FOSTERING SPATIAL ABILITIES OF SEVENTH GRADERS THROUGH AUGMENTED REALITY ENVIRONMENT IN MATHEMATICS EDUCATION: A DESIGN STUDY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BİLAL ÖZÇAKIR

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSHOPY
IN
THE DEPARTMENT OF ELEMENTARY EDUCATION

JUNE 2017

Approval of the Graduate School of Social Sciences

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ABSTRACT

FOSTERING SPATIAL ABILITIES OF SEVENTH GRADERS THROUGH AUGMENTED REALITY ENVIRONMENT IN MATHEMATICS EDUCATION: A DESIGN STUDY

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June 2017, 291 pages

In this study, design and development of an augmented reality learning toolkit for fostering spatial ability of seventh graders and their spatial understanding with this tool among different trials on mobile devices were reported. This study was conducted within two phases as preliminary and prototyping phases. The designed toolkit was evaluated, revised and redesigned throughout prototyping iterations with two mathematics education experts and two seventh grade students. Finally, possible contributions of intervention with this toolkit in terms of spatial ability and learning opportunities for seventh graders were investigated at the last prototyping iteration with eight seventh graders from various spatial ability levels.

Findings guided characteristics for designing an augmented reality learning toolkit with set of spatial tasks for seventh grade students. Findings also showed that students

found, used or adapt spatial strategies with this toolkit among continuum of holistic – analytic approaches in order to accomplish given tasks. In the light of these results, it can be inferred that students could perform and improve their spatial ability with this toolkit. Students did not encounter any technical difficulty with the last prototype of the toolkit, and they could use this toolkit, fluently. Therefore, this toolkit have showed practical usability in this study.

To conclude, augmented reality seemed helpful in enhancing the usage mobile devices, for not only just reading books or playing games but also learning mathematics. Thus augmented reality toolkit in this study presented a new way to use mobile devices for students or teachers in learning and teaching mathematics.

Keywords: augmented reality, spatial ability, spatial strategies, mathematics education, educational design research

ÖZ

MATEMATİK EĞİTİMİNDE ARTIRILMIŞ GERÇEKLİK ORTAMLARI İLE YEDİNCİ SINIF ÖĞRENCİLERİNİN UZAMSAL ZEKALARININ GELİŞİMİ: BİR TASARIM TABANLI ARAŞTIRMA

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Haziran 2017, 291 sayfa

Bu çalışmada, ortaokul öğrencilerinin uzamsal zekalarının geliştirmeye yönelik artırılmış gerçeklik tabanlı bir öğretim aracının tasarımı ve geliştirilmesi ile yedinci sınıf öğrencilerinin bu araç ile yaptıkları farklı uygulamalardaki uzamsal anlayışlarındaki değişimler bildirilmektedir. Bu çalışma eğitsel tasarım araştırması olarak tasarlanmıştır. Genel olarak, ön çalışma evresi ve prototip geliştirme evresi olmak üzere iki evreli bir eğitsel tasarım araştırması yapılmıştır. İlk iki prototip geliştirme döngülerinde artırılmış gerçeklik tabanlı öğretim aracı, iki matematik eğitimi uzmanı ve iki yedinci sınıf öğrencisinin çalışmalarından elde edilen veriler ışığında revize edilmiştir. Son döngüde ise bu öğretim aracı ile yapılan eğitimin uzamsal zeka ve öğrenme fırsatları açısından olası katkıları, çeşitli uzamsal zeka seviyelerinden seçilmiş olan sekiz yedinci sınıf öğrencisi ile araştırılmıştır.

Bu çalışmanın bulguları, öğrencilerin uzamsal zekalarını desteklemek için tasarlanan bir artırılmış gerçeklik tabanlı öğretim aracının ve uzamsal etkinliklerin temel özelliklerini ve tasarım ilkelerini ortaya çıkarmıştır. Bu öğretim aracı ile yedinci sınıf öğrencileri uzamsal stratejiler için bütünsel – çözümsel yaklaşımlar sürekliliğinde yer alabilecek stratejiler belirlemiş, uygulamış ve gerektiği durumlarda etkinliğe özel olarak uyarlayabilmişlerdir. Çalışmanın bulgularına göre, tasarlanan öğretim aracının öğrencilerin uzamsal zekalarını işe dökebilmeleri ve geliştirebilmeleri için fırsatlar sağladığı görülmektedir. Bunun yanında, öğrenciler artırılmış gerçeklik temelli öğrenme ortamına kolayca uyum sağlamışlardır. Bu sebeple, bu çalışma kapsamında tasarlanan öğretim aracı uygulanabilir bir eğitim aracı olduğunu kanıtlamıştır.

Bu çalışmada tasarlanan artırılmış gerçeklik tabanlı öğretim aracı, öğrenciler ve öğretmenler için matematiği öğrenirken ve öğretirken mobil cihazları kullanmanın yeni bir yolunu sunmaktadır. Bu çalışmada ele alınan ve tasarlanan öğretim aracını öğretmenler matematiksel kavramları görselleştirmek için yeni bir araç olarak öğrencilere ders esnasında sunabilirler.

Anahtar kelimeler: artırılmış gerçeklik, uzamsal zeka, uzamsal zeka stratejileri, matematik eğitimi, eğitsel tasarım araştırması

DEDICATION

To My Family

Who have always shown their trust in me…

ACKNOWLEDGEMENTS

There are many people who I would like to thank for their helps during my dissertation study. First of all, I am thankful to my supervisor Prof. Dr. Erdinç Çakıroğlu for his guidance, valuable comments, feedbacks and edits during my study. Moreover I would like to thank to the members of committee, Assoc. Prof. Dr. Çiğdem Haser, Assoc. Prof. Dr. Didem Akyüz, Assist. Prof. Dr. Erhan Güneş and Assist. Prof. Dr. Mesture Kayhan Altay for their helpful comments and guidance.

I am grateful to my colleagues at Ahi Evran University who have helped and provided suggestion throughout the completion of this dissertation.

I especially owe my thanks to my friends, Duygu Özdemir, Rukiye Ayan, Şenol Namlı, Ömer Faruk İslim, Uğur Başarmak and Cahit Aytekin, for their encouragements, suggestions and moral support.

Finally, I would like to express my sincere appreciation to my wife Nurgül Özçakır, my parents Kadriye and Mehmet Ali Özçakır, and my brothers Ömer Yasin and Ahmet Özçakır for their support, encouragement, tolerance, patience and helps. Without their unconditional love and their pray, I cannot achieve to be here.

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LIST OF ABBREVIATIONS

AR	Augmented Reality
ARLE	Augmented Reality Learning Environment
CAS	Computer Algebra Systems
CST	Content-specific Technologies
DGS	Dynamic Geometry Software
EDR	Educational Design Research
HMD	Head-mounted Display
ICT	Information and Communications Technology
MISAR	Model for Improving Spatial Ability with Augmented Reality
MoNE	Ministry of National Education
MSMC	Middle School Mathematic Curriculum
NCTM	National Council of Teacher of Mathematic
NRC	National Research Council
SB	Smart Glasses Based
SDK	Software Development Kit
SOC	Spatial Operational Capacity
SPATIAL-AR	Spatial Augmented Reality Toolkit
TB	Tablet Based
TSA	Training of Spatial Ability
VR	Virtual Reality

CHAPTER ONE

INTRODUCTION

Geometry can be considered as a bridge between real life and mathematics, since, historically, basic elements of it originates from real life applications. Nowadays, in order to provide effective learning environments, instructional technology researchers tend to establish near to real life applications with technology based environments. In this sense, novel technologies can be helpful in providing real life applications of abstract concepts in mathematics. One of these technologies is augmented reality (AR). The AR is a type of the virtual reality (VR), and a technology that allows users experience reality by superimposing virtual objects on real world. With the help of the AR, both students and teachers have an opportunity of working directly with shared virtual objects in real world. While working with virtual objects, spatial relationships between and within objects can be realized and understood more and effectively than with conventional methods either concrete materials or desktop based computer technology (Kaufmann, 2004).

NCTM (2000) stated that school geometry provides learners a way to describe, analyze and understand structures in the real world. In addition, since geometry provides spatial intuition, spatial sense and geometry are inherently linked (Ontario Ministry of Education, 2014). In middle schools, students deal with basic characteristics of two dimensional and three dimensional geometric objects, and spatial relationships among them (Ministry of National Education [MoNE], 2013; National Council of Teacher of Mathematics [NCTM], 2000). Moreover, learning geometry enhances students' logical thinking abilities, spatial understanding about the real environment, readiness to understand higher level mathematical concepts, and understanding of mathematical arguments (Suydam, 1985).

The significance of spatial ability has been reported by researchers who examined students' performance and its relation with spatial ability (Battista, 1990; Clements & Battista, 1992; Maier, 1996; Olkun, 2003). The National Research Council (NRC) (2006) claims that spatial ability is a key element to be successful in thinking and solving problems. In fact, people share spatial information in real life routinely while giving directions of some places, describing visual properties of some things, explaining their thoughts about some objects, and others. (Galati & Avraamides, 2012). In other words, spatial ability involves skills that are useful in real life for contexts such as mobility, navigation or visual literacy. Therefore, in many countries, developing some components of spatial ability such as mental rotation and spatial visualization is a goal school mathematics curriculum, including Turkey (Clements & Battista, 1992; MoNE, 2013). However, although some contents for developing spatial ability exist in school mathematics, the NRC (2006) claims that it is presumed through curriculum, but exclusively taught. In Turkish middle school mathematics curriculum (MSMC), there are objectives specifically aiming to develop spatial ability of students (MoNE, 2013). But, these concepts are typically represented on textbooks with two dimensional projections of figures.

NCTM (2000) states that students should start to develop their visualization skills through hands-on activities with geometrical figures and objects, use technology to view and explore two dimensional and three dimensional objects, and move on analyzing and drawing perspective and side views of the three dimensional objects. Similarly, many researchers show that spatial ability of students at different ages can be trained (Battista, Wheatley & Talsma, 1982; Embretson, 1987). Usage of physical models or real models have shown good results in developing spatial ability (Maier, 1996). However, solid models are static and usually are not changeable without breaking. At this point, technological tools can provide dynamic and interactive virtual shapes. By this way, students have the opportunity to make dynamic interactions with technological tools. On the other hand, virtual three dimensional objects on computer screen may not be seen as realistic as physical models to students (Alcaniz, Contero, Perez-Lopez & Ortega, 2010). What happens if we replace computer screen with something which has the capacity for representing virtual three dimensional objects far more realistic and give us opportunity to interact with these object as real objects?

1.1. A New Tool for Supporting Learning

Human imagination has always affected our lives. Lives of human beings proceed to higher levels by power of imagination (Garrett, 2011). Technological changes and tools are the products of these progresses and achieved imaginations of people (Pelaprat & Cole, 2011). In recent decades, people have started to take advantages of technology in nearly every step in their lives (Wilken & Goggin, 2012). Since education forms a basis for both imagination and life, it is apparently inevitable to use technology in education (Santosh, 2013).

Traditional environments for learning geometry through viewing two dimensional figures in textbooks or blackboards create some kind of "cognitive filter" on realizing these figures as representative for three dimensional objects (Alcaniz et al., 2010). Furthermore, since the manipulative interaction with the objects in analytic space on computer screen is possible through using mouse and keyboard, the cognitive filter still remain as an issue while working with three dimensional objects through computer screen (Alcaniz et al., 2010, Shelton & Hedley, 2004). The AR technology, on the other hands, helps us to deal with this cognitive filter by combining real environment with virtual elements.

In AR environment, learners view the real environment with virtual elements on a screen through tablet, smartphone or head-mounted display (HMD), or view without any interface with see-through HMD (Alcaniz et al., 2010). Therefore, AR possesses a place between real world and virtual environment (Milgram, Takemura, Utsumi & Kishino, 1995). In other words, AR can be considered as a bridge on the gap between real world and virtual world (Figure 1.1).

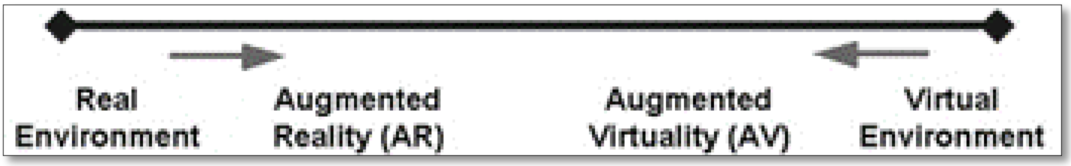


Figure 1.1. Milgram and others' (1995) Reality-Virtuality Continuum

Typically, in target-based AR systems, users interact with pieces of target papers which are detected by a camera and augmented with relevant virtual objects by a computer, HMD or handheld screen (Bonnard, Verma, Kaplan & Dillenbourg, 2012). Due to the feature of posing virtual objects onto real world, AR has potential to be used in many areas, especially in education, for the purpose of training.

