daha zor biz bunları somut olarak robotla birleştirdiğimiz zaman ne bileyim bir yerden bir şeyin alınıp götürüp konulmasını çocukla somut olarak robotla yaptırdığımız zaman daha etkili yani oradaki yazılan teorikteki olan şeyleri pratiğe dökmekte çok kullanıyoruz biz bunları bu da bize çok faydalı oluyor eğitimde"

[021] "Bahsettiğimiz gibi çocuk bireysel çalışıyor birebir çalışıyor yani kendi yaratıcılığını direk bir nesneye aktarıyor, ikinci olarak ekip çalışması yapıyorsa ekip ile çalışmayı öğreniyor. Üçüncü olarak birden fazla zeka yönüne hitap ediyor aynen bahsettiğimiz gibi multidisipliner çalışıyor e bunlar çocuğu geliştiriyor ve eğitime de katkısı oluyor dördüncü olarak eğitim ortamının böyle işte sırada masada oturup sonuçta bunların hepsi robotla sağlanabiliyor ha eğitim ortamını sadece böyle masa, sıra, tahta, sandalye işte sınıftan çıkartıyor sonuçta robot denilen al bir tane drone gibi tasarlansın ve sokakta havada uçurursun veya işte denizaltı kullanabilirsin anlatabiliyor muyum eğitim ortamını çeşitlendiriyorsun sınıf olmuyor eğitim ortamı kendin bir platform tasarlıyorsun sonuçta tasarım var sonuçta çocuk üretiyor"

[022] "AutoDesk firmasının yapmış olduğu bir şey var yazılım var TinkerCad çocuklar için yapılmış olan bir versiyon, tek yapman gereken kare üçgen yada daire yada farklı aklına gelebilecek bütün şekiller var bunları keserek biçerek ve birleştirerek ve en sonunda bunları bütün hale getirerek bir tasarım oluşturuyorsun ve aslında orada geometrik şekillerin üç boyutlu şekilde nasıl görüleceğini görmüş oluyorsun. Aslında burada biz robot yapıyoruz ama eğitim tarafında baktığın zaman geometri yapıyoruz. İşte atıyorum sana sensör diyorum sensör tarafında bitki yetiştirmek için şu şu sensörleri aldığın zaman ortam sıcaklığını ışığını falan ayarlıyorsun Fen'e kattın, Sosyal Bilimlere geçiyorsun bir kuraklık ile ilgili bir konu var daha sonra bu alana katıyorsun daha sonra sanata geçiyorsun sanatta bir çizim yaptırabilirsin bunu robotlarla yaptırabilirsin sanat alanına da girebilirsin yani kadar çok alana teknolojiyi entegre edebilirsin ki yani bunun sonu yok eğitim alanında her yere katılabilir diye düşünüyorum"

[023] "Pahalı! Daha ucuzlamalı bu anlamda. Daha çok işte erişebilmek anlamında özel okullardaki öğrenciler bunlara erişme açısından daha uygun olabilir ama her gruba hitap etmeniz lazım bu anlamda böyle bir sorun oldu. Süre anlamında ise Milli Eğitimin bir müfredatı var, müfredatta da vermemiz gereken dersler var. Robot kulübüne ayrılan sürede bunu da düşünmemiz gerekiyor. Belki bu dersleri okulların açılmasından öncesine veya sonrasına ya da hafta sonuna koyabiliyoruz.

Doğal olarak da yeterli gelmeyebiliyor. Eğitim programları da daha esnek çerçevelerde hazırlanabilmeli daha ucuz olmalı okullar alabilsin”

[024] “Örneğin 24 öğrenciniz varsa bir sınıfta 24 adet kit olmak zorunda iş yapabilmemiz için yani 2 öğrenciye bir tane koyalım falan vs. yok bir de her öğrenciye okuldaki tüm öğrencilere aldırmak istersek maliyetler inanılmaz yüksek çıkıyor veliye bunu aldırabilmek için de ciddi şekilde kısıntı yapmak gerekiyor paketin içeriğinden buda bizim işimize gelmiyor dolayısıyla sınıfın olsun ama tam olsun mantığındayım”

[025] “Şu sıkıntı çıkabiliyor öğrenciler açısından baktığımızda hani gruplar her sınıfın 3 tane var ve sınıfların ortalama 18 kişi olduğunu düşünürsek bir grupta 6 öğrenci oluyor hani kimi tamamen ilgilenirken kimi bir şey yapmıyor ayrı durmayı sadece bakmayı tercih edebiliyor robota dokunmadan geçirilen süreçleri oluyor bazı öğrencilerin hani bunu yaşadık mesela robotla etkileşime girmeyen öğrenciler oluyor”

[026] “Öğretmen gözünden bakarsanız iş biraz zora biniyor çünkü tasarlamak için burda öğretmene ekstra zaman gerekecektir. Tasarım becerisi öğretmenin bir nevi robotların eğitimdeki faydasını da etkiler bu açıdan çok büyük tasarım becerisi yoksa öğretmenin hazır tasarımlara ihtiyacı vardır o açıdan döküman oluşturulması gerekecektir. Eğitimdeki faydasını arttırabilmek adına öğretmenin çok desteklenmesi gerekebilir. Ya da bu işin doğası gereği bir öğretmen adına bir ödül mekanizması konması gerekir ki öğretmen yaratıcılıkla ilgili bir eylemi daha motive olacak şekilde yerine getirsin.”

[027] “Örnek model bulamıyoruz. Mesela diyorum engellilere yönelik renk okuma ile ilgili bir örnek var mı? Türkiye’de bakıyorsun yok. Yurtdışı kaynaklarda Japonca anlatmış adam mesela Japonca videolar izledim. Ben Japonca bilmiyorum ama adamlar orada bir şeyler yapınca ha bu olabilir şu olabilir diye deneme yanılma yöntemiyle yaptık. Bir iki kere böyle kablo yandı… sensörler düzgün okumuyor düzgün okumayınca kime danışacağını bilmiyorsun… Yani ürün satılıyor ama danışabileceğin kimse yok sorunlar o danışma eksikliği var”

[028] “robot işi veya elektronik devre işi yapılacaksa öğretmenlerin gerçekten eğitilmesi lazım ve öğretmenlerin de kendi de şunu farkında olmaları lazım, çocukla beraber ben de nasıl bu işin içinde olurum bu çocuk nasıl içselleştirir bu işi. Çünkü çocuklara var erişmek için öğretmenin çocuklardan çok daha hevesli olması lazım ki devamlı çocuklara yeni bir bilgi aşılasın çocukları, devamlı motive etsin, çocukların merakını artırsın. Motivasyon bu iş için gerekli motivasyon öğrenciyi motive etmek öğretmenin bu konuda kendini yeterli hissedip çocuklara yeterli verim istedikleri cevapları verip onları tatmin edebilirim, onları yönlendirebilirim, onlara farklı fikirler düşünmelerini sağlayabilirim olay işte orası şey herhangi bir şekilde maddi bir şeyle karşılayamazsınız bu tamamen öz insanın içinden gelen öğretmenin içinden gelen bir durum bu”

[029] "… Öğretmenler en çok bize direnç koyan kişiler ve Bilgisayar Öğretmenleri daha doğrusu bunun sebebi de çünkü kendilerini yıllardır bu şekilde Word, Excel bu tarz programları kullanarak kendini alıştırdığı için zaten biliyor… yeni bir şey öğrenmeye açık değil. Çünkü yeni bir şey öğrenmesi için her hafta derse gitmeden önce o dersi çalışıp o dersin planlamasını yapıp çocuklara aktarabilmesi lazım. Bunu da öğrenebilirse aktarabilir, öğretmen için kendine çok fazla yük görüyor. Bunların aşılması gerektiğini düşünüyorum tabi burada en büyük set bizim önümüzde öğretmen. Sonuçta öğretmen öğrenmezse öğrenci hiç bir zaman öğrenmez. Öğretmen öğrenciyi yönlendirmeli ki öğrenci farklı noktalara gelebilmeli diye düşünüyorum

[030] "Birincisi en basiti yetişmiş öğretmen bu konu ciddi bir problem bu işi genelde Bilişim Teknolojileri Öğretmeni yapar, genelde temel bilgisayar öğretimi ile alakalı çalışıyorlar ya bu alanlarda zayıf olarak geliyor bunu biz kendimiz eğitimler vererek çözmeye çalışıyoruz ya da es kaza kendini geliştirmiş insanlar çıkabiliyor bunların arasında onlar üzerinden ilerliyor bu konu"

[031] "Bunun yaratacağı bir öğrenme yükü var. Daha fazla şey öğrenemek zorunda kalacaksınız robotu daha iyi hale getirmek için çok zaman alıcı diyebilirim. Özellikle vucut parçalarını yerine getirmek bir araya getirmek zaman alıcı. Hepsi hata verebiliyor kablolar falan çıkabiliyor. Onun yarattığı sorunlar var. Fazlasıyla elektronik bilgi gerekebiliyor. Kimi zaman çözemiyorsunuz problemi şeyin ayarıylada ilgili sorun olabiliyor kabloların dirençleri falan filan. O anlamda hani bir direktör bilgisi de gerekiyor ekstra"

[032] "Her çocuğun önüne yeteri kadar malzeme koyup, malzemeleri kullanımı konusunda çok iyi bir sistem getirmeniz lazım yoksa her taraf robot parçalarıyla dolu karmaşık bir atölyeye dönüşebilir. En büyük problem bu oluyor. Başka şimdi düşünüyorum. İki çeşit çocukla karşılaşıyorum çocukların bir kısmı tasarımla çok ilgileniyor, bir kısmı da aslında programcılıkla da çok ilgilenen çocuklarda var. Buradaki dengeyi iyi sağlamak gerekiyor. Çünkü çocuk programcılıkla ilgilenmeyebiliyor. Orda da takım çalışması yaparak iki tane programcılıkla ilgilenen çocuk iki tane tasarımla ilgilenen çocuk bir araya getirirseniz ortaya faydalı işler çıkıyor."

[033] "program sürecinde öğrenmek hani her hafta bizde ona göre çalışmalar yapıyoruz öğrenciler gelmeden önce hani sadece orada zaman zaman sıkıntı yaşanıyor yada yapıyorsun milimetrik ayarlıyorsun hani öğrenciler gelmeden önce deniyorum ama ders sırasında ufak bir sıkıntı çıkıyor o anda mesela olmuyor o anda sıkıntı yaşanabiliyor öğrenciler tarafından da etkili öğretmen tarafından da etkili mesela ben renk sensörleriyle alıştırma yaparken ortamın ışığı bile hani onu etkileyebiliyor onun duracağı yeri yansımasından dolayı etkileyebiliyor."