The core benefit of implementing the AR interface in education is that students actually have opportunities to see virtual objects as if they really exist in real environment and to interact these virtual objects collaboratively with natural ways of interactions (Figure 1.2).

Figure 1.2. Learners were exploring sphere, cones and conic sections with an AR interface (Kaufmann & Schmalstieg, 2003)

Learners can recognize and comprehend spatial problems and spatial relations between and within objects while interacting and working directly with virtual elements as in real settings, more effectively (Kaufmann, 2004). Similarly, previous research findings indicate that AR interface reduced mental effort more than other interfaces, such as paper-pencil instruction or computer-assisted instruction in common ways (Haniff & Baber, 2003; Wang & Dunston, 2006). In addition, researchers stated that AR could influence learning as opposed to traditional classroom materials, more positively (Chen, 2006; Vilkoniene, 2009). Previous research also revealed that AR interface has potentials to enhance understanding of concepts, improve students' learning in spatial structures and functions (Lindgren & Moshell, 2011; Kaufmann, 2004; Vincenzi, Valimont, Macchiarella, Opalenik, Gangadhara & Majoros, 2003), develop students' long-term memory retention (Vincenzi et al., 2003), and increase students' motivation (Kaufmann & Dünser, 2007).

1.2. Problem Statement

In school mathematics, representation of three dimensional concepts generally relies on orthographic and perspective projections. Since pages of textbooks and blackboard are two dimensional objects, they only permit these types of representation modes. Thus, students experience difficulties in realizing and imagining these projections as representation modes of three dimensional concepts (Ma, Wu, Chen & Hsieh, 2009; Pittalis & Christou, 2010). These difficulties are defined as cognitive-filter by Alcaniz and other (2010). Brown and Wheatley (1997) stated that spatial ability of students, which is related to combining and analyzing visualization of three dimensional objects by means of representing objects with two dimensional projections, requires analyzing a projective representation of an object in terms of its components and recombining these components. In other words, students should be able to transfer information between three dimensional objects and their projective representations by combining and analyzing their components in order to comprehend spatial information for these objects. These transfers from projective representations to three dimensional objects need understanding, manipulating or interpreting relationships of their components mentally (Tatre, 1990). These mental processes could be developed and trained with appropriate learning tasks (Maier, 1996).

Researchers stated that the spatial ability could be improved and trained by using concrete manipulative materials or by using digital materials in school mathematics (Olkun, 2003; Sundberg, 1994). In educational settings, students can use manipulatives to explore three dimensional concepts and objects. However, most of the manipulatives could be static and most of them are not changeable without breaking. On the other hand, computer technology provides students changeable dynamic objects and also animated demonstration of concepts. However, our world is not two-dimensional as projected on screens of computers and mobile devices. Thus, even if students use computers, tablets or mobile phones in common ways as a supplementary for educational contexts, they still deal with the cognitive-filter which is caused from two dimensional representations of our three dimensional world (Shelton & Hedley, 2004). This might be the biggest limitation in providing real life experiences to students for educational contexts via computer screens. This limitation might be overcome with AR technology. AR technology, as described before, is a derivative of VR with a significant difference such that AR technology supplements reality with virtual objects rather than completely replacing it with virtual one like in VR.

Taking in consideration the important role of spatial ability in mathematics as well as in real life, improving spatial ability has very important place in education to eliminate negative effects of the cognitive filter on students' spatial understanding for representations of three dimensional objects. Because, traditional learning environments such as textbooks or computers have limitations while representing three dimensional objects in two dimension via orthographic or perspective projections. The AR interface gives us very important and effective ways of learning for three dimensional geometric objects by mimicking reality via only supplementing it with virtual elements in order to overcome this cognitive filter.

As stated before, people share spatial information every time while describing a place, object or others to another person (Galati & Avraamides, 2012). Therefore, they tend to build spatial ideas while explaining them to other individuals (Youniss & Damon, 1992). Moreover, learners' interactions with peers play a key role for their learning while working with virtual objects (Park, 2012). The augmented reality learning environment (ARLE) provides such opportunities for multi-user learning experiences with a shared virtual space among learners. Hence, virtual objects can be seen, interacted and used by other learners simultaneously while they have the opportunity of seeing other learners' actions and interactions, as well. Previous research claimed that AR helps to improve spatial ability of students in collaborative learning environment as well as retain and translate this ability on other environments (Kaufmann, 2003; Kaufmann, 2004; Matcha & Rambli, 2011). Similarly, AR provides an enhancement of shared learning environment (Billinghurst & Kato, 2002). Hence, AR technology enhances interactions of learners between themselves and with virtual objects that is difficult with desktop-based technology since a disconnection exists between the task space and display space in instructional environment based on desktop-based technology (Billinghurst & Kato, 2002). Therefore, AR technology provides more solid and authentic ways of collaborative and immersive environment similar to real world by providing opportunities for interactions among learners as well as virtual objects in order to foster their learning gain (Park, 2012).

Since the AR has still been relatively a novel technology in educational fields, there is a need for research based guides to design effective and feasible AR tools for school learning. Moreover, a mobile AR tool for handheld devices or smart glasses could provide more realistic interactions for learners since learners can move freely in learning environment with these mobile devices. Therefore, the main focus of this study are to form needed design principles to set up an effective, feasible and applicable ARLE and to design mobile AR interface for fostering spatial ability of students in line with these design principles. Thus, general purposes of this study was to find out factors to be considered in order to design and develop an AR learning toolkit, which includes set of spatial tasks and a mobile AR interface, in order to foster spatial understanding of seventh grade students in an ARLE. Correspondingly, the literature was reviewed within the context of this study in order to derive needed characteristics to provide a learning environment for improving spatial ability with a mobile AR included spatial tasks. The collection of these spatial tasks and the mobile AR interface compose of a toolkit which was named spatial augmented reality (SPATIAL-AR) toolkit throughout this research.

The literature guided design and development process of SPATIAL-AR toolkit by providing needed characteristics of ARLE, tasks and interface. In other words, conjectured design principles were considered as a framework while designing and developing SPATIAL-AR toolkit and planning an ARLE to utilize this toolkit. In this research, the following research questions were answered within cycles of iterations.

Research question of first prototyping cycle:

- To what extent does the SPATIAL-AR toolkit embody the design principles?
- To what degree is the SPATIAL-AR toolkit relevant to intended curriculum?

Research questions of second prototyping cycle:

- Is the SPATIAL-AR toolkit valid and relevant with the intended curriculum?

Research questions of third prototyping cycle:

- Is the SPATIAL-AR toolkit efficient in improving spatial ability with mobile devices?
- How effective is the SPATIAL-AR toolkit in improving spatial ability and enhancing learning opportunities?

In this study, the SPATIAL-AR toolkit was designed to support students' active participants, self-assessment process and interactions between each other during carrying out spatial tasks, since technological tools, especially AR interface, could be suitable to train spatial ability as well as enhance natural ways of interactions of students between each other and virtual objects in learning environment. With the help of AR interface, one may have the opportunity to see various views of a three dimensional object by providing features of rotating, transforming and representing in real environments.

1.3. Significance of the Problem

Individuals gain knowledge and skills through a variety of representations including visual, auditory, and in some situations tactile (Park, 2012). With the help of the technological tools, we can show or use multiple representations in instructional phase. By this way, they provide students an opportunity to explore mathematical relations interactively. Moreover, technological tools, especially AR interface, are suitable to visualize virtual objects in real time and real environment. Because, with the help of AR interface, one may have the opportunity of seeing various views of a three dimensional object by having features of rotating, transforming and representing in real environment, and animated representations of both two and three dimensional objects. With AR interface, both traditional textbooks and technology gain a new place as educational contexts (Özçakır, Çakıroğlu & Güneş, 2016). The digital objects and representations, integrated virtually onto real environment, result in a deeper learning, and could help to eliminate the cognitive filter about representing three dimensional objects by two dimensional projections.

One of the basic suggestions of MSMC is about effective usage of technological tools in learning environment for learning gains (MoNE, 2013). In parallel with this, MoNE has started to provide smart boards to classrooms and tablets to students in order to integrate Information and Communication Technologies (ICT) with educational settings. Although these recent advances have provided the opportunities of using computer technology in teaching and learning, effective, practical and various ICT based learning tools for all content area of mathematics are needed in order to use these tablets and smart boards for the purpose of learning. In this study, spatial tasks based on AR interface were developed and used in intervention for improving spatial ability in mathematics lesson. The collection of spatial tasks and mobile AR interface represent a new way to use tablets that have been provided to students throughout Fatih project (Movement of Enhancing Opportunities and Improving Technology) especially in mathematics lessons by providing an AR software for these tablets. Therefore, it was also supposed to enhance the usage of tablet not for just reading books but for as a tool for mathematics since AR can be used as an educational medium, and nowadays it is more accessible to young users (Radu, 2014).

Although previous studies have evidences for that AR environments have potential to improve students' learning, there has yet been little research about ARLE in Turkey for mathematics education. Moreover, since smart glasses have still expensive and in developer stage, studies about design principles for mobile AR interface for smart glasses and usage of them in instructional phases have been limited in number. Therefore, there occurs a need to understand how AR learning tools enhance spatial ability of Turkish middle school students, and what constitute principles for designing a mobile AR for tablets and smart glasses as well as usage of them in lessons. Moreover, design principles in this study guide curriculum and material developers to develop suitable tasks and materials in order to provide ways of using tablets, provided through Fatih project, in ARLE. Therefore, with the help of SPATIAL-AR toolkit which was discussed through this study, teachers are provided with a new tool to visualize mathematical concepts and students could be supported with this new tool as a new learning material.

1.4. Definition of Important Terms

Augmented Reality: It is a type of VR. It supplements and enhances reality rather than completely virtualizing and replacing it. In other words, the AR enhances reality by mixing views of real environment with virtual objects (Azuma, 1997). In learning environments, AR provides students a unique opportunity of "walking around" virtual objects in real environment (Kaufmann, 2011).

Head-Mounted Display: A HMD is a type of headgear, which is often used for training and in virtual environments. A HMD is operated by superimposing a visual information display (3D stereoscopic image) over a viewer's field of view (Liu, Jenkins, Sanderson, Fabian, & Russell, 2010).

Smart Glasses: It is a type of HMD. It is a wearable computer glasses to visualize virtual images as if they were in the real world. In other words, it has own operating system and sensors to operate without connected any computer or external device (Rauschnabel, Brem & Ro, 2015).

Spatial Ability: It is defined as "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1993, p.3).

SPATIAL-AR toolkit: It is an augmented reality learning tool designed and developed in order to foster students' spatial ability throughout the study.

Target Image: It is also known as marker for marker-based or target-based AR interface. Target-based AR interface superimposes virtual elements like animations, three or two dimensional models onto a target image in the real world. AR interface detects and processes information on a known target image in order to match and project related virtual elements on specified locations in real world by the target image (Rekimoto, 1998).

Virtual Reality: It is an artificially created environment which is experienced throughout sensory stimuli such as visual or auditory stimuli, which is provided by a computer. Within this environment, actions of an individual partially determine what happens in the environment (Vila, Beccue & Anandikar, 2003). VR is not the focus of this study, but it shares similar properties with AR, such as presence, spatial properties, and the ability to present tactile modality through the use of haptic devices.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents the review of the related literature. For this purpose and based on the main focus of the research, the review is organized into seven sections. The first section is about spatial ability and spatial strategies. After that reviews of the research on spatial ability and relation with mathematics are presented. The next section focuses on the literature that provides ideas about possible effects of using technology-based tools in improving spatial ability. This is followed by a section which summarizes role of technology in mathematics education. After that studies about spatial ability with technological tools are reviewed. The following section includes reviews some information about augmented reality (AR), and the studies about learning with AR are presented. At last, a brief summary of the review of the related literature is presented.

2.1. Spatial Ability and Strategies

Many different terms can be found to define and describe spatial ability in the literature. For example, *spatial thinking* (NRC, 2006; Yakimanskaya, 1991), *spatial sense* (NCTM, 1989), *spatial skills* (Tartre, 1990), *spatial reasoning* (Battista, 2007; Clements & Battista, 1992; NRC, 2006), *spatial cognition* (Sjölinder, 1998) are presented by researchers to define mental visualization, manipulations as well as rotations for figures and shapes. First of all, *spatial ability* has been defined as "the ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1993, p.3). *Spatial thinking* has been defined as a cognitive activity which helps a person to construct and manipulate spatial representations of objects in order to solve problems (Yakimanskaya, 1991). On the other hand, Battista (2007) defined s*patial reasoning* as "the ability to see, inspect, and reflect on spatial objects, images, relationships, and transformations" (p. 843). In addition, NRC (2006) defines *spatial thinking* and *reasoning* as one term as "Spatial thinking, or reasoning, involves the location and movement of objects and us, either mentally or physically, in space" (p. 3). NCTM (1989) defined *spatial sense* as "an intuitive feel for one's surroundings and objects in them". Moreover, *spatial skill* has been defined as the cognitive skills related with understanding, manipulating, or interpreting relationships spatially (Tatre, 1990). Lastly, *spatial cognition* was referred as which enables a person to handle spatial relations and orientations of objects within spatial tasks in three dimensional space (Sjölinder, 1998). In brief, the essence of these definitions implies common ideas like ability of rotating, transforming or envisioning an object and manipulating its properties mentally.

Similar to the use of multiple concepts to define spatial ability, there are several categorizations for components of spatial ability, too. Battista (1994), and Clements (1998) categorized spatial ability into two components as *spatial orientation* and *spatial visualization*. Similarly, Pellegrino and Kail (1982) divided spatial ability into two categories but as *spatial relations* and *spatial visualization*. Additionally, some researchers categorized spatial ability into three elements as *mental rotation, spatial perception* and *spatial visualization* (Linn & Petersen, 1985) or as *spatial visualization, spatial orientation*, and *spatial relations* (Lohman, 1993). Maier (1996) claims that due to a variety of spatial-visual problems which we are faced in today's technological worlds, and to gain detailed knowledge of spatial abilities, there is a need for a specification into more than three elements. Therefore, Maier (1996) distinguishes five elements of spatial ability as *mental rotation, spatial perceptions*, *spatial visualization*, *spatial relations*, and *spatial orientation*. In addition, Maier (1996) suggests that the technological developments demand the training of these five elements. Although there were different categorizations for components of spatial ability, these all components could form a common sense for spatial ability.

In general, *spatial perception* is the ability to designate spatial relationships about the location of the vertical or the horizontal despite of distracting information (Maier, 1996). *Spatial visualization* is the skill to visualize and manipulate complex spatial information for a figure when there is a movement or displacement among components of the figure (Linn & Petersen, 1985; Maier, 1996). *Mental rotation* is the skill to make a rapid and accurate rotation of two or three dimensional figures mentally (Linn & Petersen, 1985; Maier, 1996). *Spatial relations* refer to the skill to understand the spatial configuration of objects or components of an object and their relations to each other (Maier, 1996). *Spatial orientation* is "understanding and operating on relationships between different positions in space, especially with respect to one's own position" (Clements, 1998, p.11). As is seen from the literature review, there is no general agreement on both definitions of spatial ability and components of spatial ability. On the other hands, Fennema and Sherman (1977), and van Garderen (2006) argued that spatial visualization component of spatial ability is more related to mathematics achievement and also the focus is mainly given on spatial visualization component in terms of objectives related to spatial ability in seventh grade mathematics curriculum of Turkey (MoNE, 2013). Therefore, this study focused on spatial visualization ability.

In literature, some strategies to make use of spatial ability while solving spatial problems can also be found. Studies tend to deduce two types of spatial strategies as holistic and analytical approaches where holistic approach focuses on objects or spatial information as a whole, and analytic approach focuses on objects or spatial information by reducing them in simpler forms and processing systemically (Burin, Delgado & Prieto, 2000; Eme & Marquer, 1999; Glück & Fitting, 2003; Gorgorio, 1998; Workman & Lee, 2004). For example, a student could solve a spatial problem either by thinking object as a whole and envisioning how many components in touch or by simply counting the components in touch in a systematic way such as from left to right or top to bottom (Hsi, Linn & Bell, 1997, Kayhan, 2012). These two approaches could be considered two end points of a continuum for holistic – analytic approaches of spatial strategies (Glück & Fitting, 2003). Moreover, Hsi and others (1997) defined an intermediate approach between of holistic and analytic approaches which was named pattern-based strategy. This strategy focuses on separating objects or spatial information into familiar elements or previously solved cases. As an example, student brakes down objects into familiar parts or focuses on each layer at once (Table 2.1).

Table 2.1. Spatial strategies for solving tasks from studies of Burin and others (2000), Glück and Fitting (2003), Hsi and others (1997), Kayhan (2012), and Workman and Lee (2004).

Holistic Strategies	Intermediate Strategies	Analytic Strategies
Mental rotation and manipulation	Partial rotation and manipulation	Comparing based on key feature
Counting as whole	Counting as partial	Counting systemically
Following a route with spatial relations	Following a route with partial spatial relations	Following a route without spatial relations

Compared to strategies in holistic approach, one can solve a spatial task with strategies for analytic approach in more time but less effort, since spatial information is reduced less complex one (Glück & Fitting, 2003). Generally, people can use holistic strategies for simpler spatial tasks. However, if spatial tasks become more complex in terms of spatial information, strategies tend to move to a more analytic approach by dividing spatial information to less complex parts (Figure 2.1).

Figure 2.1. Continuum of holistic – analytic approaches for spatial strategies

On the other hand, choice for strategy can be affected by spatial ability level. Some studies show that if students have low spatial ability levels, they tend to solve spatial problems without using no strategy, or with analytical approaches or ineffective usage of holistic approaches where as high spatial ability students more likely tend holistic approaches (Gitimu & Workman, 2008; Lohman & Kyllonen, 1983). Similarly, Snow

(1980) deduced that low and high spatial ability students differed in choice of strategies, efficiency in using a strategy, and flexibility in changing strategies as tasks characteristics changed. Therefore, task characteristics affect choosing spatial strategies as well as students' spatial ability level (Glück & Fitting, 2003; Hsi, et al., 1997; Kayhan, 2012).

Spatial ability is often related with the experience of students, their choices for strategies and training to use these strategies to solve problems (Strong & Smith, 2002). According to Khoza and Workman (2009) spatial ability could be thought as combination of these aspects. Hence, students can be trained to choice appropriate strategy for spatial tasks and use effectively for solving problems, as a consequence to develop their spatial ability, as well.

2.2. Spatial Ability and Mathematics Education

In Turkish Middle School Mathematics Curriculum (MSMC), training spatial ability is subjected and handled throughout mathematics lessons (MoNE, 2013). The objectives related to spatial ability in MSMC include directions like; to determine the line of symmetry, to draw the line of symmetry, to explain rotation, to explain reflection, to understand folded and unfolded nets, to identify symmetry or views of the three dimensional objects (MoNE, 2013). Therefore, it can be said that MSMC contains objectives to refer mental rotation, spatial orientation, spatial relations, and spatial visualization through fifth to eighth grade.

The literature contained discussions about the possible relations between mathematics achievement and spatial ability. There are some evidences for relationship between spatial ability and mathematics achievement as well as other fields such as science achievement, navigation in environment and others (Battista, 1990; Clements & Battista, 1992; Gardner, 1985; Higgins, 2006; Olkun, 2003; Sundberg, 1994). For instance, some researchers found positive correlations between science achievement and spatial ability (Gardner, 1985; Pallrand & Seeber, 1984; Pribyl & Bodner, 1987). Furthermore, Higgins (2006) states that a person who has high spatial ability is very good at understanding maps, navigating, solving puzzles and giving different representations for problems.

The spatial ability has been also referred to as an important cognitive factor in learning geometry. In other words, learning activities based on spatial visualization and manipulation could improve geometric learning (Christou, Jones, Pitta-Pantazi, Pittalis, Mousoulides, Matos, Sendova, Zachariades & Boytchev, 2007). As mentioned before, spatial ability and understanding have been related achievement of students in many fields. Therefore, improving spatial ability could be important dealing with difficulties in learning which requires some kind of spatial understanding. In literature, there is evidence that spatial ability could be developed with appropriate learning tasks (Maier, 1996).

According to Bishop (1973) and Sundberg (1994), spatial ability of primary and middle school students could be improved by using concrete manipulatives in instructions, and by making students active in lessons they are able to build ideas about shapes better, rather than passive observation. In addition, spatial ability was stated to be able to be improved with digital materials (Olkun, 2003). Previous studies came up with spatial contents for tasks to improve spatial ability through some models and task types. One of them is Spatial Operational Capacity (SOC) model (Figure 2.2). In studies of Sack and van Niekerk (2009), Sack and Vazquez (2013), and Sack (2013), they designed instructions based on the SOC model with dynamic geometry activities in order to improve students' spatial ability. In the SOC model, students engage in activities that proceed cycles between three dimensional objects, two dimensional isometric models, semiotic representations, and verbal expressions or written descriptions of virtual objects (Sack, 2013). The SOC model emphasizes using figures, conventional-graphic pictures that resemble three dimensional figures (isometric drawings), verbal descriptions by using appropriate mathematical language, and semiotic descriptions such as side-views or top-view coding (Sack & van Niekerk, 2009).

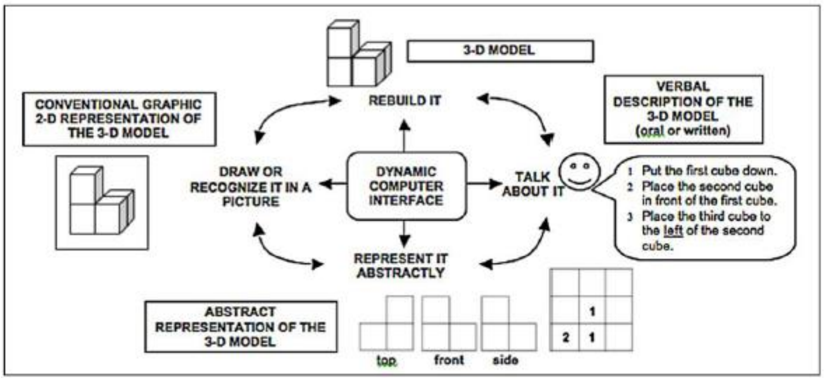


Figure 2.2. A representations of the spatial operational capacity model (Sack, 2013)

The results of these studies with the SOC model revealed that the students were able to visualize and accurately enumerate cubes of a two dimensional conventional picture, also to determine multiple solutions for given set of side and top views.

On the other hand, there is another model to improve students' spatial ability by using not only simple shapes like cubes, prisms or pyramids but also complex shapes as combination of these simple shapes. This model of training spatial ability (TSA) was proposed by Perez-Carrion and Serrano-Cardona (1998) in order to improve spatial ability of university students. This model is consisted of sequential levels in terms of difficulty of spatial tasks. Therefore, before carrying out the task for a level, it is essential to have completed the task in the previous level. In addition, this model of TSA allows student self-assessment process (Perez-Carrion & Serrano-Cardona, 1998). The model of TSA has been divided into six levels: (1) Identification and recognition; (2) Understanding; (3) Application; (4) Analysis; (5) Synthesis; and (6) Evaluation.

In level 1, namely identification and recognition level, students are supposed to identify surfaces on both side-views and isometric representations of three dimensional objects (Figure 2.3 and Figure 2.4).

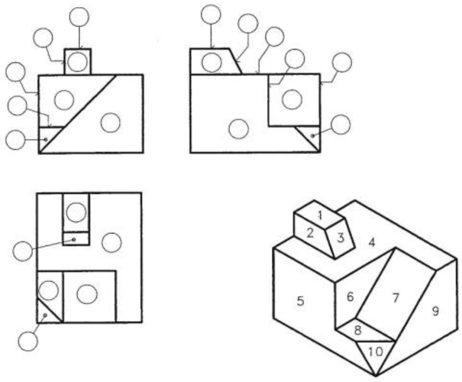


Figure 2.3. Identification of surfaces on side-views

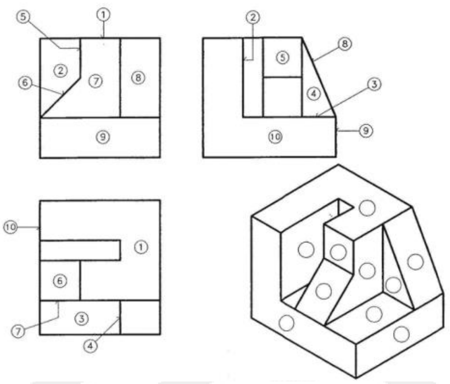


Figure 2.4. Identification of surfaces on isometric representation

In level 2, namely understanding level, students are supposed to identify correct side views of three dimensional objects among many side views (Figure 2.5).

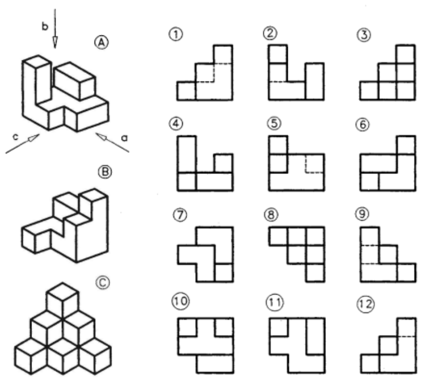


Figure 2.5. Identification of side views of three dimensional objects.

In level 3, namely application level, it is expected form students to discriminate three dimensional objects from their nets, and also to identify rotated version of given three dimensional objects around different axis (Figure 2.6 and Figure 2.7).