[034] “Mesela yeni bir sensör kullanacaksın projede sensörün nasıl çalıştığını bilmen gerekiyor. Ondan daha çok bir de demin ((aşamada?)) konuştuğumuz gibi sistemi çalıştırman gerekiyor mesela seri bir şekilde. O yüzden sensörün nasıl çalıştığını tamamen bilmen gerekir ki o şekilde kodlayasın. Burası dediğim gibi çok uzun zaman alıyor belki haftalar alıyor sensöre göre değişiyor..”

[035] “Yani robotun kendisini öğrenmek başlı başına bir mesele haline gelebiliyor. Dolayısıyla öğrenciler tam olarak özgür olamayabiliyorlar. Kimisi bundan çok keyif alırken kimisi aynı şekilde aynı oranda keyif alamayabiliyor. Kimi öğrenciler için bilişsel bir yük doğurabiliyor. Kimi öğrenciler için o kadar büyük bir yük doğurmuyor o anlamda, aslında robotların kullanımı öğrencinin aktif olduğu bir çalışma şeklinde olabilse çok iyi olur”

[036] “özel ilgi duymazsa algortmik olarak düşünemiyor bundan kaçıyor bunu terk ediyor bırakıyor zahmetli iş içerisine girmiyor bazılarında da mekanik oluyor nedir onlar bilgisayarı yetersiz kalıyor mesela çocuğun aile yeni bilgisayar almıyor okuldaki bilgisayarlar da belirli bir aşamaya kadar kullanabiliyor çünkü biz onların evine götürmesine izin vermiyoruz okuldaki bilgisayarı doğal olaraktan öğrencinin elindeki makine yetersiz olunca bırakıyor yapamıyorum edemiyorum gibisinden moral bozukluğu içerisine giriyor”

[037] “Öğrenciler açısından baktığımızda hani gruplar her sınıfın 3 tane var ve sınıfların ortalama 18 kişi olduğunu düşünürsek bir grupta 6 öğrenci oluyor hani kimi tamamen ilgilenirken kimi bir şey yapmıyor ayrı durmayı sadece bakmayı tercih edebiliyor robota dokunmadan geçirilen süreçleri oluyor bazı öğrencilerin hani bunu yaşadık mesela robotla etkileşime girmeyen öğrenciler oluyor. İstemeyenHani çok genelde bunlar kız öğrenciler oluyor ilgi alanını çekmeyen öğrenciler oluyor bazılarının gerçekten ilgi alanında olmuyor robotlu bu tarz şeyler işine yaramayacağını da düşünüyor ileride onların ilgisini çekmiyor biraz daha uzak durmayı tercih ediyor.”

[038] “Başka bir şey şimdi bizim çalıştığımız kısım özellikle ortaokul çocukları bu ergenlik dönemindeki çocuklar şimdi bu yaştaki çocuklarda çok fazla şeyle ilgili 12-13 yaşından itibaren değişik problemler ortaya çıkabiliyor bu da ilgi kayıyor hani bir bakıyorsunuz bambaşka şeylere mecralara kaymış oluyor”

[039] “Çok el becerisi gelişmemesinden yani o kaslara hakim olamamasından. Bir de tam kontrolünü sağlayabilen bir yaş grubu değil… Hani çok daha/ beden kas koordinasyonu (kontrolünde) değil. Ama uğraşa uğraşa yapa yapa dediğim gibi onlarda da epey o hiper-aktivitenin önüne geçtik. Derste yerinde oturmayan çocuk, robota geldiği zaman hareket etmiyor. Demek ki bu bir problem değil yani tamamen çocuğun ilgisiyle alakalı”

[040] “genelde İngilizce bu işler çocuklarımızın da tamam ben yabancı dilde çok sıkıntı yaşamıyorum ama çocuk da gelişmiş bizim çocuklarımız bu arada ekip olayı itibaren haftada 8 saat İngilizce falan görüyorlar ama hiç biri İngilizce bilmiyorlar bir makaleyi okuyup anlayacak kadar İngilizce bilmiyor konuşmalarından falan bahsetmiyorum temel seviyede okuduğunu anlamaktan bahsediyorum gerçi Türkçede de okuduklarını anlamıyorlar ama yani böyle sıkıntımız var”

[041] “Robotlarda en büyük sorunun robotları öğrencinin gözüyle, öğrencinin robotları hangi gözle algıladığını kontrol etmek zor, öncelikle şey aşamasını anlatmak gerekiyor, robotta bilinç olmadığını anlatmak kolay olmuyor. Vermiş olduğunuz komutların robotun sensörleri tarafından en fazla dünyayla iletişim kurarken o sensörler tarafından olabileceğini öğretici bir şekilde giriş yapmak gerekebilir. Sensör kavramını çok kolay öğrenemiyebiliyor öğrenciler bir nevi sayısal değer yani renki gösteriyorsunu onun renk olduğunu değil, onun fenomenel anlamını değil de sayısal karşılığını algılaması lazım öğrencisinin bu bir nevi zihinsel bir dönüşüm.”

[042] “Çocuk hayalinde işte şöyle hayaller kuruyor mesela ben bir aynadan gireceğimde öbür taraftan ışınlanıp çıkacağım çok uçuk ayağı yere basmayan hayallerle geliyor sana projelerle geliyor sen onun ayaklarını yere basman gerektiği için robotta da aynı şey geçerli yani o öyle bir robot hayal ediyor ki kafasında gerçekten cyborg hayal ediyor merhaba ben geldim nasıl yardımcı olabilirim falan bir şeyler hayal ediyor tabi setleri görünce hafif bir hayal kırıklığı yaşıyor hani setlerimiz çok gelişmiş değil birinci olarak çocuk burada sıkıntı yaşıyor, ikinci olarak … çocuğun bununla ilgili no….yok zaten duyumu yok o yüzden öncelikle bir robot nediri bile bilmiyor anladın mı kumandaları bile robot sanabiliyor veya robot deyince direk cyborg geliyor aklına”

[043] “Mesela hiç Lego yapmayan çocuk oluyor bazen hani geliyor ve burada yapmak istemiyor ısrarla en büyük sıkıntımız o oluyor bazen ama hani yaptıkça kendi bireysel olarak yaptıkça hoşuna gidip yapmaya başlıyor hani sadece tek karşılaştığım o onun dışında gayet ilgili istekli gelen çok öğrenci var”

[044] “Çocukların bazıları korkabiliyor çünkü işte kız çocuğu mesela hayatı boyunca hiç biz de klasik şey vardı ya erkek çocuğu tornavida tutar kız çocuğu tutmaz falan kafası vardır ya çocuk hiç tornavida tutmamış olabiliyor veya hiç Lego takmamış olabiliyor ve yapamayacağım diye korkabiliyor çünkü onun için yeni bir şey ama onları aşıyoruz problemler bu şekilde oluyor”

[045] tasarım kısmında şöyle… şibiz hazır kit kullanmadığımız için sıfırdan onları birleştirmemiz gerekiyor. Bu kısımda da öğrencilerin güçlük çekiyor yada kullandıkları aletler kesici olduğu için zorlanıyorlar. Bu şekilde engeller çıkabiliyor. Yeri geliyor bazı çocuklar hani bir yerini de kesebiliyor ama bu çok

nadir rastlanan bir şey. benim karşımda gördüğüm engeller tasarım konusunda biraz bu ve dediğim gibi bazı tasarım konularını da önceden alırsa derslerini mesela 3D tasarım dersi gibi hani çocukların birazcık daha 3 boyutlu düşünme becerilerini biraz geliştirirsek o engeli aşabileceğimizi düşünüyorum

[046] “elektriği bilmiyorlar çocuklar elektronik cihazları ve hani önyargılı olarak karmaşık biz buna bir şey yapamayız gibi bir şey var bir ürperiyorlar işte başlangıçta dokunmak istemiyorlar hani o başlangıçta şeyi yeniyorsunuz işte dokunuyorlar, bağlıyorlar bir iki tanesinin çalıştığını gördükleri zaman üzerinde devam ediyorlar hani ilk başlangıçta hiç bilmedikleri için kabloları karıştırıyorlar tabi yanlış yerlere bağlıyorlar sonra bilgisayara bağlıyorsun çalışmıyor farklı şeyler olabiliyor ama işte zaman içerisinde şey ilerliyor hızlı bir şekilde ilerliyor”

[047] “Bazen çocuklar kendileri devreyi yanlış bağlıyorlar o yüzden işte kısa devre yaptırıyorlar ama farkında olmuyorlar çünkü çok işte telaşlı takarken kabloyu takarken o bordur üzerinde deliklere çok dikkatli takmak lazım bazen bir deliğe elektrik veriyor diğer aynı sırada deliğe takacağım diye fark etmeden takmış olabiliyor sonra devreyi yapamadım diye bir şey oluyor durum ortaya çıkıyor kontrol ettiğimiz zaman gerçekten kabloyu ters bağladığı için kısa devre yaptığını yada başka yerden bağlıyor kabloyu bu tarz ufak tefek sıkıntılar çıkıyor onun haricinde yaşadığımız çok büyük bir problem yok”

[048] “Sensörlerle ilgili çok sıkıntı yaşıyorlar işte dediğim gibi robotun aslında program mantığında baktığında algoritmasına baktığımda programın doğru çalışmasını bekliyor ama kullandığı parçalar robotun tasarımından dolayı verdiği süre içerisinde o işin doğru hedefe gitmediği için işte başlattığı yer önemli robotun sağına taktığı bir parça var o işi yapması için o parça onun hafif sağa doğru kayarak gitmesini neden oluyor örneğin ağır geliyor orada ergonomiyi düşünmesi gerekiyor, fizik kurallarını düşünmesi gerekiyor bunlar karşılaştığı en önemli sorunlar"

[049] “Genel olarak yaşadığım problemler, tasarımın ben çocukların yapması gerektiğine inanıyorum*, Çocuklara tasarım ilkelerini veriyorum, tasarım ilkeleri bunlardır bunlara göre tasarlamalarını bekliyorum, tasarlarken her çocuk bireysel olarak kendisi yapmak istiyor, burada karşılaştığımız durum herkes kendi tasarımını empoze etmeye çalışıyor. Göreve yönelik bir şey koymaktansa herkes kendi bildiğini empoze etmeye çalışıyor* ve bu konuyu grup çalışmasına döndürmekte zorlanıyoruz bireysel fikirler çatışıyor aslında

[050] “bazı çocuklar bencillik yapıp* programın başına geçip sadece kendileri programlamaya çalışıyorlar. Böyle bir şey var, insanın doğasında var çocuklarda da bu bencillik çok daha fazla olabiliyor.** Paylaşmayı bilmeyen çocuklarda özellikle de tek çocuklarda bu olabiliyor. Hep kendisi yapmak istiyor çocuk programı. Onlarıda değiştirerek farklı görevler vererek. Birazda işte arkadaşın yapsın.* Ahmet sen yap diye. Bazı çocuklar kopabiliyor görevden koptuğu zaman çocuğu çağırıp 1, 2, 3, başlat görevini ona veriyoruz mesela* kopan çocukları o şekilde işin içine sokuyoruz.”