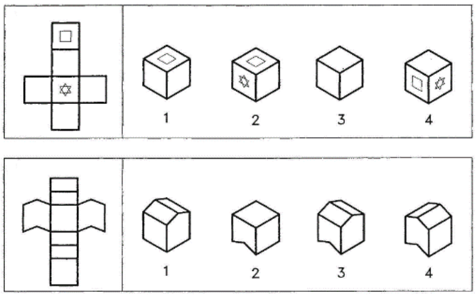


Figure 2.6. Discriminating of three dimensional objects from their nets

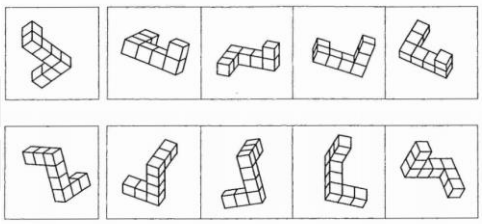


Figure 2.7. Identification of rotation around different axis

The second phase of the level three requires students to identify side views of consecutively rotated versions of given three dimensional objects (Figure 2.8).

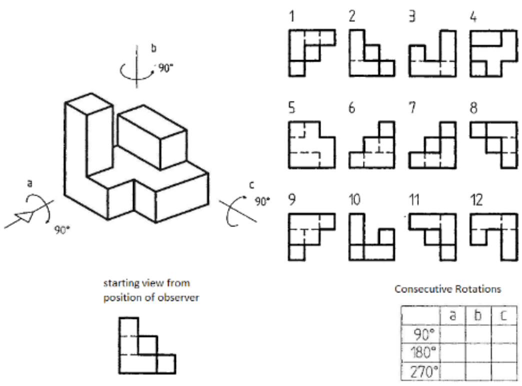


Figure 2.8. Identification of side-views of consecutively rotated versions of given three dimensional objects

In level 4, namely analysis level, spatial relationships within objects are essential. This is carried out with counting exercises. These tasks are about finding how many parts are in touch with the specified part on three dimensional objects (Figure 2.9).

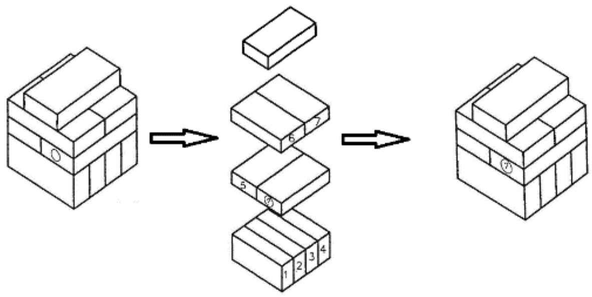


Figure 2.9. Counting of parts in touch

In level 5, namely synthesis level, the students are expected to sketch side views of three dimensional objects, and to sketch isometric representations from given side views of the objects (Figure 2.10 and Figure 2.11).

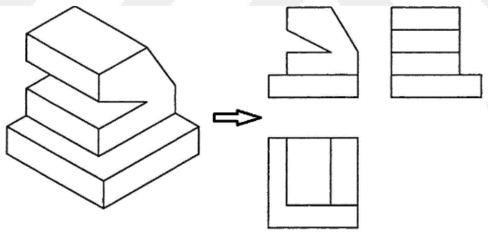


Figure 2.10. Sketching side views of three dimensional objects

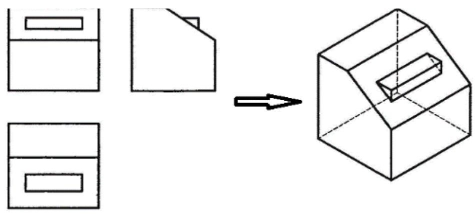


Figure 2.11. Sketching isometric representation from side views

The last and most difficult level is evaluation level. In this level, it is expected from students to sketch both missing side view of a three dimensional object and isometric representation of this object (Figure 2.12).

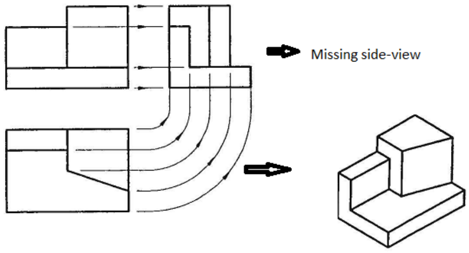


Figure 2.12. Sketching missing side view and isometric representation of object

The study of Perez-Carrion and Serrano-Cardona (1998) resulted, in a significant way that students' last performance was measured as 72.6%, who carried out spatial tasks prepared in accordance with the model of TSA. In other words, they concluded that after the training there was an increase in 25.2% of the students' performance relative to the initial average of 47.4%, for 95% of cases in the training perform under similar conditions.

Pedrose, Barbero and Miguel (2014) also used the model of TSA in their study. This study was about developing a web-based tool to improve spatial ability. They used only first four levels of the model of TSA for their research. They stated that the web-based tool developed in accordance with the model of TSA was more efficient for students who experienced greater difficulties with spatial visualization. In other words, these type of tasks enhanced spatial understanding of students with low spatial ability more than other students.

In addition, Martin-Gutierrez, Saorin, Contero, Alcaniz, Perez-Lopez and Ortega (2010) modified the model of TSA for their research. They developed a desktop-based AR interface for this study based on this model in order to improve spatial ability of university students. They excluded third level of the model of TSA which is application level. Moreover, they also made changes in spatial contents of the levels. In general, the original model of TSA and modified model of TSA have some spatial contents and levels similar, modified or changed. For example, in the level 1, the modified model of TSA has a new spatial content as "identification of vertices on side-views" (Figure 2.13).

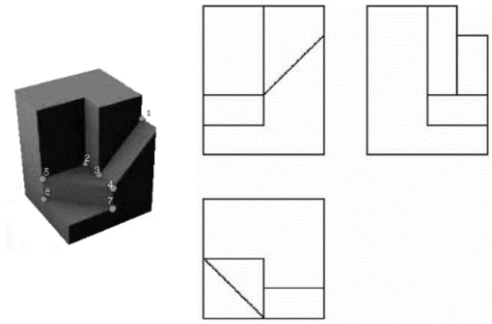


Figure 2.13. Identification of vertices of three dimensional objects on side views

Similarly, the level 2 is also included an added spatial content as “identification of wrong side views” from given at least four side views for a three dimensional object (Figure 2.14).

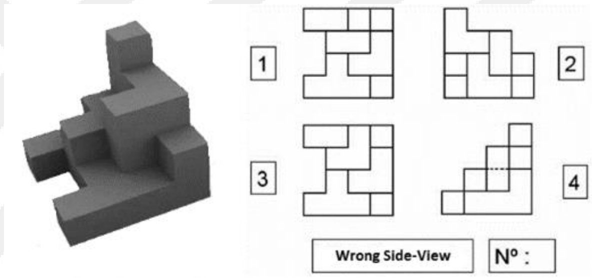


Figure 2.14. Identification of wrong side view

In the analysis level, the modified model of TSA includes selecting minimum number of side views to define an object in addition to original level 4 (Figure 2.15).

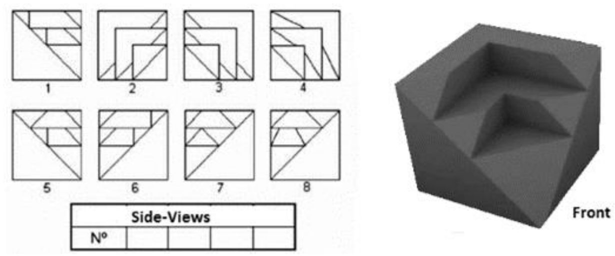


Figure 2.15. Selection of minimum number of side views to define an object

Lastly, synthesis and evaluation levels are mixed in the modified model of TSA. One of the spatial contents of synthesis level which is sketching isometric representation from side views is moved in evaluation level, and the spatial content of evaluation level is moved in synthesis level.

As a result of this study, Martin-Gutierrez and others (2010) concluded that intervention for improving spatial ability with these spatial tasks had showed positive impact on students' spatial ability. Moreover, they stated that students were able to use AR interface easily without boring from tasks.

Wiesen (2003, 2015) also proposed spatial contents for spatial tasks in terms of two dimensional type and three dimensional type. Two dimensional type for spatial tasks include identifying rotated and changed shapes, line following, assembling pieces, matching shapes and map reading spatial contents. Three dimensional type for spatial tasks include paper folding, two dimensional to three dimensional translations, counting touching or hidden blocks, making square or rectangular boxes, assembling components and rotated objects (Wiesen, 2003; 2015). Some examples are presented in the following figures 2.16 to 2.19.

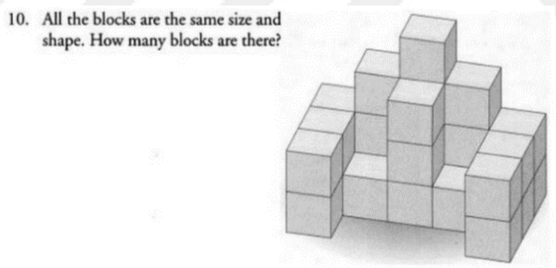


Figure 2.16. Counting block tasks

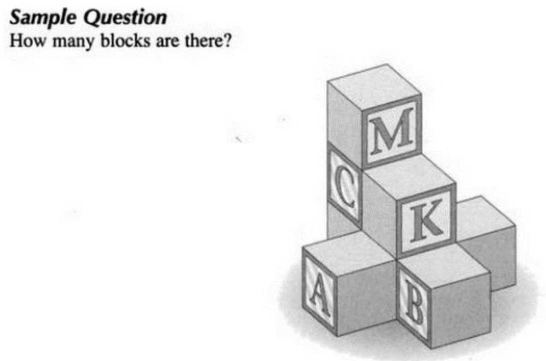


Figure 2.17. Counting hidden blocks tasks

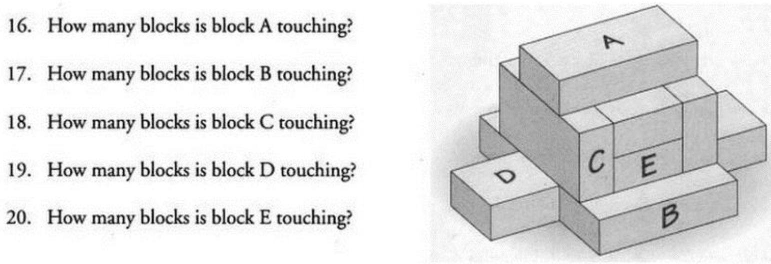


Figure 2.18. Counting touching blocks tasks

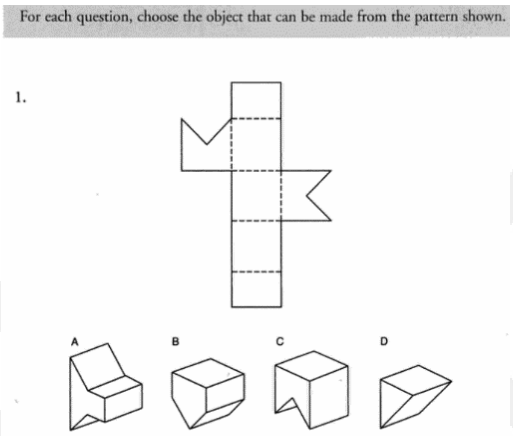


Figure 2.19. Paper folding tasks

As a matter of fact, these spatial tasks of Wiesen (2004, 2015) consist spatial contents of previously explained models for improving spatial ability, thus these tasks are more comprehensive. For the current study, spatial tasks and virtual objects in AR interface were designed and developed based upon characteristics derived from these explained spatial contents of models. In addition, in order to make these characteristics more appropriate to seventh grade mathematics curriculum and mobile AR interface, these characteristics were formatively evaluated throughout this research.

These models and spatial contents were modified and some of them were merged or excluded in order to make content of spatial tasks suitable for AR interface and seventh grade mathematics curriculum of Turkey. For instance, the models of TSA do not include tasks about identifying vertices on perspective views, objects with unit-cubes, and matching side-views from organized lists. A draft model for improving spatial ability in an AR environment (MISAR) came into existence from mixture of these models and spatial contents (Table 2.2).

Table 2.2. Draft five-parted model for improving spatial ability in an AR environment

Parts	Spatial Contents
Part 1: Surfaces & vertices	Identification of surfaces on orthographic views
	Identification of surfaces on perspective views
	Identification of vertices on projective views
Part 2: Matching Correct Views	Determining side-views from organized orthographic views
	Determining side-views from disorganized orthographic views
Part 3: Nets	Identification of nets of three dimensional objects
Part 4: Counting	Counting the number of objects in touch with given part of an object
Part 5: The Second Dimension – Sketches	Sketching missing orthographic views
	Sketching all orthographic views from three directions

The initial draft MISAR was constituted with these additions and modifications on some selected characteristics of the models of SOC and TSA by preserving its order of progress and spatial contents proposed by Wiesen (2004, 2015). Basic characteristics of the draft MISAR were summarized below as in five parts. This table summarizes the draft five-parted MISAR. Within the draft five-parted MISAR, the spatial contents for tasks were explained as follows.

Surfaces & vertices: Spatial tasks should include identifying some parts of virtual three dimensional objects for entrance level so that they can be adapted on working with spatial tasks. Spatial contents can include identifying surfaces & vertices of virtual three dimensional objects on both orthographic views and perspective views (Martin-Gutierrez, et al., 2010; Perez-Carrion & Serrano-Cardona, 1998).

Matching correct views: In order to make students to understand views of virtual three dimensional objects from one of the exact side, students should find and match correct side views of the virtual objects from a list with full of side views. These virtual objects could be composed of complex shapes like prism or pyramids, and unit-cubes. Thus, students could match sides from organized and disorganized lists of views from top, front and left for these virtual objects (Perez-Carrion & Serrano-Cardona, 1998).

Nets: Tasks should refer folded and unfolded nets of objects make students to recognize spatial relationships between objects. Thus, spatial tasks could cover identifying nets of three dimensional objects (Maier, 1996; Perez-Carrion & Serrano-Cardona, 1998; Wiesen, 2004; 2015).

Counting: Students should recognize spatial relationships within objects. This can be carried out with counting components of virtual objects which constitute these virtual three dimensional objects (Perez-Carrion & Serrano-Cardona, 1998, Wiesen, 2004; 2015).

The Second Dimension – Sketches: Students should synthesize three dimensional spatial information with two dimensional information. Therefore, spatial tasks could include sketching views of three dimensional objects from different views (Perez-Carrion & Serrano-Cardona, 1998; Sack, 2013; Sack & van Niekerk, 2009; Sack & Vazquez, 2013), and virtual objects could be composed of complex shapes like prism or pyramids, and unit-cubes.

In this study, spatial tasks in the first prototype were designed in accordance with this explained initial draft five-parted MISAR, and virtual objects for these tasks were also designed regarding this draft MISAR.

2.3. Spatial Ability: as Enhancer or as Compensator within Technology

Recent studies have showed that spatial ability has an influence on understanding three dimensional objects. However, for virtual three dimensional objects, two opposite hypotheses have been proposed. Although the *ability-as-compensator* hypothesis states that working with virtual representations is beneficial for in particular learners with low spatial ability levels (Hays 1996), the *ability-as-enhancer* hypothesis argues that it is beneficial for learners with high spatial ability (Mayer & Sims, 1994).

Some previous studies, which is in line with the *ability-as-enhancer* hypothesis, indicated that favorable design of instructional environment could be more helpful to high spatial ability learners than to low spatial ability ones (Huk, 2006). Additionally, Hegarty (2005), stated as supporting *ability-as-enhancer* hypothesis that spatial ability might play an important role in enhancing learning with dynamic virtual objects in such way that learners with high spatial ability have more profit from learning with animated and dynamic virtual objects, while low spatial ability students might not.

The other hypothesis is ability-as-compensator or known as compensating effect for low spatial ability students. According to this hypothesis, learners with low spatial ability could be engaged working with virtual objects. These virtual objects are beneficial to learners to build a suitable mental model since constructing such a model by using static pictures could be more difficult for them (Hays, 1996). Höffler, Sumfleth, and Leutner (2006) found some evidence for this effect for virtual representations. Additionally, Lee (2007) stated that learners with low spatial ability work better with virtual objects while for high spatial ability students it made no difference. Similarly, Höffler (2010) stated that learners with low spatial ability can be supported by a dynamic instead of a non-dynamic visualization and by three dimensional instead of two dimensional illustrations.

These two hypotheses were tested in the study of Huk (2006). Results of this study demonstrated that the addition of sophisticated virtual three dimensional models contributed to remembering of auditory as well as visually presented information only in high spatial ability learners as claimed in ability-as-enhancer hypothesis. Therefore, the study supported the ability-as-enhancer hypothesis, but it was stressed that graphical presentation formats may support learners with low spatial ability as stated in the ability-as-compensator hypothesis. As a result, Huk (2006) proposed that educational value of virtual three dimensional models depends on spatial ability level of students.

Hence, the current study tried to design and develop a mobile based AR environment to support different levels of spatial abilities by considering these two hypotheses and also to determine which hypothesis could be more applicable in mobile AR environments and middle school students.

2.4. Role of Technology in Mathematics Education

Technology can be helpful to provide real life or world applications to present concepts of mathematics as closer to life. With such learning tools, students can construct their knowledge (Tutkun, Güzel, Köroğlu & İlhan, 2012), since technology usage in mathematics education could facilitate being able to perform standard skills and "think mathematically" (Tall, 1998).

The MSMC places emphasis on the integration of ICT with education to improve more permanent learning (MoNE, 2009; MoNE, 2013). Moreover, MSMC emphasizes taking advantage of technological tools that makes possible visualizing multiple representations of concepts and investigating relationships between these representations. In addition, it is suggested that learning environments, in which students can develop problem solving, communication, and reasoning skills throughout modeling, should be prepared (MoNE, 2013).

Technological tools to learn mathematics include content-specific and content-neutral tools (Thomas & Holton, 2003). Content-neutral tools include tools for increasing students' accessibility to information, ideas, and interactions such as communication and web-based digital media. Content-specific tools include some computer based applications like micro worlds, dynamic geometry software (DGS), computer algebra systems (CAS), and handheld computing device, which is a migrated technology from desktop machines to portable calculators and microcomputers for educational use (Thomas & Holton, 2003). Related research have revealed that the conscious and strategic use of either content-specific or content-neutral tools can support both the learning of procedures and skills of mathematics as well as problem solving, reasoning, and justifying (Kastberg & Leatham, 2005; Nelson, Christopher, & Mims, 2009; Pierce & Stacey, 2010; Suh & Moyer, 2007). Besides, these tools provide students a digital environment for exploring and identifying mathematical concepts and relationships within or among objects by virtual elements (Thomas & Holton, 2003).

In this section, especially the role of the content-specific tools (CST) is discussed since the AR interface developed for this research is defined as a kind of CST.

CST have numerous implications for the learning and assessment processes (Masino, 2011). By ICT integration to instructional phase, we can design both procedural and conceptual learning activities for mathematics education. In other words, the CST can be used for procedural works, gaining intuition, discovering patterns, exploring, and testing conjectures (Zbiek, Heid, Blume & Dick, 2007). Therefore, this construct indicates suitability of the CST for teaching mathematics. As an illustration for this, Drijvers, Boon and Van Reeuwijk (2010) distinguish three main roles of CST for mathematics education; first as a tool for doing mathematics, which states simplifying calculations with hand; second as a tool for providing environments for practicing skills, and third as a tool for enhancing the improvement of conceptual understanding in mathematics. Similarly, Kissane (2002) describes three roles of technology in mathematics education; computational role, influential role and experimental role. A computational role is concerned with using technology to complete operational or difficult mathematical tasks. An influential role refers that the availability of technology needs to be considered in developing on curriculum. An experimental role emphasizes the new opportunities for teaching and learning mathematics afforded by technology (Kissane, 2002). Within these described roles either of Drijvers and others (2010) or of Kissane (2002), the essential feature of technology is its enactive interface. This enactive interface makes human and computer interaction possible. In other words, computers can provide an interactive way to manipulate virtual objects. These interactive manipulations provide an environment in which active exploration is possible rather than learning to do procedural computations at the beginning (Tall, 1998).

Learning and teaching mathematics with CST may provide easier access to concepts since the CSTs are able to carry out the algorithms by enabling visual and symbolic manipulations. Additionally, it allows the learner to focus on specific aspects of concepts by carrying out the necessary algorithms in background implicitly. They can also provide external representations of a mathematical object. With the help of these tools, we can show or use multiple representations in instructional phase. For example, GeoGebra, which is a DGS and so a CST, can create hot-links for mathematical objects to show their both symbolic representations and visual representations at the same time (Hohenwarter & Jones, 2007). These hot-links enable to see changes in an object with multiple representations of it at the same time, interactively. Therefore, the DGS offers interactive exploratory environments providing dynamic conceptualizations of geometric figures (Tall, 1998). Additionally, students' curiosity and motivation toward mathematics could be enthused by interactively exploring concepts with virtual objects which can result in mathematical reasoning (Drijvers, 2012). In addition to the interactive interfaces, students could work with the CAS to "think with" by formulating the solution of problems as computer algorithms (Tall, Smith, & Piez, 2008). By this way, they could have a better understanding of representing variables with letters in algebra (Tall & Thomas, 1991).

Students can benefit from the CST to understand mathematical concepts by perception as receiving information from the tools, by reflection as thinking about concepts, and by action as manipulating visual objects or symbols (Tall, 1998). While understanding is taking place by action with mathematical objects in CST, it is possible for students to focus on either the mathematical objects themselves or results of that action or their actions with devices (Tall, 1998). Therefore, it is essential that teacher support or guidance is needed in order to focus on main learning objective of the activity in order to eliminate distracting things about usage of CST. Because, conscious and strategic use of technology empowers mathematics teaching and learning processes (Dick & Hollebrands, 2011).

In short, the CST can provide changeable and interactive virtual elements. Hence, students have the opportunity of dynamic interactions with the CST. For example, DGS involves manipulation with virtual geometric objects in both two-dimensional and three dimensional geometry. In fact, aside from the CST, there are lots of concrete models and manipulatives for three dimensional concepts of mathematics. However, the usefulness of concrete models and manipulatives for three dimensional geometry is severely limited by their rigidity. One cannot cut them along precise planes or look into it easily, if they are not flexible. This issue is discussed in the following part.

2.5. Studies about Training of Spatial Ability with Technological Tools

As mentioned before, the CST can enhance training spatial ability by providing changeable and dynamic virtual manipulatives in learning environment. The use of CST in the improvement of spatial ability was studied by researchers. For instance, Lajoie (2003) has studied training of spatial ability with a CST. This study resulted that spatial understanding could be taught to certain individuals.

The CST is asserted to be useful in terms of improvement of spatial ability in some studies. For instance, Onyancha, Derov, and Kinsey (2009) conducted a research in order to investigate the effects of Computer Aided Design course for spatial abilities of engineering students. They stated that students' spatial ability were found to be significantly higher after the intervention. Moreover, Raquel (2001), Sack (2013), and Sack and Vazquez (2013) investigated the effects of dynamic geometry activities on spatial ability. In these studies, dynamic geometry activities were advocated as beneficial for improvement of spatial ability. Since dynamic geometry activities provides students an instructional environment where they can examine, investigate, discuss and assume geometrical concepts with their peers, DGS could be beneficial for them to manipulate images easily so they have opportunities to think spatially and collaboratively (Raquel, 2001). Similarly, Raquel (2001) suggested that instruction based DGS makes students to think coherently and improve their spatial abilities.

In terms of VR, Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis (2013) studied to explore effectiveness of virtual learning environment for fostering students' spatial abilities. They used "Second Life" interface for VR as a virtual platform. They found that students with low spatial ability levels showed greater improvement in understanding virtual three dimensional objects if they carried out related activities in a VR environment. Thus, this VR environment performed as compensating effect for spatial ability. Similar to Merchant and others' (2013) study, results of Lajoie's (2003) study showed training spatial ability with CST was beneficial to low spatial ability individuals more than high spatial ability individuals in terms of strategies for solving spatial tasks. The results of this study are also in line with the ability-as-compensator hypothesis (Hays, 1996), which proposes that learners with low spatial ability levels could have more benefit from virtual objects while they have difficulty constructing their own mental visualizations.

Another research about training spatial ability in VR environment was done by Rafi, Anuar, Samad, Hayati, and Mahadzir (2005). The research was about understanding the effectiveness of Web-based Virtual Environment to improve the spatial ability of prospective teachers. This study focused on the mental rotation and spatial visualization through explorative and interactive three dimensional tasks in VR environment in order to aid the improvement of the spatial ability. Learning through Web-based Virtual Environment was found as effective to improve basic spatial ability. In other words, this study had demonstrated the educational benefits of virtual environments in terms of basic spatial abilities.

On the other hand, Boari, Fraser, Stanton Fraser, and Carter (2012) presented a study about the effects of interactivity on mobile devices on performance in working with spatial tasks. They concluded that if interaction with virtual objects was enabled, physical interactions with these objects reduced learners' workloads. In line with their results, they suggested that learning tools on mobile devices could be designated to enhance spatial abilities by supporting physical interactions with virtual elements and providing some opportunities to use of imagination with these virtual elements.

To sum up, previous studies indicated that spatial ability could be trained through various spatial tasks with CST. In these studies, there are evidences to support the ability-as-enhancer hypothesis of Mayer and Sims (1994) and the ability-as-compensator hypothesis of Hays (1996). Hence, students could benefit spatial ability tasks with CST particularly as they have enough cognitive capacity left for mental model construction, and also students with low spatial ability could benefit from these tasks in order to mentally construct their own visualizations. Moreover, the suggestions about designing applications for mobile devices is in the same line with logic of AR technology in order to enhance spatial abilities by providing some opportunities to use of imagination with virtual elements and interacting them physically which are specifically main aim of AR technology.