[051] “Bizim genelde sıkıntı yaşadığımız nokta şu bizim öğrencilerimiz takım halinde çalışmaya uygun öğrenciler değiller aslında genelde bireysel olarak çalışmaya tercih eden yani gruptaki öğrenci sayısı arttıkça aslında potansiyel olarak problemlerde artış gösteriyor normalde gruba katılım arttıkça işin daha kolay yürümesi gerekirken bizde tam tersi oluyor grubu ne kadar küçültürseniz o kadar hızlı bittiğini görürsünüz projenin en büyük problemlerimizden bir tanesi bu yani öğrenciler aslında birbirlerini kötü etkiliyor gruplar içerisinde onun dışında grupları oluştururken problem yaşamamak için şu tarz önlemler alıyoruz 3D modelleme konusunda çok iyi olan öğrencilerimiz var gruba muhakkak ondan bir tane bu öğrencilerden atıyoruz çözüm üretebilen problem karşısında çocuklar var özgün düşünebilen bunları da yine atıyoruz oraya birde programlama konusunda başarılı olan çocuklar var gruba bir tane de ondan atıyoruz bu şartlar sağlandıktan sonra zaten problemimiz çözülüyor tabi bir de el becerisi iyi olan çocuklar var onlarda montaj aşamasında ciddi hızlandırıyorlar sizi sıkıntı şurada başlıyor bunları çitlediğiniz zaman bu tarz öğrencileri birbirlerini yemeye başlıyorlar dolayısıyla her grupta bu özelliklere sahip birer öğrenci tercih etmek gerekiyor en büyük yaşadığımız problem bu”

[052] “Çeşitli zamanlarda çeşitli oyuncaklar böyle popüler hale geliyor. Ne vardı mesela önceden böyle topaç gibi çevrilen oyuncaklar vardı. O oyuncaklardan alıyor bir çeşitini alıyor sonra ikincisini alıyor üçüncüsünü alıyor o oyuncak bir dönem sonra artık cazibesini yitiriyor, neden? tasarım bitiyor. Şimdi bunu aldınız bunu çocuk tüketti bitirdiği zaman başka bir şey yapma şansınız yok ama “lego” gibi “rex” gibi modellerde bugün bunlarla bir araç yaparsınız yarın* inşaat makinası yaparsınız ertesi günü ne bileyim küp çözücü yapabilirsiniz. İmkanlar daha sonsuz ve sınırsız modüler olmasını tercih ederim”

[053] “Çocuklar robot üzerinde kendi tasarımlarını yaptıkları zaman robotla etkileşimleri daha yüksek oluyor bu kapsamda bunu söyleyebilirim. Bir görev robotu yaptırıyorsunuz, görev robotunda neler var; 2 tane teker var altta 2 motor var, üstte 1 tane controller var sevimsiz bir şey ama çocuğa: "hadi bunun önüne bir tampon yapın" dediğimiz zaman ve çocuk ona bir tampon yaptığında arkasına da iki tane renkli far koyduğu zaman o etkileşim daha farklı oluyor. Çocuk onu artık kendi bir şeyiymiş gibi görüyor. Robot olarak alıp ta onu sadece görev robotu gibi gördüğünde etkileşim daha düşük oluyor ama çocuk onu kendisi tasarımıyla özelleştirdiği zaman bu etkileşim daha üst seviyelere çıkıyor. Kendi tasarımıyla özelleştirme de diyebiliriz.”

[054] “Modüler olmalı, sensörleri rahatlıkla çıkarılabilir olmalı ki sonraki derse hazır olsun. Bu her öğrenci için bir tane olması birazcık hayal ancak sınıfa almak daha mantıklı dolayısıyla sınıfa oldukça zengin sensör paketlerinden oluşan, kolaylıkla devresi kurulup daha sonra kolaylıkla bozulabilen bir tasarıma sahip olmalı.”

[055] “Bunlar aynı toplama bilgisayar gibi: İşlemciyi alıyorum hard-diski alıyorum, şu kasayı alıyorum gibi keyfinize göre tasarlayabiliyorsunuz daha yaratıcı bence. Tabi ki de farklı şeyleri alıp bir araya getirmek daha da uygun, yaratıcılığı attırır. Hem de kullanışlıdır. Sonuçta yapmak ve tasarlamak istediğin ne ise ona özgü ürünleri alarak burada yapılabilir.

Bu biraz özgürlük katıyor işin içine, bu önemli bence bir de dediğim gibi görüntü de çok şirin.”

[056] “Eğitimi için kodlama tarafında faydası olabilir. Geri kalan her şey kendilerinin belirlemiş oldukları sınırların dışarısına çıkamazsın bununla belli bir sınırı vardır.Çünkü kullanılan sensör bellidir ve kullanabileceğin yapıların hepsi sınırlıdır ama bunu sıfırdan icat ettiğiniz zaman şu an bile piyasada bine yaklaşık sensör var. Farklı farklı sensörleri entegre edip çocuğa farklı hayalindeki projeleri yaptırabilirsin, burada ise sadece hayallerini sınırlarsın.”

[057] “Bizim o istediğimiz "Bir şeyi" üretmesi, hayal gücü, hayal kurması, yeni şeyler keşfetmesi, yeni şeyler düşünmesi... Bunu bir taraftan kısıtlamış oluyoruz yani onda sadece oyuncak gibi oluyor. Çocuktan sadece belli işlemleri yapabilen ve belli işlemleri görebilen bir şeyi yapmasını ve onu gerçekleştirmesini istiyoruz. Bu şekilde bir puzzle çözüyor gibi oluyor ama öbüründe baştan, sıfırdan bir ürün tasarlatmış oluyorsunuz. Yani bunda bir karton kullanıyoruz belki görüntü olarak diğeri kadar hoş olmuyor. Karton kullanıyoruz görüyorsunuz işte kartondan onu yapmış, kartondan onu yapmış orada bambaşka bir şey yapmış yani işte yokluk yaratıcılığı tetikler mi derler ne derler hani öyle bir şey vardır. Biliyorsunuz yani onu çözmesİ, o tip problemlerle uğraşması bile bizim açımızdan önemli bu şekilde arduino kullanmak bizim için önemli.”

[058] “Parçaları çok küçük müdür? Kaybolur mu? Okul ortamı şöyle bir ortam çabuk unutur çocuklar her şeyini. Parçaların küçük olması bir dezavantajdır. Çünkü o parçaları bulup tekrar almak da çok bir masraf. O yüzden belki şöyle olur eğitim sistemindeki robotları böyle daha büyük parçalı ve yani belki öyle bir şey olabilir. Ya da yaşa göre parça büyüyüp küçülebilir.”

[059] “Dediğim gibi (lego parçaları) onların gerçekten el becerilerini geliştirir.İlk başta, dersin dışında sadece bir şeyi yetiştirirken çok az bir kısmını yapabilirken sene sonunda bir senenin sonunda gerçekten daha hızlı yapabiliyor ya da bir sene daha geçtiğinde hani o yapamadığı şeyleri bir ders saati içerisine sığdırabiliyor.El becerilerini gerçekten çok geliştiriyor.”

[060] “Hem alttakini tutacak hem üsttekini tutacak kenardaki bir parçayı monte edecek. Haklı olarak eli yetmiyor çocuğun. Gerçi iki ele daha ihtiyacın var. Ama bunu tek başına yapan da var. O sırada ters bir hamle yapıyor, öbür parça yere düşüyor, tutturamıyor gibi ama bu da tamamen değişkenlik gösteriyor. Yaptığı robotla alakalı. Kolay bir şey yaparsa kendisi zaten tak tak tak yapıyor.”(

[061] “Parça kullana kullana gelişiyor. Zaman geçirmekle alakalı robotun tasarımında birazcık daha parçalara baktığınız zaman daha kolay birbirine monte olan şeyler olsa böyle şeyleri yaşamazdı. ama bence böyle şeylerin olması pozitif bir etki. Zor olsun ki zor bir şey için uğraş öbür türlü iki parça tık diye birbirine girsin iş bitti yani. Hani mekanizmayı gör. Niye buranın hepsini art arda yapmak zorundasın? Ne yaptırmaya çalışıyosun da bunu yapıyorsun? gibi bir durum var.”

[062] “Makeblock hepsinden üstündür. birde Makeblock’un şöyle bir avantajı var; hem çok küçük yaş gruplarına hitap eden bir ürünü var, hem de gerekli yükseltmeleri yaptıktan sonra ve Arduino’ nun kendi idesini kullanarak Lise gruplarına da aynı kit ile eğitim verebiliyorsunuz. Bu ciddi bir esneklik çünkü diğer markalara baktığınız zaman hep hedefledikleri yarılar ayrı ayrıdır. İlkokuldan Liseye kadar bir ürünü genelde görmeyiz diğer kitlerde. Makeblock bu esnekliği sağlıyor.”

[063] “Ara yüz sıkıntıları var bazı ara yüzler çok ağır bazı yüzler çok basit. Çocuk diyor ki: "ben scratch kodları koyacağım ama kodları koyduktan sonra şunu yapmak istiyorum." diyor.O arayüz çok basit olacak onu geliştirmiyor. Çok kolay ile çok zor arasında ara bir seviye olmalı. Aslında çocuğa yönelik olan her projeye yönelik öneri yazılıyor tadında bir şey olmalı. Bunları yaşadık genelde programlama konusunda tabi kısıtlı imkanlar da var robotların kısıtlı kapasiteleri var senin her verdiğin komutu her verdiğin düşündüğün algoritmayı aktaramayabiliyorsun sisteme çünkü çok gelişmiş sistemler değil bunlar. Orta seviye robotlarda çok büyük programlama yapamıyorsun.Hata veriyor,almıyor, resetleniyor veya kodu yazıyorsun sıfırlanıyor.”