2.6. Augmented Reality and Learning with Augmented Reality

Software like Cabri3D or GeoGebra 5 visualize three dimensional geometric objects. However, since these software represent virtual three dimensional objects on the two dimensional screen of computer via projecting them on two dimensional layers, some care is needed to avoid misconceptions which can be arise from their limitation and dependency on two dimensional screen. For example, three dimensional objects are represented as two dimensional projections and these projections do not preserve angles, distances, depth, and so on. This construct was previously discussed in the term of "cognitive-filter". Learning environments for spatial contents or three dimensional analytical geometry by viewing two dimensional projections or two dimensional representations of graphs of functions create some kind of "cognitive filter" (Alcaniz et al., 2010). Furthermore, since the manipulative interaction with the objects in analytic space on computer screen is possible, through using mouse and keyboard, the "cognitive-filter" even remains a problem while working with three dimensional diagrams through computer screen. (Alcaniz et al., 2010). Because, with DGS and CAS, students need to change point of view of digital diagram by mouse or keyboard to investigate properties of diagrams and to avoid misleading information from diagram such as, loss of information due to projections and non-displayed parts of an object (Accascina & Rogora, 2006). In addition, virtual three dimensional mathematical objects on computer screen may not be felt and seen realistic as physical models to students (Alcaniz et al., 2010). By the way, the physical models or manipulatives have their own limitations that they do not always allow manipulation for changing their views or physical properties. Nevertheless, even though there exists a cognitive barrier limiting students to process three dimensional information, we need to use some kind of technology in some cases to provide changeable, flexible and dynamic virtual manipulatives in learning environment. What happens if we replace computer screen with something which has a capacity of representing three dimensional objects far more realistic and provide the opportunity to interact with these object as similar with real objects?

New technologies allow changes in the manner of learning experiences. As in traditional desktop software, students do not necessarily use keyboard and mouse to interact with digital content. But now, they may use their whole body to interact with digital content by also seeing them virtually in the physical world with the help of AR technology. AR is relatively a new technology (Billinghurst & Kato, 2002). Unlike the VR, the AR interface gives opportunity to see the real environment through devices and also it visualizes virtual graphics as attached to specific pre-determined locations on real-world. The AR supplements and enhances reality rather than completely virtualizing and replacing it. In other words, the AR enhances reality by mixing views of real environment with virtual objects (Azuma, 1997). Kaufmann (2011) stated that students can actively walk around an object with AR, which builds up a spatial relationship between learner's position and object. He claimed that this is the key element in the potential success of using AR interfaces for learning geometry. Similarly, Shelton (2003) and Hedley (2003) stated that AR interface allows users to "fly into" the three dimensional display and experience virtual objects as if virtual objects are standing in real world or users are moving inside a virtual world. Without this kind of representation, students have little prior knowledge of the shapes or lack of spatial visualization ability and this may lead to difficulty in conceiving representative diagrams as representations of three dimensional shapes because of the "cognitive-filter" issue. While working directly in three dimensional space with AR interface, complex spatial problems and relationships between and within objects can be understood better and faster than with conventional methods (Kaufmann, 2004). Therefore, mixing of reality and virtuality in an AR interface holds unique advantages for teaching and learning.

There are also some weaknesses of this technology, especially in educational implementations. First of all, this technology has still been relatively new. Therefore, some necessary tools for AR such as HMD or smart glasses, either too expensive or hard to be found in markets. This weakness can be overcome by designing AR interface applications for handheld devices like smartphone and tablet, or for desktop pc. Therefore, the use of tablets in classroom, which are planned to be distributed to middle school students through F@TIH project in Turkey, may have potential new application areas. Second weakness is related to HMD or smart glasses. Previous studies showed that head-mounted AR interface was found less usable than its other counterparts in short time applications (Kaufmann & Dünser, 2007). Researchers stated that students have still been enthusiastic in long term applications with head-mounted AR interface. Lastly, there has been still no packet software, which has been designed for educational purposes, yet. Therefore, one has to build his own educational AR interface by programming and designing or using some Software Development Kits (SDK), which are especially designed to make easy software development of AR interface, such as Qualcomm's Vuforia SDK[1], AR-media SDK[2], ARtoolkit SDK[3] and so on. This weakness of AR could be eliminated if you have even a little programming skill.

There are three types of AR interface depending on hardware (Figure 2.20); (1) Handheld-based AR permits students to travel through real environment while looking at the augmented digital content through a mobile device or tablet. With this interface, learner interaction is limited through some touch buttons or gestures on screen of mobile device (Xu, Mendenhall, Ha, Tillery, & Cohen, 2012). (2) Desktop-based AR allows use of a webcam to capture a physical space and display augmented content on a screen. This screen can be a computer screen or a projector. (3) HMD-AR, contained an internal display and attached video camera, permits students to have a personal perspective on integration of real space and virtual space at the same time, and

[1] Information and documents about Vuforia can be found in https://developer.vuforia.com/

[2] Information and documents about AR-media can be found in http://www.inglobetechnologies.com/en/new_products/arplugin_su/info.php

[3] Information and documents about ARtoolkit can be found in http://artoolkit.org/about-artoolkit

interaction can be provided by their hand movements or virtual augmented buttons on real space (Juan, Beatrice, & Cano, 2008).

Figure 2.20. Three types of AR interface in terms of hardware

In short, in mathematics education, multiple representations enhance conceptual learning (Van de Walle, Karp, & Bay-Williams, 2013). However, traditional textbooks are designed to carry static diagrams and text. Traditional digital media content can be given in a variety of forms such as statistic diagrams like in traditional textbooks, animations from this static diagrams, two dimensional projections of three dimensional objects with changeable point of view, audible texts, interactive contents, and so on (Radu, 2014). AR interface may enhance traditional textbooks from static to dynamic and also technology by providing more tangible and more lifelike experiences. Since, it is a technology in development phase and just differentiates visualization process of digital diagrams; any computer software for education could be transformed and presented with AR technology, perhaps not yet but soon.

2.6.1. Studies about Augmented Reality

Training of spatial ability could be accomplished via novel technologies like VR and AR by creating interactive three dimensional environments (Rafi, Samsudin & Said, 2008). There is a limited number of systematic studies about human spatial cognition and spatial abilities, which is related to AR environments. To substitute this lack of research, studies that focused on the influence of two dimensional and three dimensional objects, and problem solving on learners' visual spatial abilities were reviewed in this section.

Kaufmann and Schmalstieg (2003) developed Construct3D software in order to foster spatial abilities of learners and to maximize transfer of learning, and investigated its effects. They claimed that Construct3D improved spatial abilities and encouraged experimentation with geometric constructions. On other hand, Shelton (2003) examined how learners change the way to understand topics that involves dynamic spatial relationships while interacting with virtual objects. The content explored in this experiment was related to the earth – sun relationship. The results showed that the AR interface indeed changed the way students for understanding the earth – sun relationship. Findings of the study of Shelton (2003) indicated that AR can be used in learning environments to influence and supplement students' spatial understanding to envision concepts and create a more comprehensive understanding about these concepts.

Similarly, Hedley (2003) found that AR interface provides advantages over desktop-based CST interface in a range of task-based activities for users, including task performance, task speed, completeness, and the level of user's spatial ability to directly manipulate three dimensional AR models. Hedley (2003) also suggested that through multisensory interaction, AR interface may spread cognitive load for users, thereby reducing cognitive inertia.

Furthermore, Dünser, Steinbügl, Kaufmann, and Glück (2006) studied about trainability of spatial ability by AR application. They used Consturct3D AR application in this study. They found interesting gender specific results. Although male participants could improve their overall performance in terms of spatial ability, performance of female participants slightly dropped after AR treatment, and only performance of female participants without geometry education was improved. They deduced that fostering spatial ability using AR could be possible. Although, AR could also be used to develop useful learning tools for spatial ability training, they stated that traditional spatial ability measures did not cover all skills that are used when working in augmented three dimensional space. This can be possible by AR tools to measure spatial ability directly in augmented three dimensional space.

Lastly, Martin-Gutierrez and others (2010) developed AR-Dehaes book and AR-based application based on the modified model of TSA to improve spatial abilities of college students. Students worked with desktop-based AR interface on PC with web camera. They found that this intervention had positive impact on spatial ability of students. Moreover, students' interviews revealed that AR-based application could be considered as easy to use, attractive, and very useful technique for training of spatial ability.

In summary, AR interface has potentials to increase understanding about concepts, to improve students' learning in spatial structures (Dünser, et al., 2006; Hedley, 2003; Kaufmann & Schmalstieg, 2003; Martin-Gutierrez et al., 2010; Shelton, 2003) and to increase students' motivation (Kaufmann & Schmalstieg, 2003; Martin-Gutierrez et al., 2010; Shelton, 2003). In addition, Dünser and others (2006) stated that traditional spatial ability measures could not cover all skills that are used while working in augmented three dimensional space. Therefore, AR interface should possess a feature of measuring spatial ability as well as training it.

2.6.2. Augmented Reality in Turkey

As stated before, the AR is relatively new technology and a new area of research in Turkey. Therefore, number of systematically done studies is limited both in general AR contexts and mathematics education. Due to this reason, the studies reviewed in this section include not only AR research in the field of mathematics but also in other educational areas.

First of all, Abdüsselam (2014) studied effects of AR environment on students' achievement and physics attitude in teaching magnetism subjects. He developed an AR device called MagAR as an AR environment. As a result of this study, it was found that AR environment supported enhancing students' performance and attitude towards value of physics. In addition, AR environment enhanced students' motivation positively. The researcher stated that AR helps students to understand concepts better and to make concepts more realistic. Additionally, the AR environment had a benefit for student understanding, explaining, and concretizing the abstract concepts.

Another related study was conducted by Küçük, Yılmaz, and Göktaş (2014). It is about examining achievement, attitude and cognitive load levels of students learned English in AR environment. The participants of this study were 5th graders in five middle schools. The result of the study showed that middle school students were motivated to learn English within AR environment, and they had a low anxiety level. In addition, their attitudes were significantly higher than other students.

On the other hand, research of Yılmaz (2014) is about examining the effects of AR technology on stories in terms of narrative skill, length of story and creativity in stories included three dimensional contexts. Similar to Küçük and others (2014) study, the participants of this research were 5th graders. This research resulted that students benefited from AR technologies in terms of narrative skill, length of story and creativity in stories.

Another study was conducted by Küçük (2015) to determine the effects of learning anatomy via mobile AR on medical students' academic achievement, cognitive load, and views toward implementation. The participants of the study were undergraduate students. The results of this study reported higher achievement and lower cognitive load of students. Students' views toward mobile AR based learning environment were highly positive. Additionally, the researcher stated that mobile AR based learning environment generated sense of reality, concretized the concepts, increased interest in the lesson, and supported individual study by providing a flexible learning environment.

The other study was about investigating the effect of augmented reality on students' attitude towards computer and self-efficacy towards computer while teaching geometry in an AR environment (İbili & Şahin, 2015). The researchers developed

ARGE3D program in order to display the static virtual three dimensional objects for geometric figures in the sixth grade mathematics textbook. Therefore, the study group included sixth graders. Although the results showed that ARGE3D did not significantly affect students' self-efficacy and attitude towards computer, it enhanced students' learning of geometry. In addition, ARGE3D helped to reduce the anxiety and fear of mathematics.

The research of Gün (2014) aimed to investigate the effects of mathematics education supported with AR on students' spatial ability and academic achievement. The researcher prepared AR materials with BuildAR interface for geometric figures. Participants of the study were 6^{th} graders in a middle school. This study was based on desktop-based AR environment. The researcher reported that both AR based environment and traditional environment enhanced students' spatial ability and performances in geometry. Additionally, she stated that AR made learning environment as entertainment, easier to envision abstract concepts in mind, and easier to learn the mathematics for students.

To conclude, AR environment supports enhancing students' performance (Abdüsselam, 2014; İbili & Şahin, 2015; Küçük, 2015; Yılmaz, 2014), students' motivation (Abdüsselam, 2015; Gün, 2014; Küçük, 2015; Küçük et al., 2014), and AR interface makes abstract concepts more realistic and easier to envision and concretize these concepts (Abdüsselam, 2014; Gün, 2014; Küçük, 2015). Furthermore, in terms of mathematics and spatial ability, AR interface enhances students' learning, reduces mathematical anxiety, and makes mathematics as an entertainment activity (Gün, 2014; İbili & Şahin, 2015).

2.6.3. Collaborative Augmented Reality

People share spatial information in real life routinely while giving directions of some places, describing visual properties of some things, explaining their thoughts about some objects, etc. (Galati & Avraamides, 2012). Similarly, Youniss and Damon (1992) state that individuals tend to build spatial ideas while explaining them to other individuals. In literature, it is seen that high spatial ability individuals use partner-centered attributions to define spatial descriptions of a thing whereas low spatial ability individuals use egocentric attributions (Schober, 2009). So that, while students are carrying out spatial tasks, interactions between them have importance for arising strategies (Galati & Avraamides, 2012). Additionally, learners need to be at the center of learning to understand own and others actions and interactions which play a key role for their leaning while working with virtual objects (Park, 2012). Moreover, these interactions can be enriched if learners are provided such opportunities for active participation to learning tasks. It is important to note that, within these opportunities, learners should be encouraged to collaborate in learning environment, not compete (Park, 2012). Similarly, Vygotsky (1978) argues that learning occurs working together to accomplish a task with shared goals in collaborative ways since learners in groups take more responsibility for their own learning in such groups (DeBacker, Goldman & Islim, 2014; Gilbert & Driscoll, 2002). An ARLE, learning with virtual objects, can be considered a collaborative learning environment since these objects can be seen, examined and used by other learners at the same time and same place. Therefore, ARLE can also be defined as a multi-user learning experiences and provides a shared virtual space among learners. Additionally, advances in computer technology like AR technology have been providing more solid ways of collaborative and immersive environment similar to real world (Park, 2012).

Collaborative learning is used as an umbrella term to cover a variety of approaches which involves students working in groups, searching for mutual understanding, solving problems, carrying out tasks or searching for meanings. It has been influenced by theories of Vygotsky (1978), Dewey (1938 as cited in Davidson & Major, 2014), and Piaget (1951 as cited in Davidson & Major, 2014). As stated by Smith and MacGregor (1992), collaborative learning provides students opportunities for working in small groups, mutually exploring situations, or creating products for a common goal. It emphasizes a common understanding for pairs (Daniels & Walker, 2001). It is a student centered approach and involves students' exploration not teacher centered lecture (Smith & MacGregor, 1992). Therefore, authority is shared among members of groups and does not belong to a specific person (Panitz, 1999). Hence, it represents a shift from lecture-centered approaches to student-centered. In the meantime, teachers are designers for intellectual experience for students as coaches in collaborative environments (Smith & MacGregor, 1992). Dillenbourg (1999) defined collaborative learning as "a situation in which two or more people learn or attempt to learn something together" (p.1). Collaborative learning environment has impact on students learning with factors about task characteristics, students' characteristics, diversity in group and interaction among students (Panitz, 1999). First of all, in collaborative environments, learning is an active and constructive process. Students work actively with partners in groups for a common objective in order to learn new information, ideas or skills by integrating what they already know (Smith & MacGregor, 1992). Thus, in collaborative environments, students do not simply get new learning from teacher, and they need to construct their own knowledge together.

Moreover, students' learning is affected by the contexts and tasks in this environment. In order to engage students in active learning process, therefore, contexts or tasks, which students deal with, get their importance. Challenging and edutainment tasks could get students' attention and engage them in collaborative learning (Smith & MacGregor, 1992). Thereby, all students become active participants of environment rather than being distant and passive observers for questions, problems, tasks, or other contexts presented. Such opportunities for rich contexts foster students to examine, practice and explore contexts and develop higher reasoning skills (Smith & MacGregor, 1992). Furthermore, in collaborative environments, students could also benefit from their partners' backgrounds and experiences to develop such skills. Students may have multiple perspectives for same situation or context, different experiences and various levels of understanding. While students are working in groups collaboratively, they could bring these different ideas, abilities, point of views, or experiences to their works (Lai, 2011; Smith & MacGregor, 1992). Therefore, they contribute to learning with examples and different connections from their own experiences (Davidson & Major, 2014). Hence, collaboration between students has powerful effects on students' learning even for low-achieving ones since their interactions also contribute their learning in collaborative environments (Lai, 2011).

In fact, studying with small groups provides opportunities to students for making discussions, talking with partners and taking responsibility for their own learning (DeBacker, Goldman & İslim, 2014).

"Learning through talking" as Vygotsky (1978) stated. Collaborative learning environments allow students to talk with each other and learning occurs within this talking and interactions. In other words, discussions within groups and explanations to partners as well as asking questions could provide some benefits to their thinking as well as valuable information to teachers about their level of understanding (Davidson & Major, 2014). Thus, learning becomes a social event with mutual participations on tasks or contexts. These mutual events could lead students to a better understanding and creation of new knowledge. Thus, students become responsible for maximizing their own as well as each other's learning (Panitz, 1999). These explained features of collaborative environment were described by Davidson (1994) and LeJeune (2003) as common task, small group learning, cooperative behavior, interdependence, and individual responsibility.

Teachers could provide a collaborative learning environment for students through problem-based paper-pencil tasks, discussion-based situations or technology-based materials. Computer-Supported Collaborative Learning (CSCL) refers to using computers to provide collaborative learning opportunities for people (Lipponen, 2002). Computer usage with common ways generally provides with online or only verbal interaction of peers rather than face-to-face interaction. In other words, with the use of computers, some of the interactions modes could be hidden like non-verbal communication and physical interaction. AR technology could enhance usage of computers or more portable ones like smart devices, by allowing co-existence of real and virtual environments together with real time and physical interactions (Kaufmann, 2003).

The AR provides a novel experience for learning environments by mimicking reality with virtual elements in real environments. Thus, AR interface can offer more natural and similar interactions to collaborative learning in real environment than classical

CSCL. For example, a learning environment with an AR interface could support not only verbal interactions but also non-verbal interactions like point, gesture and gaze communication and other modes for face-to-face interactions (Matcha & Rambli, 2011) since students could also see real environment with AR interface so that they see each other during tasks. In an ARLE, as learners move or rotates a target page, the virtual objects attached to this page will move or rotate accordingly. This interaction is a familiar and intuitive way of interaction and it does not require any special skill (Shelton & Hedley, 2004). In other words, in real world, if an individual wants to see the other side of an object, he rotates or walk around this object or to see details on it, he brings it closer (Shelton & Hedley, 2004). These interactions are provided exactly in the same manner within AR interface. Moreover, AR technology allows users to control their own views and each user has different point of view for inspected virtual elements. Therefore, this feature eliminates being passive observers in group works and shares authority of environment between members of group (Szalavari, Schmalstieg, Fuhrmann & Gervautz, 1998). Similar to classical collaborative environment, authority shifts and is shared among groups of students, and does not belong to specific student or teacher. Teacher could be a mediator for environment by providing challenging and gamified tasks and necessary information when needed. Students work actively with these challenging and gamified tasks by talking and learning from themselves with face-to-face interactions. Members of groups depend on themselves to learn and responsible for themselves for learning as in classical collaborative environment. Moreover, teacher has opportunity to assess students' understanding through their works and interactions on tasks in the ARLE (Kaufmann, 2003; Matcha & Rambli, 2011; Szalavari et al., 1998).

These features of ARLE were summarized by Szalavari and others (1998) as follows. An AR interface in ARLE supports "virtuality of objects" so that objects do not need to exist in the real environment to be examined, "augmentation of environment" by superimposing virtual elements on real ones, "multi-user support" so that multiple users could see each other collaboratively, "independence of viewpoint" so that users could control their point of view, "sharing vs. individuality" that users could see shared space and individual space for objects, and “interaction” so that users could interact with virtual elements and each other with modes of natural way for interactions (Szalavari et al., 1998). Furthermore, using AR interface with a mobile device has its own unique feature like mobility. The mobility could support students’ active participations by allowing them freely walking around virtual objects and it could allow students’ interactions with each other easily than a desktop based systems (Sugimoto, Hosoi & Hiromichi, 2004; Zurita, Nussbaum & Shaples, 2003). While designing and programming an AR interface two basic principles for AR technology were regarded in this study as key elements of an AR interface since other stated principles were not related specifically coding a mobile AR interface for fostering spatial ability. These key elements were virtuality and augmentation principles.

Virtuality: Three dimensional objects do not have to be physically in the real environment. This restriction is removed via using virtual objects which are designed to be as almost real with their simulated physical properties such as size, position and complexity. Therefore, even if they do not exist in the real environment, they can be viewed and examined in the real environment (Kaufmann, 2003; 2004; Szalavari et al., 1998).

Augmentation: Objects physically existed in the real environment can be augmented with virtual elements. Dynamic information and variation of new parts for an existing object can be superimposed on this real objects via virtual annotations (Azuma, 1997; Szalavari et al., 1998).

These two principles were derived from literature in terms of key elements of AR interface and characteristics for supporting ARLE. Moreover, as stated above, the ARLE supports active interaction of students as well as learning through interface collaboratively and intuitive interactions (Shelton, 2003). These opportunities could provide and result better understanding for students (Grasset, Dünser, Seichter & Billinghurst, 2007). Previous studies have shown that the AR interface provides a natural setting for interactions with virtual objects as well as between students (Billinghurst & Dünser, 2012). Students can walk around virtual objects in real environment as if they exist. Therefore, students see both virtual objects and themselves in this environment. The ARLE preserves social interactions like in natural settings since the AR offers seamless interaction between real and virtual environments (Billinghurst & Dünser, 2012; Kaufmann, 2003). Therefore, students could see each other and virtual elements at the same time in real environment.

To sum up, collaborative learning approach involves groups of students working together and collaborate with each other in order to solve a problem, complete a task or create a product. In addition, collaborative learning pairs have higher level of critical thinking than independently working individuals (Johnson & Johnson, 1989). Because, studying with small groups provides opportunities for students to make discussions and take responsibility for their own learning (DeBacker, Goldman & İslim, 2014). Gerlach (1994) defined it as learning from talks. Similarly, sociocultural perspective within the concepts of Vygotsky specify the role of social interaction in creating an environment that supports learning through language (Vygotsky, 1978). Previous studies stated that AR provides an enhancement of shared learning environment (Billinghurst & Kato, 2002). Therefore, AR technology can enhance interactions of students between each other and virtual objects that is difficult with desktop based technology since in instructional environment based on desktop based technology, a disconnection exists between the task space and display space. Hence, in order to provide these features for ARLE, three main characteristics of draft design principles for ARLE were derived from literature to cover all aspects of the design and development processes of an AR toolkit for improving spatial ability of seventh grade students. These characteristics of these design principles were summarized below.

Interactions: Learning with virtual objects should support natural ways of interactions, which mimics real world in order to make adaptation of students to this environment easy and fast (Park, 2012). Similarly, Winn and Bricken (1992) supported this principles as that interaction with virtual objects is intuitive in an AR environment since learners interact with objects in natural ways by grasping, pointing, gazing and others. Hence, learners could help each other in order to solve problems by interacting with virtual objects and each other. They can use speech, gesture, gaze and non-verbal cues to attempt to communicate (Billinghurst & Kato, 2002; Smith & MacGregor, 1992; Vygotsky, 1978). These interactions within AR interface could be provided via supporting physical and natural way of interactions like with hands or walking around an object so that students can explore an object by seeing each other and cooperate in a natural way (Szalavari et al., 1998).

Active process of learning: Students should be engaged in an active process for learning since they could build ideas about shapes better through active participation in learning, rather than passive observation (Smith & MacGregor, 1992; Sundberg, 1994). Active participation within AR interface could be provided through challenging tasks, gamified tasks and independence of viewpoint. In order to actively engage groups, learning environment has a need of some challenging tasks so that learners can process and synthesize needed information rather than memorizing and regurgitating concepts (Smith & MacGregor, 1992). Moreover, learners should also be engaged with scoring systems or fail states with gamified tasks. That is, they can become more ambitious to accomplish tasks (Dunleavy, 2014). In addition to these characteristics about tasks, AR interface could also provide a novel way for point of view. In such environment, each student has an opportunity to move freely in environment, and to control and to choose own independent viewpoint for inspected virtual objects. Therefore, control of environment does not belong to a specific student and this eliminates other students being passive observers (Szalavari et al., 1998).

Teacher as mediator: Teachers should mediate learning through dialogues and collaborating students within learning process by providing needed information or tasks. Thus, AR interface could provide teachers with such opportunities to mediate learning. First of all, AR interface could provide different type of tasks so teacher can administer and determine spatial tasks for linking new information to prior one by providing opportunities for collaborative work in accordance with current situations of learning (Billinghurst & Dünser, 2012). Moreover, AR interface could allow teacher to provide necessary information about learners' progress with feedbacks about their works just-in-time (Wu, Lee, Chang & Liang, 2013).

These initial draft design principles for ARLE were considered to prepare a suitable learning environment for AR based intervention to foster spatial ability of students.

2.7. Summary of the Related Literature

The literature was reviewed to derive needed characteristics of ARLE, mobile AR interface and spatial contents for tasks in order to design and develop a prototype material to foster spatial ability of students. Before designing a prototype for fostering spatial ability, it is important to understand current research about improving spatial ability models and suitable technological tools. Previous research in mathematics has shown the importance of visualization processes in learning (Presmeg, 2006). Similarly, Clements and Battista (1992) gave some research results regarding importance of visualization. For example, one of these results was that if a problem is presented visually, students comprehend better than when this problem is verbally presented. Some geometric thinking models have also signified the importance of visualization. For instance, the geometric thinking model of Duval (1998, 2002) involves three main processes; visualization, construction and reasoning. Within this model, Duval emphasized the role of visual representation in mathematical statements.