[064] “En temelde müfredat programının uygulanabilir olmasıdır. Hani siz eğer Pisagor teorimini robotla anlatabiliyorsanız tamam ama Pisagor teorimini robotla anlatamıyorsanız o zamanlar o robotun o an orada kullanım alanını geçiyor gibi veya nasıl diyeyim fasulyenin çimlenmesini Fen dersinde robot üstünden gösterebiliyorsanız tamam. Ancak burada eğitim programlarının robotlar üzerinden çok iyi kurgulanması gerekiyor belki biraz daha üst düzeylerde olacak bunlar ders içinde yapılamadığı için zaten şu an turnuva olduğunda First Lego Ligi veya çizgi izleyen sumo yapan veya pinpon toplarını atan sistemler gibi çalışmalar devam ediyor.”

[065] “Bilişim Teknolojileri Yazılım dersinde 5.ve 6. sınıfda kodlama kısmında ne dersi kodlama kısmında Scratch'i zaten anlatıyoruz. Scratch'i anlattığımız için, Scratch'i arduinoda yani orada öğretilen mantığı kullanıyor. Onun dışında ekstra dan bir şey öğretmene gerek kalmıyor sadece arduino ile ilgili olan kısımları birkaç tane ekstradan blok var onları öğretiyoruz ve yolumuza devam ediyoruz. Yani sıfırdan işte editörü tekrar anlat, ne bileyim bloklar şu işe yarıyor şunu şöyle kullanıyorsun? Gibi bir şeye gerek kalmıyor. O, birinci adım oluyor hemen ikinci adımdan da devam etme imkanımız oluyor yani tekrar kodlama kısmının eğitimi ile ilgili kısmıyla uğraşmak zorunda kalmıyoruz”

[066] “Eğer kit olarak çalışacaksam genelde ben Arduino platformu ile çalışıyorum ve bu platformu destekleyen robot kitleri tercih ederim. Hazır bitmiş ürünlerden genelde uzak durmaya çalışıyorum. Buna karşılık daha özelleştirilebilir platformlar üzerinde yoğunlaşıyorum. Bitmiş tek parça ürünlere çok fazla sıcak bakmıyorum açıkçası birde açık kaynak toplu olması önemli bunun yanında donanımsal uyumluluğu da benim için önem arz ediyor. Örneğin; ben farklı bir markanın sensörünü bağlayamayacaksam bu benim için eksi bir değerlendirmedir. Gerekirse kablolama pin yapısını değiştirebilecek bile olsam ben bunu kullanmak isterim.”

[067] “Saydıklarınız arasında en yatırım yapılabilir ürün budur (robotis) çünkü ben bununla mbotu inceledim ve mbotu aldım. Boardun üzerinde bir çok sensör bağlantısı var gerekli bütçeyi zaman ben bunları alıp tekrardan geliştirebiliyorum. Bunun dışında mekanik aksamı

da standart bir mekanik aksam Metrik4 vida tasarımı destekliyor. Herhangi bir Metrik4 vida ve benim tasarladığım bir 3D printerdan çıkmış bir parçayı buna doğrudan bağlayabiliyorum çünkü kendine has perçinli bir yapısı vs.yok. Sizi ondan ürün almaya zorlamıyor ve bir de şöyle bir şeyi var ki bunun kendi orijinal parçalarının da 3D modellerini de ücretsiz olarak paylaşıyorlar. Dilerseniz aynısını 3D printerdan çıkartabiliyorsunuz. Örneğin; tekerini satın almanıza gerek yok ya da bir dişli yapısını ya da o dişliyi siz 3D printerdan üretebilirsiniz. Satın almanıza gerek yok. Üretemediğiniz parçaları sadece alabilirsiniz. Bir diğer güzelliği de Lego'nun parçaları ile de uyumlu onunla birlikte de çalışıyor."

[068] "Genelde bütün robotların kendi arayüzleri geliyor. Biliyorsunuz ki bunlardan kullanıyoruz ama ben bunların dışında yetenekli çocuk varsa işte çocuğa direk arduino gösteriyorum. Sürükle bırak programlama yaptırmıyorum da direk bildiğimiz programlama mantığı arduino gösteriyorum. Biraz hafiften C veya Python tabanına kendim giriyorum çünkü lazım oluyor. Sonuçta önde çalışan programın temelini benim anlamam lazım ki çocuğa da öndeki şeyi veya sıkıntıyı çözebileyim diye onun dışında programların kendi yazılımlarını kullandım"

[069] "Neden tercih ettim bir kere hazır ara yüzler zaten çocukların kullanabilmesi için ve daha sıkıntısız daha stabil çalıştıkları için otomatik olarak tercih ediyorsunuz. Seti bende tanımıyorum sonuçta benim içinde yeni bir set geliyor karşına kendi ara yüz ve kendi programı ile başlıyorsun onun dışında arduinoyu niye tercih ettin arduino biliyorsun nerdeyse bütün cihazlarla çalışabiliyor. Yani kolayda bir arayüz çok da böyle synthax bilmene gerek yok benim temelimde C ve pascal vardı.Lise eğitimimde zaten C ile uğraşıyordum java ile az çok uğraşıyordum o yüzden de onları kendi açımdan, arkada onları geliştirmek için bunları tercih ettim."

[070] "Şimdi en çok sıkıntı yaşanan şey robotik uygulamanın genelinde robotun kendi ara yüzüydü veya robotla çalışacak program bu en iyi programlama dili C'de olabilir, Piton'da olabilir hangisini kullanıyorsunuz hiç fark etmez bunlarla robotun birbiriyle uyumsuz olması. Belki bütün robotları kullanmışımdır ama tam birebir yüzde yüzde yüzde yüzü bırak yüzde kırk yüzde elli çalışan bir robot görmedim diyebilirim. Çünkü her zaman bir şekilde bir problem çıkıyor. Yani programla robotun kendi fiziksel ve oradaki bizim yapmış olduğumuz program arasındaki sıkıntılar… Yapılan uygulamaların her türlü flexible her şeye uygun olmaması parçası her şeye uygun değil o uygunluğu daha da çok geliştirmek lazım."

[071] "Kullanışlı denir. Hem emek hem para yönünden daha iyi olması... Eğer bir malzeme ya da bir ürün alıpta ya da bir Fen bilgisi dersi için aldık diyelim… Bunu bir den fazla şey için kullanabileceksek bu bizim isteme ve tercih sebebimizdir. O yüzden arayüzler ya da bunlar ne kadar fazlaysa ya da bunları ne kadar müfredat ile ilişkilendirebilirsek o kadar tercih edilebilir. Örneğin; bunun beş ve yedi versiyonu varsa yedi versiyonu olanı çocuklarla öyle bir etkinlik yapmak isterim. Yani tek bir amaç değil birkaç amaç eğitimde daha farklı olur."

[072] "Legoya da uyumlu olduğunu da görüyorsun Legoyla birebir de kullanılabildiğini görüyorsun buda açık kaynaklıklara çok daha yatkın olduğunu gösteriyor bize zaten. Arduinoydu gibi değişik şeylerle ortamlarla kullanabildiğimiz ve sensörleri çok fazla ve fazla olduğu için aynı şekilde çok

fazla da değişik. Fazla ders açısından, fazla kullanılabilirlik açısından, çok daha veya kullanıcıyı koruduğu mu diyeyim yoksa kullanıcıyı çok daha sevdiği mi diyeyim kullanıcıya çok daha yakın bir şey.”

[073] “Bunlarda biraz daha fazla kaynak grupları açısından …yazılımlar kullanabildiğin için yani ne kadar çok programlama dilini çok kullanıyorsan bir robotta o kadar çok fazla yerde kullanabilirsin sende katılıyorsundur ne kadar çok açık kaynak bulduysak kendisine kapalı değilse o kadar çok fazla kullanma şansın vardır. Bunlarda da benim gördüğüm şeyler o yani değerlendirmelerim genelde o şekilde.”

[074] “Şimdi motor şöyle demir aksam var burada vida var burada tam turunu tutturamadığınız zaman dışa atıyor motor tam çalıştıramıyor bunu bu seferde istediğiniz gibi gitmiyor. Birde pil olayı, pil çok çabuk bitiyor onu söylemeyi unutmuştum şimdi hatırladım pil çok çabuk bitiyor. Mesela EV3’de de nedense bu robotlarda nedense pil biraz daha yavaş gidiyor az gidiyor bunuda ben hatırlıyorum 6 tane mi,9 tane mi pil kullanıyorduk? Yarım saat bile gitmiyordu hemen bitiyordu. Pil de ucuz değil sonuçta maliyet artırıyor ondan sonra da bırakıyorsunuz bir köşeye.”

[075] “…kullanımı kolay çünkü sadece anladığım kadarıyla yalnızca tek işleri yapabiliyor. Çizgi izliyor hem de renkleri seçiyorsun sürüklüyor bu kadar onun dışında bir işlev yapmıyor. Onun için tek işte ürünü daha kolay buluyorsun.”

[076] “Şimdi ben mesela bu kitin benzerini ben kullanmıştım bunu kullanmadım ama burada görselini görüyorum bu kitin kullanımını yani sök, tak mantığı vida, kaynak maynak işi olmadığı için rahat dediğim gibi benzerini kullandım fakat buradaki sorun şu parçalar çok küçük lego parçalarının özelliği hangi parçayı tam nereye takacaksın onun için çok zaman kaybediyorsunuz.”

[077] “Lego kadar kolay olmamalı bir şey kolay olmalı, Şimdi birleştirme açısından da diyebiliriz buna kurma açısından da diyebiliriz yani set up konusundan da bahsedebiliriz. Şimdi çocuğun karşısına böyle sayfalarca katalog koyup da bir şeyleri birleştirip de şemadan maket oluştur gibi oluşturması güzel değil. Bu hem zorluk hem de kolaylık açısından değişken bir şey olması lazım.”

[078] “… adobe flash vardı işte genelde oyunlar hep onun üzerine geliştiriliyordu zor bir dildi ve bu metinsel taban tek tek oturup aslında klavyede yazmak gerekiyordu. Çünkü bunu çocuğa ben o zamanlar hani derslerinde bunu anlatmaya çalışırken böyle yakaladığım mesela 20 kişilik sınıfta 3 öğrenci oluyordu bu işi anlayabilecek ama şuan "Scratch" diye bir şey çıktı müthiş bir şey veya Google ‘ın "blockly" diye blok alt yapısı var sürükle ve bırak kodlarını çalıştırabildiğiniz… Milat oldu aslında programlama sadece klavyeden takır

takır yazmaktan ziyade çocuklar bunu sürüklüyorlar ve yap boz parçaları gibi birleştirerek o anda programın nasıl çalıştığını görebiliyorlar.”

[079] “Çocuklara kolay kullanım olması için çocuğu birinci olarak bıktırmaması,synthax’a ,kurallara çok takılmaması lazım. Çocuk yeni neslin yani şu anki neslin son beş senedir neslin çocuklarında hemen sonuca gitmek istiyorlar. Sanki yetişkin eğitimi gibi bir şey yaptığı zaman onu hemen canlı görmek istiyor ve bir noktalı virgüle takılmak istemiyor bilmiyorum anlatabildim mi? Haliyle sürükle bırak, onla gel Scratch'te bunda sürükle- bırak şeyler olduğu için çok kolay ve tabi ki oyunlaştırmadan bu çocuklara bir şey veremiyorsun.”

[080] “Yazılım kısmı gerçekten böyle, hani gördüğüm kadarıyla böyle biraz daha zahmetli bir iş herkesin de yapabileceği bir iş değil herkesin de farklı bir yeteneği var. Sabır gerektiren bir iş bir virgül bir noktayı unutabiliyorsunuz ama sürükle bırak mantığı ile çalışan o robotlar biraz daha albenisi olan robotlar oluyor.Çünkü kişi zaten tasarladığı şeyi robotun davranışı aslında onu görmek istiyor. Yazma kısmıyla pek uğraşmak istemiyor ama yine kendi yapmak istiyor blok olunca bu sefer ne yapıyor? Sürükle bırak en son ürünüde rahat bir şekilde görüyorsun o uzun ve meşakkatli olan yoldan kurtulmuş oluyorsun. O yüzden özellikle benim açımdan tercih sebebim o.”

[081] “Burada üretime yönelik eğitim yapıyoruz. Bunları destekleyecek ve bir şekilde ara yüzlerinde kolaylıklar sağlayacak. Çocukları ilk başta gördükleri zaman ürkütmeyecek. Ara yüzleri kolay olmalı ki algoritma mantığını önce algılayıp daha sonra geliştirebilsinler. Bir şekilde bir yerlere daha sonra gitsinler tabi ki sorun çıkartmayan robot veya robotlarla bir şekilde ilerlerken her dakika sorunlar çıktığı zaman çok büyük problemler yaşıyoruz.Robotlarda da sorun çıkmayan robot da yok neredeyse hepsinde bir şekilde sıkıntılar yaşıyoruz.”

[082] “… çocuk şunu da hesaplaması gerekiyor; Mesela robotunu çalıştıracak turnuvada masadaki robotunda buradaki denemelerinde görevi başarı ile tamamlıyor ama oraya gittiğinde başlatırken bile düğmeye basarken bile daha fazla basınç uyguladığında robot bir mili saniye belki geç başlıyor. Çocuğun bunu da yaşaması gerekiyor çünkü bu şekilde bütün olasılıkları ve riskleri dikkate alarak yazıyor. Gerçek hayatta da böyle. Hayat her an karşına farklı riskler çıkabilir ve onu görmesi açsından da aslında iyi ama yazılımsal sıkıntılar oluyor karşılaşılan en önemli sıkıntıda bu diyebiliriz. Yazılımsal ara yüz ile ilgili sıkıntılar… çocuklar açısından daha böyle kullanıcı dostu ara yüz ile çalışmak başka bir şey birde daha zor yani zaten programlamayı anlamaları zaman alıyor birde olayın ara yüzünde sıkıntılar yaşarlarsa iş daha zorlaşıyor.”

[083] “Tamam robot ile etkileşim ara yüzde hani şöyle bir şey var hani küçük yaşta çocuklarda eğer kullanmış olduğumuz ara yüzler biraz İngilizce terimler fazla ise bazen

anlamakta zorluk çekebiliyorlar ama tabi bir de şöyle bir durum var bazı kodlama yapıların Türkçe karşılığı çok saçma oluyor ve çocuğun bunu ilişkilendirirken aslında mesela kendi kafasındaki olan yapı ile o İngilizcedeki terim çok farklı bir yapıya sahip bu yüzden böyle terimler arasında bir sorunlar çıkabiliyor terimlerin yanında ara yüzde diyebileceğim bu olabilir yani anlaşıla bilirlik, kullanılabilirlik ve anlaşıla bilirlik"

[084 "… Code org'a bakarsak hem öğretmene için uygulama kitapçığı veriyor hem içerikleri ücretsiz internet üstünden çalışıyor herhangi bir kurulum yapılmasına gerek yok bunun dışında öğretmen hesabını rahatlıkla açıp öğrencilerini takip edebiliyor… dolayısıyla bu bir kodlamaya başlangıç için önemli bir adım gayet de başarılı buluyorum oradan eğitiminden görsel özdeki yatkınlık aslında bizim robotiğe geçişimizi kolaylaştıran bir şey şimdi ondan tamamen zıt bir şeye geçtiğiniz zaman bu sefer zaman kaybetme durumu söz konusu robotu programlamak için o yüzden Scratch vari ara yüzler daha mantıklı İlkokul kademesi için konuşursak"

[085] "Yani artı eksi kısmını bulmada ya da artısı eksisi var mı yok mu onu belirlemede çok da büyük bir sıkıntı değildi sadece biraz daha dikkatlice bakmak gerekiyordu. En başta bizi şey yaparken sıkıntı oluyor bazı sensörler şimdi iki bacaklı sensörler de şey belli artısı eksisi ama mesela dört bacaklı, beş bacaklı sensörler var mesela işte bunların hangisi artı bacak hangisi eksi bacak işte diğer iki bacaklar ne işe yarıyor işte bunlar konusunda ne oluyor internetten araştırıyoruz mesela bazı durumlarda atıyorum ısı sensörü diye yazıyor."

[086] "Yani dediğim gibi o görsellerin bazen çok açık olmaması hem onları da etkiliyor ya da doğru parçayı bulmakta sıkıntı çekiyorlar bazen. İçinde hem çok fazla parça var hani atıyorum mesela ultrasonik sensör diyorsun ona benzer bir parça daha oluyor o sensöre benzer bir parça daha olduğu zaman kafaları karışıyor, ya da motorlar iki tane geniş motor var large motor, medium motor var onda sıkıntı yaşıyorlar medium motor hangisiydi large hangisiydi bunda sıkıntı yaşıyorlar çok benziyor ikisi birbirine onlarda sıkıntı yaşıyabiliyorlar."

[087] "Ya bu tamamen çocuğun tamamen vakit geçirmesi ile alakalı… benim için de aynı sıkıntı vardı/ çünkü ben de ilk seti aldığımda atıyorum bir robotu oluşturmak üç saatimi almıştı. Tanımıyordum parçaları. Atıyorum şimdi çok komplike bir şey değilse bir saat içinde ya da 45-50 dakika içinde ((sumo?)) robotu yapıp ortaya koyabiliyoruz. Tamamen el becerisi. Yapa yapa alışması ve hakim olmakla alakalı yoksa aldığımız sette bir problem yoktu…"

[088] "Ama görünüş itibariyle "LEGO" kadar etkin bir eğitim seti olabileceğini düşünüyorum. Renk yok tabi burada yine renklere takılıyorum ama renk yok renk* çocuklar için önemli çünkü çocuk bunun önüne bir kolye yapayım dese, kolye de gri olacak, koporta da gri olacak"

[089] “Biraz alışkanlıklar ile ilgili yani kimisi tekerleri çok seviyor. Kimisi beyinin etrafındaki şeylerden hoşlanıyor onunla ilgilenebiliyor. Burada bireysel faktörler olduğu için. Kişisel ilgi alanları daha etkileyici oluyor. Renkler bile etkili olabiliyor. Renk bile başlı başına kırmızıları alacağım diyebiliyor çocuklar yani işte beyazı alacağım renk bile fark ettirebiliyor.”

[090] “Önce öğrencilere ben danıştım ne yapalım ne edelim çocuklar arabalardan sıkılmışlardı yani bir şey tasarlamıştık biz ilk başta otokar tasarlamıştık çok ilgi çekici gelmedi başlangıçta sonra benim kullandığım bir kaynak vardı robot lego tasarımları olan oradan böyle en ilginç olan bir tane seçip öğrencilere danıştım bunu yapabilir miyiz? Öğrenciler heyecanlandırdı, çünkü değişik bir görünüm vardı. Görsel olarak, dolayısıyla ilgilerini çekti sonra gruplara bölündüler başta çok hevesli olan arkadaşlar zorlanınca ayrılmak istediler”

[091] “robotun dış tasarımı da çok hoşlarına gitmeli yani ben kendi adıma söyleyeyim biraz arabaya benzeyen robotlar öğrenci açısından biraz sıkıcı oluyor bu mu robot diyor öğrenciler albenisi olmalı dış görünüşü güzel olmalı”

[092] “Biraz daha ara yüzü soğuk duruyor robotun bence, (renkli varyasyonlar) bunlar daha sevimli duruyor daha çok dikkat çekebilir eğitim açısından daha hani dedim ya kız öğrencilerde genelde uzak duruyor belki onlarında dikkatini çekebilir biraz daha sempatik sıcak gelebilir.”

[093] “Valla beğendim ilk defa görüyorum bunu dediğim gibi böyle birazcık fotoğrafta olduğu gibi küçük yaş grubundaki çocuklarda ilgiyi çekip devamını getirmesi açısından pozitif bir robot bence. Hani çünkü okul öncesine şunu [mBOT’u gösteriyor] veremezsiniz ya da ROBOTIS’i veremezsiniz gel yapıyoruz diye ama küçük yaşlar için bence dikkat çekmek açısından/ yani yazılım nedir ne yaptırabiliyorum duygusunu oluşturmak açısından beğendim. Küçükten başlayıp bir temel oluşturulabilir bununla”

[094] “OZOBOT”ta ise küçük yaş grubunda yüksek etkileşim sağlanabilir çünkü görselliği var* küçük yaş grubundaki çocukların bu robotla iyi etkileşim sağlayacağını düşünüyorum ama tabi çok kısıtlı şeyler yapılabileceğini değerlendiriyorum. Renk tanıma var gördüğüm kadarıyla. Kendi çeşitli oyunlar sunuyor içerisinde. Bir müddet sonra biter diye düşünüyorum çocuklar çünkü hani bir oyuncağı tüketme olayı var”

[095] “tasarımlar genelde bu yönde ya çok şirin ya da çok endüstriyel tam evet arada çok güzel robotlar ama daha yeni yeni olduğu için tam şey yapmıyor tasarımı bol olabiliyor ve yahut şekil olarak daha doğrusu aslında hani çok oyuncaksı veya endüstriyel değil de ortada bir tasarımlar ortaya çıkabilir”

[096] buradaki temel hareket kanunlarını öğrenebilir mi çocuk öğrenebilir evet ama çok uzun vadeli bir çalışma olamaz bu bir de dediğim gibi fazlaca almak gerekiyor ve bunlarda dijital sarmal kullanılıyor veri aktarabilen ve bunlar ciddi şekilde şişiriyor maliyetleri arıza durumda da ciddi bir maliyet getiriyor bize ve arıza yapma olasılığı da yüksek okulda kullandığınız için bize daha rijit dayanıklı robotlar lazım arıza durumunda da bizim onarabileceğimiz robot kitleri lazım

[097] "Robot ile ilgili bu sıkıntı yaşanıyor ha mesela bu robotun bir parçası bozuluyor bu arada sallıyorum kolun şeyi bozuluyor ve onun yedek parçasını bulmam çok zor olduğu için yada bütçem olmadığı için orada hemen konuyu değiştiriyoruz yani hani o zaman da bu görevi öyle yapmayalım ya şu görevi değiştiriyoruz düşün ya hani robotu değiştirmediklerine göre görevi değiştiriyoruz çünkü robotun parçasını bulamıyoruz"

[098] "...dengeli ve sağlam olması için dikdörtgen prizması şeklinde olması gerektiğini söylüyoruz. Kablolarının düzenlenmesi, kablolarının sağa sola takılmayacak şekilde kablo düzeninin iyi sağlanması. Bataryalarının değişebilir şekilde tasarımda bataryaya ulaşılabilir şekilde bir tasarım yapmak, bataryaya erişimi düşünüyoruz. …kumanda panelinin bize dönük olmasına dikkat ediyoruz,"Lego" da önemli bu*. Tekeri kumanda paneline uygun yerleştiriyoruz. Teker boyutunu teker çaplarını yüksek kullanıyoruz, daha hızlı ve kısa sürede daha çok mesafe için teker çapları. Arka tekerlerde yalpalamayı önleyecek şekilde düzenliyoruz..."

[099] "sonuç kısmında bizim genelde yaşadığımız sorun şu bu robotların enerji olayı enerji çok çabuk bitiyor. Sürekli pil değiştiriyorsunuz… Pil kullanıyorsunuz, lipo kullanıyorsunuz en büyük sorun o idi hemen bitince yarıda kalıyordu bu sefer iş hiç bir anlamı kalmıyordu"

[100] "Robot ile etkileşime yönelik, robot ile etkileşirken programı önce yazıyorlar. Robotun tasarımına göre ters ya da düz olabiliyor. Robotun tasarımında ters koyup programı sanki robot düzmüş gibi robotun yönüyle ilgili sorunu yaşayabiliyorlar. Batarya seviyeleri, programı yapıyor çocuk batarya seviyesi düşükken program çalışıyor, batarya seviyesi yüksek replikasıyla çalıştırınca daha farklı sonuçlar alabiliyorlar. Bu tarz sorunlar oluyor."

[101] "mesela en büyük problem batarya problemlerimiz her bir seferinde bataryanın bir saatlik kullanımı ile iki saatlik kullanımı veya bir dakikalık kullanımı çok büyük farklılıklar gösteriyorlar bunlar optimize edilememiş ve edilemeyen çok fazla sıkıntılar yaşadığımız konular ben çok fazla yarışmaya katıldığım için bu yarışmalarda en büyük sıkıntımız batarya sıkıntısı batarya en ufak bir yerde bir şey yaptığı zaman biraz düştüğü zaman ürün değerleri direk saçmalayabiliyor hiçbir şey yapmayabiliyor."

[102] “burada çok iyi çalışıyor mesela robotları oraya gidiyoruz şarjı etkiliyor işte ne bileyim başlatma şekli etkiliyor tam o çizgiden başlatmıyor çok az bir sapma robotun hedefine ulaşmasına engel oluyor vs darken arkaplanda aslında çocuk bütün bu duyguları ile baş etmeyi öğreniyor.

[103] “öğrenciler gelmeden önce hani sadece orada zaman zaman sıkıntı yaşanıyor yada yapıyorsun milimetrik ayarlıyorsun hani öğrenciler gelmeden önce deniyorum ama ders sırasında ufak bir sıkıntı çıkıyor o anda mesela olmuyor o anda sıkıntı yaşanabiliyor öğrenciler tarafından da etkili öğretmen tarafından da etkili mesela ben renk sensörleriyle alıştırma yaparken ortamın ışığı bile hani onu etkileyebiliyor onun duracağı yeri yansımasından dolayı etkileyebiliyor.”

[104] “en süper şaştığımız dedim ya gerçek hayatta sürtünmedir yerdeki tozdur vs.dir bunlardan yola çıkarak çocuk yazdığı programın sonucunu görmek istiyor ama diyoruz ki ona bazen çalışmıyor aslında algoritmasında hiçbir sorun yok ama robotta çalışmıyor beklenen sonuca varmıyor yada işte belli bir derece dönmesini istiyoruz O-botlarda işte onlar öyle bir mantık geliştirmişler işte bir dakikada 360 derece döner diyor şimdi o çocuk 90 derece döndürecek o zaman bir dakikanın dörtte birini alması gerekiyor ama tam anlamıyla 90 derece dönmüyor bir takım sapmalar oluyor o sapmaları görünce de aslında robotun varmasını istediği hedefe ulaşmıyor tamam gerçek hayatta bir takım şeylerle karşılaşıyor işte hava koşullarıdır tekerdeki tekerin yıpranmışı robotun tekerinde bile etki eden şeyler bunu da görmesi gerekiyor belki ama program mantığında simülatörde de o tarz sorunlar vardı yani bir saniye cinsinden süre geliyor derece dakika cinsinden bir takım şeyler yapıyor işte programını yazarken hesaplamalar yapıyor ama o hesaplamaların çok net yapmıyor”

[105] “her proje doğal olarak her robota da uygun olmuyor böyle bir robotta yok zaten olması da çok fazla beklenemez zaten bu tip problemler yaşanıyor en çok gördüğüm benim biz ara yüzle robot arasında o ilişkide çok sıkıntılar yaşayabiliyoruz ve de normal programlarla da robotlar çok koordineli çalışmıyorlar.”

[106] “Lise öğrencilerinin atölye çalışması adı altında yaptığı dört saat altı saatte çok daha iyi işler çıkabilir. Keyif alan öğrenciler kullanıldığında ama bizim ortaokul için benim için risk hassas parçalar ya bunlar. Bizim ROBOTIS’le ilgili böyle bir sıkıntımız yok. Yani o işlemci yere bile düşse çok şükür bir şey olmuyor. Hani çünkü bunları yere atıyorlar. Yerde dövüştürelim diyorlar. Onu yapıyorlar hani kendim kullanmayı çok tercih etmedim böyle bir şey problem yaşamamak için.”

[107] “devre elemanlarının bozulmaması çünkü ondan çok korkuyoruz burada şimdi çünkü tam devreyi yaparken devre elemanlarını kopartacak, kıracak veya işte bozacak diye düşünüyoruz çünkü hani gene tam o şey yapılır telafisi yapılır ders esnasında olması bizim

için çok büyük sıkıntı olur ders esnasında onun telafisini yapamayız orada bir devre elemanını kıracak olsa veya parçayı düşürecek olsa bir sonraki derste telafi ederiz ama o ders içerisinde o çocuğun o eğitimi alması gerekiyor”

[108] “Küçük çocuklarla çalıştığım için çünkü bazen endişeleniyorum. Parçalar/ gerçi yutma gibi bir şey olmuyor ama bazen o küçük parçaları birbirinden çıkarırken sökücüsünü kullanmıyor. Elini kullanıyor parça çok küçük olduğu için tırnağının arasına giriyor “ah elim acıdı” diyor. Parça biraz daha büyük olsa bunlar olmaz ama bu tamamen yaş rubumla alakalı benim artık öğrendiler kendilerine ne kadar ((minimumda?)) az zarar vereceğini.”

[109] “Evet işte yani genelde işte çocukların bağlantıları nasıl yapacağını yapması/ mesela bazen oluyor burada onun da eğitimini veriyoruz. Lehim yapmak mesela şimdi bağlantıları yapacağız. Çocuk kabloları birbirine bağlayacak ama nasıl bağlayacak? Bir lehim öğrenmesi lazım. Onlarda birazcık şey/ daha önce hiç yapmamışlar, lehim nedir bilmiyorlar. Birazcık öğrenmelerine burada biraz öğrenmeleri için zaman geçiyor. Bazen işte ellerini yakıyorlar korkuyorlar falan. O tarz şeyler olabiliyor.”

[110] “…çocuk lehim yapmak istemiyor Ortaokul çocuğu lehim yaparsın ama yapmamalısın yani sağlıklı bir kişisel güvenlik olarak iş güvenliği olarak sağlıklı bir alan olmuyor o kadar da endüstriyel olmamalı söyleyebileceğim bu…bir set vardı çocuk genel olarak elektronik parçaların kavramlarını ve işte görevlerini anlıyordu ve bunları mıknatısla birleştirdiği için hiç lehim falan yapmayıp birleştiriyordu ama sadece hazır olan şeyleri elektronik devre üzerinden işte verilen şablonları yapıyor çocuk nesil çok araştırıp çok üretime yönelmiyor o tasarımda onu ona yöneltmiyor”

APPENDIX B

INFORMED CONSENT FORM

This study is conducted by graduate student Cengiz Hakan Gürkanlı, Asst. Prof. Dr. Gülşen Töre Yargın, and Research Assistant Aslı Günay and is a part of the METU Industrial Products Design Department ID531 Methods of User Research course. This form is designed to inform you about the research.

What is the aim of the study?

The study aims to understand the needs and expectations of educational robot kits used in K-12 education from the perspectives of educators. The information gained will be useful in improving robot interaction and in designing new robot interactions.

What you need to know about participating:

Participation in this study is entirely voluntary. Data will be collected by voice recording during the study. You can abandon the study at any time.

If there are questions that you do not want to answer during the survey, you may not respond.

Data collected in the research and identity information will not be matched in any way, and the research results in publications will be presented anonymized. Only the researchers and course instructors will be able to reach the collected data. The results of this research may be used for scientific and professional publications or for educational purposes, but the identity of the respondents will be kept confidential.

If you would like to learn more about the research:

You can send your questions and comments about the study to the researchers: hakan.gurkanli@metu.edu.tr, tore@metu.edu.tr, and agunay@metu.edu.tr.

I have read the above information and participate in this study entirely voluntarily.

(Once you complete and sign the form, give it back to the practitioner).

Name Date

Signature

ARAŞTIRMAYA GÖNÜLLÜ KATILIM FORMU

Bu çalışma ODTÜ Endüstri Ürünleri Tasarımı Bölümü ID531 Kullanıcı Araştırması Yöntemleri (Methods of User Research) dersi kapsamında yüksek lisans öğrencisi Cengiz Hakan Gürkanlı, Yrd. Doç. Dr. Gülşen Töre Yargın ve Ar. Gör. Aslı Günay tarafından yürütülmektedir. Bu form sizi araştırma hakkında bilgilendirmek için hazırlanmıştır.

Çalışmanın Amacı Nedir?

Çalışma, K-12 eğitiminde kullanılan eğitim robot kitlerine ilişkin ihtiyaç ve beklentileri eğitimciler perspektifinden anlamayı amaçlamaktadır. Edinilen bilgi robot etkileşiminin iyileştirilmesinde ve yeni robot etkileşimlerinin tasarlanmasında fayda sağlayacaktır.

Katılımınızla İlgili Bilmeniz Gerekenler:

Bu çalışmaya katılmak tamamen gönüllülük esasına dayalıdır. Çalışmada ses kaydı ile veri toplanacaktır. İstediğiniz anda çalışmayı bırakabilirsiniz. Araştırma esnasında cevap vermek istemediğiniz sorular olursa cevap vermeyebilirsiniz.

Araştırmada toplanan veriler ve kimlik bilgileri herhangi bir şekilde eşleştirilmeyecek, araştırma sonucu yapılacak olan yayınlarda bilgi anonimleştirilerek sunulacaktır. Toplanan verilere sadece araştırmacı ve ders yürütücüleri ulaşabilecektir. Bu araştırmanın sonuçları bilimsel ve profesyonel yayınlarda veya eğitim amaçlı kullanılabilecek, fakat katılımcıların kimliği gizli tutulacaktır.

Araştırma ile ilgili daha fazla bilgi edinmek isterseniz:

Çalışma ile ilgili soru ve yorumlarınızı araştırmacılara hakan.gurkanli@metu.edu.tr tore@metu.edu.tr ve agunay@metu.edu.tr adreslerinden iletebilirsiniz.

Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.
(Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyad Tarih
İmza

APPENDIX C

INTERVIEW QUESTIONS

The research questions are aimed at creating design criteria for improving and enhancing robot interaction in robot-based education applications.

QUESTIONS AIMED AT THE TEACHER

1. How long have you been teaching for?
2. Which branch or branches do you teach?
3. How long have you been personally using robotic applications? In which branches do you use it.
4. How long have you been using robots for education? Eğitimde (başka) hangi dallarda kullanıyorsunuz?
5. Have you got any training on robots? What kind of training have you got? What was the scope of the training?
6. What type of robots did you use? Did you choose these robots? If so, why?
7. What pieces of software do you use for the training process? Did you choose these pieces of software? If so, why?

QUESTIONS AIMED AT EDUCATION

8. According to you, how should a robot, used for training purposes, be?
9. For what purposes do you use robots in the training process? Why?
10. Apart from what you mentioned, what other purposes can robots (robotic applications) be used for? (In which situations can robotic applications be used when educational purposes are considered?)
11. What are the benefits of using robots in education for students?
    a. What are the educational benefits? Why?
    b. What are the developmental benefits? Why?
    c. What are other benefits? (are there any other benefits that come to mind except educational and developmental benefits? If so, what?) Why?
12. What are the problems or deficiencies that you encounter when using robots for training? Why?

QUESTIONS AMIED AT THE PROJECT

Could you give an example of one of the most typical projects you carry out? Let's discuss the questions that I will ask now with this project in mind.

13. What educational aims did you set when you created the project?

14. Could you describe the project process? Did you have a plan? Could share it with me? (If not: Would you describe the steps of the process? –Let's write together- Step 1: …) On the steps (for each stage):
    a. What kind of problems do you have in interact with the robot at this stage? Why? (Why do you think these problems arise?) Do you have any suggestions for improving/ enhancing this interaction?
    b. What kind of problems do the students have at this stage in interacting with the robot? Why? (Why do you think these problems arise?) Do you have any suggestions for improving/ enhancing this interaction?

COMPARISON OF ALTERNATIVE ROBOT SYSTEM DESIGNS

15. Now let's talk about alternative robot designs that I will show you. (For each alternative)
    a. What do you think about this?
    b. What can be the benefits be for education?
    c. When you compare it with what you use, what are the positive aspects of this alternative in terms of robot interaction? What are the negative aspects?
    d. What are the positive aspects of this alternative, in terms of robot interaction, when compared to others? What are the negative aspects

RÖPORTAJ SORULARI

Araştırma soruları, robot ile eğitime dayalı uygulamalarda, robot etkileşiminin geliştirilip iyileştirilmesine yönelik tasarım kriterleri oluşturulmasını amaçlamaktadır.

ÖĞRETMENE YÖNELİK SORULAR

1. Ne kadar süredir öğretmenlik yapıyorsunuz?
2. Hangi dalda veya dallarda eğitim veriyorsunuz?
3. Kişisel olarak ne kadar süredir robotik uygulamalar kullanıyorsunuz? Hangi dallarda kullanıyorsunuz?
4. Ne kadar süredir eğitim için robot kullanıyorsunuz? Eğitimde (başka) hangi dallarda kullanıyorsunuz?
5. Robotlar ile ilgili herhangi bir eğitim aldınız mı? Ne gibi eğitimler aldınız? Eğitimin kapsamı nedir?
6. Hangi tip robotları kullandınız? Bu robotları siz mi tercih ettiniz? (Ettiyseniz) neden?
7. Eğitim sürecinde hangi yazılımlardan faydalanıyorsunuz? Bu yazılımları siz mi tercih ettiniz? (Ettiyseniz) neden?

EĞİTİME YÖNELİK SORULAR

8. Sizce eğitim amaçlı kullanılacak bir robot nasıl olmalı?
9. Eğitim sürecinde robotları hangi amaçlarla kullanıyorsunuz? Neden?
10. Bahsettikleriniz dışında robotlar (robotik uygulamalar) sizce başka hangi amaçlarla kullanılabilir? (Eğitim amaçları göz önünde bulundurulduğunda hangi durumlarda robotik uygulamalar kullanılabilir?)
11. Eğitim için robot kullanımının öğrencilere sağladığı faydalar nelerdir?
    a. Eğitimsel faydaları nelerdir? Neden?
    b. Gelişimsel faydaları nelerdir? Neden?
    c. Diğer faydalar nelerdir? (eğitimsel ve gelişimsel faydalar dışında aklınıza gelen başka faydalar var mı? Varsa nelerdir?) Neden?
12. Eğitim için robot kullanımda karşılaştığınız sorunlar veya eksikler nelerdir? Neden?

PROJEYE YÖNELİK SORULAR

Yürüttüğünüz projelerden en tipik olanlar birinden örnek verebilir misiniz? Şimdi soracağım soruları bu projeyi düşünerek tartışalım.

1. Projeyi oluştururken ne gibi eğitim amaçları belirlemiştiniz?
2. Proje sürecini tarif edebilir misiniz? Buna ilişkin benimle paylaşabileceğiniz bir planınız var mıydı? (Yoksa: Süreç adımlarını tarif eder misiniz? –Birlikte yazalım- Aşama 1:....)

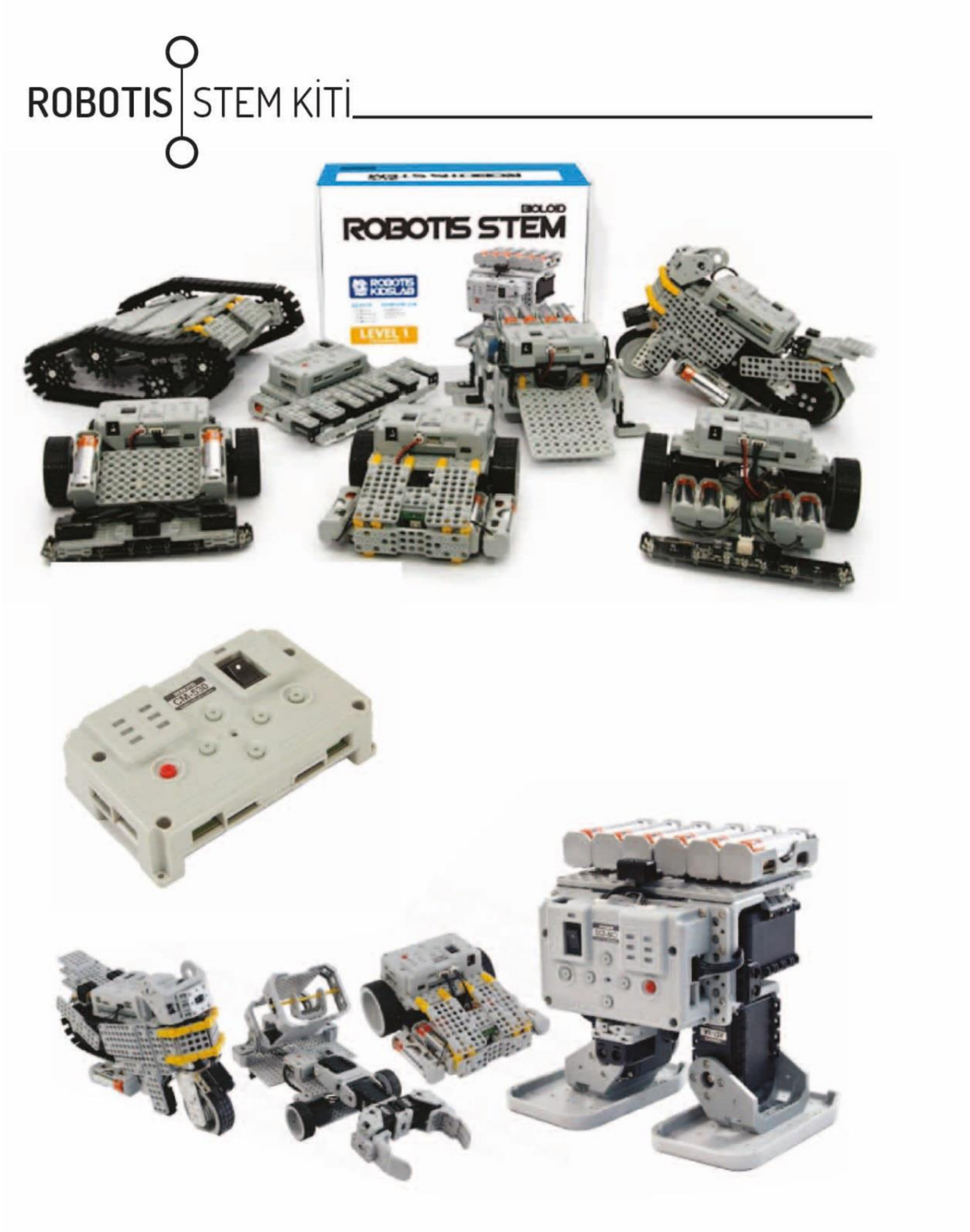
   Aşamalar üzerine (her aşama için):

   a. Bu aşamada robot ile etkileşime yönelik ne gibi problemler yaşıyorsunuz? Neden? (Sizce bu problemler neden kaynaklanıyor?) Bu etkileşimi geliştirmeye/iyileştirmeye yönelik önerileriniz var mı?
   b. Öğrenciler bu aşama robot ile etkileşime yönelik ne gibi problemler yaşıyor? Neden? (Sizce bu problemler neden kaynaklanıyor?) Bu etkileşimi geliştirmeye/iyileştirmeye yönelik önerileriniz var mı?

ALTERNATİF ROBOT SİSTEMİ TASARIMLARININ KARŞILAŞTIRILMASI

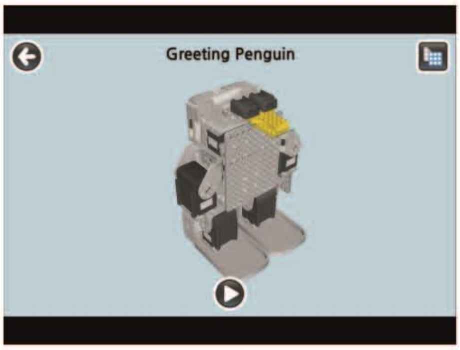
1. *Şimdi bir de size göstereceğim alternatif robot tasarımları üzerinde konuşalım.*
   (Her alternatif için)
   a. *Bunun hakkında ne düşüyorsunuz?*
   b. *Eğitim için faydaları neler olabilir?*
   c. *Kendi kullandığınızla karşılaştırdığınızda, sizce bu alternatifin robot etkileşimi açısından olumlu yanları nelerdir? Olumsuz yanları nelerdir?*
   d. *Diğerleri ile karşılaştırdığınızda, sizce bu alternatifin robot etkileşimi açısından olumlu yanları nelerdir? Olumsuz yanları nelerdir?*

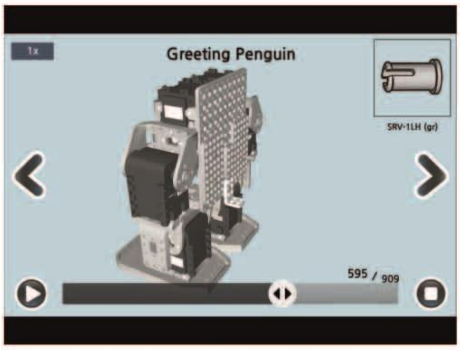
APPENDIX D




m.Design v 1.2.7
Product
Total : STEM : 16
ROBOTIS OLLO
ROBOTIS DREAM
ROBOTIS SMART
ROBOTIS SMARTⅡ
ROBOTIS MINI
ROBOTIS STEM
ROBOTIS PREMIUM
ROBOTIS

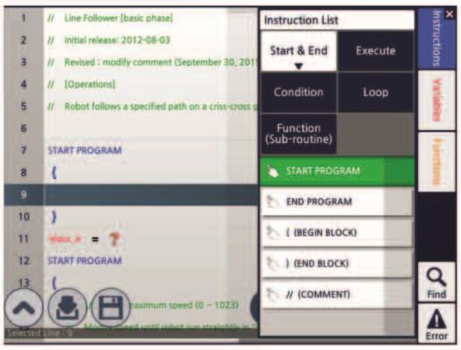

Total : 354
AX Horn


Greeting Penguin

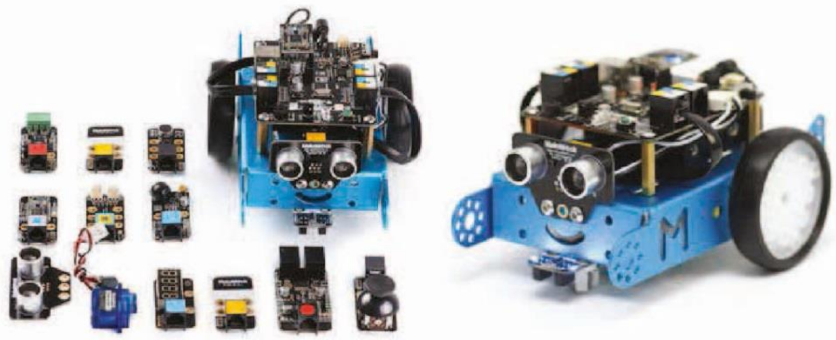

1x
Greeting Penguin
SRV-1LH (gr)
595 / 909

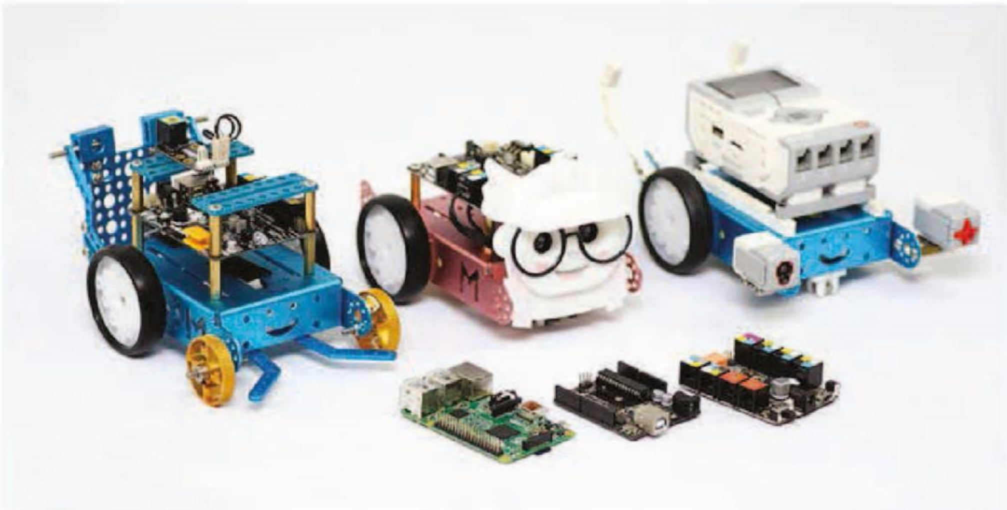

5 clap_finish
All
None


// Line Follower [basic phase]
// Initial release: 2012-08-03
// Revised : modify comment (September 30, 2015).
// [Operations]
// Robot follows a specified path on a criss-cross grid
START PROGRAM
{
// L/R wheel maximum speed (0 ~ 1023)
// Modify speed until robot run straightly in "Straightness_check_mode"
= 420
= 420
CM-530 (1.0)
Instructions
Variables
Functions
Find
Error

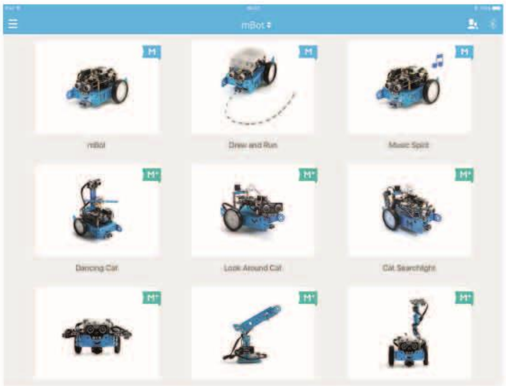

// Line Follower [basic phase]
// Initial release: 2012-08-03
// Revised : modify comment (September 30, 201
// [Operations]
// Robot follows a specified path on a criss-cross
START PROGRAM
{
}
START PROGRAM
{
Instruction List
Start & End
Execute
Condition
Loop
Function (Sub-routine)
START PROGRAM
END PROGRAM
{ (BEGIN BLOCK)
} (END BLOCK)
// (COMMENT)
Instructions
Variables
Functions
Find
Error

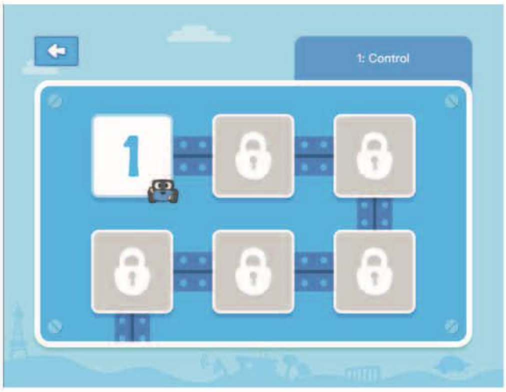
MAKEBLOCK mBOT

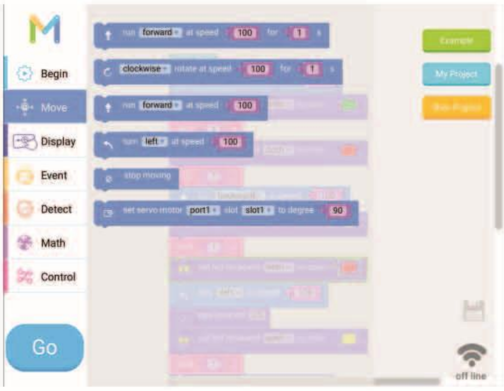


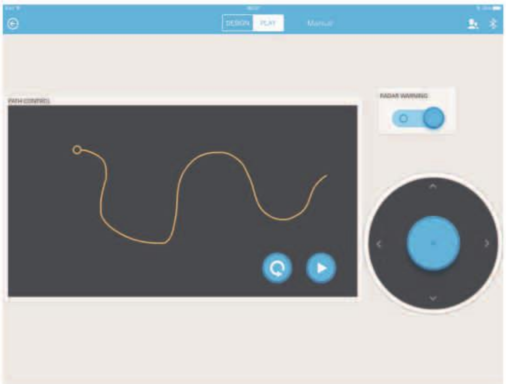


MAKEBLOCK mBOT UYGULAMA ARAYÜZLERİ









OZOBOT | OZOevo


Ozo Blockly
Getting Started with OzoBlockly
THEN
Load Ozobot


Ozo Blockly
Load Bit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ROMIBO | Sosyal Robot