In the literature, an evidence for relationships between spatial ability and achievement in mathematics as well as other fields have been found. Moreover, it is stated that learning activities based on spatial visualization and manipulation could improve geometric learning of students. Furthermore, the researchers claimed that spatial ability can be developed with appropriate learning tasks. Technological tools, especially AR interface, could be suitable to administer learning tasks to train spatial ability. Because, with the help of AR interference, one may have the opportunity of seeing various views of three dimensional objects by having features of rotating, transforming and representing in real-time and in real-environment. Although previous studies have evidences for that AR interface has potential to improve students' learning, there has yet been little application about ARLE, especially with mobile AR interface, in Turkey for mathematics education. Thus, this research provides an insight into understanding how AR technology enhances Turkish middle school students' learning in mathematics and improvement in their spatial abilities within unique opportunities in learning environment.

CHAPTER THREE

METHODOLOGY

The review of related literature summarized several issues relevant to students' understanding of two dimensional representations of three dimensional objects and needs for improving students' spatial ability. This study seeks a new way of fostering students' spatial ability which is augmented reality learning environment (ARLE). Therefore, the general purpose of this study was to find out factors to be considered in order to design and develop a spatial augmented reality (SPATIAL-AR) toolkit, which includes set of spatial tasks and a mobile AR interface, in order to foster spatial understanding of seventh grade students in an ARLE. This chapter focused on methodology of this research to design and develop AR interface prototypes and set of spatial tasks for fostering spatial ability. These prototypes were created and refined in a series of sequential cycles of evaluation and refinement.

In this chapter, methodology of this research, participants, characteristics of AR interface, spatial tasks and ARLE, and iterations of refinement were explained.

3.1. Research Design

This study was conducted as following educational design research (EDR) methodologies. EDR is a systematic way of design, development and evaluation processes of an educational intervention or innovation (Plomp, 2013). The EDR is an umbrella term for some related research designs which were named with a variety of different terms as *Design Experiment* (Cobb, Confrey, diSessa, Lehrere, & Schauble, 2003), *Design Studies* (Walker, 2006), *Developmental (or Development) Research* (Van der Akker, 1999), *Design Research* (Plomp, 2013), etc. The EDR seeks solutions for complex educational problems with a systematic analysis of designing and developing an intervention. It also contributes to our knowledge about attributes of these interventions and characteristics of these designing and developing processes (Plomp, 2013). In addition, EDR is a type of research design especially suitable for instructional design and technology field (Richey & Klein, 2014). Generally, the EDR has commonly three phases of research that are preliminary research phase, prototyping or development phase and evaluation phase (Nieveen & Folmer, 2013; Plomp, 2013).

In general, preliminary research phase examines existing problems to solve, or needs and possibilities for interventions with systematic analysis of literature, opinions or feedbacks of experts from fields, researchers' experiences, and others (Plomp, 2013). In this phase, a proposal to solve the problem or to develop an intervention is formed with set of draft design principles for intervention, and a conceptual framework in accordance with systematic analysis of above mentioned sources. At the end of this phase, a prototype of intervention is developed in line with these draft design principles. After that, a prototyping phase is conducted with participants to test out and improve this prototype as well as design principles in several iterations. This prototyping phase generally continues until prototype becomes solid and reaches some designated quality as a completed product (McKenney & van der Akker, 2005; Nieveen & Folmer, 2013; Özdemir, 2016). Hence, iterations in this phase include micro-cycles of analysis, (re)design and formative evaluation which are expected to lead a solid version of the prototype for intervention and so final design principles. Lastly, an evaluation phase can be conducted in order to reveal actual effectiveness of the intervention and more confident arguments about results of this intervention in field with target group of students in target settings. Participants for EDR can vary from target students to stakeholders within the iterations and phases.

In the context of this study, the EDR methodology is ideally suited to design and develop an AR learning toolkit to improve spatial ability of seventh grade students in an ARLE because the EDR methodology advances design of research and practice concurrently (Cobb et al., 2003; Design-Based Research Collective, 2003; Wang & Hannafin, 2005). Similarly, the EDR is referred to as a suitable for both research and design of technology-enhanced learning environments (Wang & Hannafin, 2005).

Since this research was about designing and developing a SPATIAL-AR toolkit, which includes a mobile AR interface and series of spatial tasks to improve spatial ability of seventh graders, with a variety of participants, the research methodologies presented by Nieveen and Folmer (2013) were considered while designing this research.

3.2. Phases of the Research

Throughout this research, iterations with a small number of different participants were conducted one after another in order to design and develop the SPATIAL-AR toolkit and to determine what worked and what did not work in the ARLE with formative evaluations. In addition to these, series of studies provided developmental assessment of the practicality and expected effectiveness of SPATIAL-AR toolkit in an ARLE.

In general, this study was conducted over two phases which were preliminary research phase and prototyping phase. The evaluation phase was not conducted in this research since the AR is still a relatively new technology and the devices used in research, tablets and especially smart glasses, have not been common in educational settings due to their prices, yet. Therefore, to achieve an evaluation study, which needs to reach a big number of sample, was not seen as possible for this study in current situations.

Firstly, the preliminary research phase was about reviewing related literature to find out factors to be considered while designing and developing the SPATIAL-AR toolkit in an ARLE. Thus, contents for spatial ability tasks, key elements for coding a mobile AR interface, and characteristics of learning environment to support AR based instruction were derived as draft design principles within the review of the literature. According to these design principles, a prototype of SPATIAL-AR toolkit was designed and developed as including a mobile AR interface and a student booklet which includes both spatial tasks and target images for virtual objects in this interface. As suggested by Shelton and Hedley (2004), a designed and developed AR system should be implemented in research concerning how learners use AR in learning situations and as a mobile tool in order to classroom use of this system. Hence, the general purpose of the study and literature review in preliminary research phase lead research to two main aims. The first aim is to guide and improve the design of

SPATIAL-AR toolkit which supports improvement in spatial ability of learners, and the second aim is to find out possible contributions of intervention to seventh grade students with this SPATIAL-AR toolkit in terms of spatial ability and to learning environment.

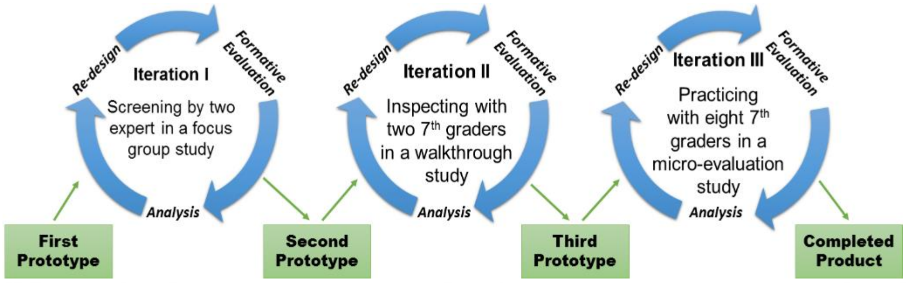


Figure 3.1. Prototyping Phase

Secondly, the prototyping phase was planned as to include at least three iterations, and these iterations include micro-cycles to re-design, evaluate and analyze the prototype (Figure 3.1). This phase was shaped in accordance with Nieveen and Folmer's (2013) methods. Nieveen and Folmer (2013) signified some appropriate methods for determining participants in order to address cycles of iterations. These methods are described as:

- *Screening:* Experts checks relevancy of the design. So that the intervention can be more relevant from a subject matter perspective.
- *Focus Group:* A group of participants as experts carries out a prototype of a product. Hence the prototype can be more consistent with design guidelines.
- *Walkthrough:* A group of representatives of the target students carries out prototype in order to reveal expected practicality of the prototype within target students.
- *Micro-evaluation:* A small group of target students, who are sampled as high-achieving and low-achieving as well as average students, uses product outside of its intended target settings for students. Thus, its practicality and expected effectiveness could be revealed.
- *Try-out:* The target group uses the final product in its target settings. So that actual effectiveness of the final version of the product can be asserted.

The first iteration of this phase was planned as a mix of both screening and focus group methods and it is called as focus group study. Two experts from mathematics education participated to this focus group study. They carried out the first prototype of SPATIAL-AR toolkit and helped to improve it by providing valuable information about its irrelevant and inconsistent characteristics from subject matter perspective.

The following iteration was planned as a walkthrough study. In this iteration, two seventh graders with high spatial ability were selected to improve the design from students' perspective as well as to conjecture expected practicality of the SPATIAL-AR toolkit for target students.

The third and last planned iteration was designed as micro-evaluation study. For this iteration, eight seventh graders were selected from high, average and low spatial ability students in order to provide diversity in groups and so constitute a sample which represents all levels of spatial ability. This time, main goal was to reveal actual practicality of the SPATIAL-AR toolkit as well as expected contributions of it to spatial ability of students and to learning environment.

During and after each iteration, the prototype of SPATIAL-AR toolkit were revised and redesigned, consequently design principles were conjectured and reshaped. In short, output of each iteration became input of following ones (Figure 3.2).

It is important to note that since first two iterations were about designing, developing and improving cycles for prototypes of the SPATIAL-AR toolkit, these iterations were conducted in individual learning settings. Therefore, some revisions and additions to design principles in terms of learning opportunities were conjectured from these individual learning settings until this toolkit reached solidness. As for the last iteration, ARLE included a shared virtual space in order to provide students opportunities for natural way of interactions with virtual objects and each other for a shared goal via this novel toolkit to foster their spatial ability.

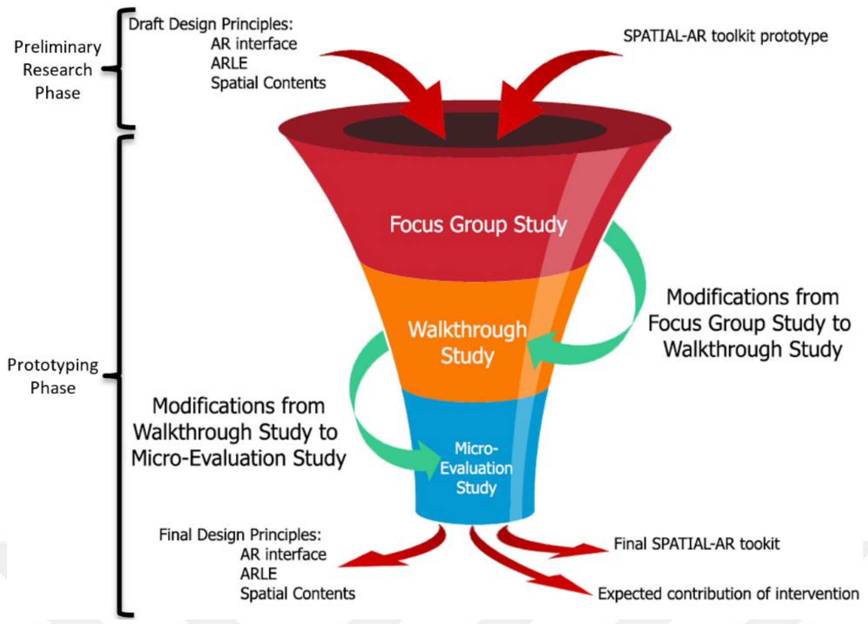


Figure 3.2. Cycles of iterations in the prototyping phase

The design, development and improvement of the SPATIAL-AR toolkit involved making numerous design decisions throughout a process of iterations. In other words, these developmental processes of the SPATIAL-AR toolkit were made on the basis of data collected from iterations which were conducted one after another in which different participants interacted with prototypes of the SPATIAL-AR toolkit. These developmental processes and design decisions were handled with a group of researchers from different fields. These researchers formed a "*design support group*" throughout this study.

The design support group collaborated the researcher while deciding on revision and modifications of the design throughout the whole study. The design support group consisted of two mathematics education experts and three instructional technologists. The mathematics education experts, included one expert with PhD degree and other one with MS degree in the field of elementary mathematics education, were participated discussion meetings for issues about implementation and spatial tasks. On the other hand, the instructional technologists, who have PhD degree in the field of computer education and instructional technology, were participated discussion meetings about issues about AR interface and design of booklets. Hence, modifications and revisions in the design were consulted with the design support group before continuing the implementation. However, the design support group meetings were not handled on a regular basis. So, if any issue or a remarkable point with regard to design had experienced, a discussion meeting was arranged with the members of the design support group.

Table 3.1. Time schedule for the phases, procedures and goals of the iterations

Phases and Procedures	Time Schedule	Goals
Preliminary Phase	Oct.2014 - Nov.2015	Finding out factors to be considered in order to design and develop a SPATIAL-AR toolkit and designing it accordingly
Designing Software	Dec.2014 - Nov.2015	
Preparing Tasks	Aug.2015 - Nov.2015	
Designing Booklet	Oct.2015 - Nov.2015	
Prototyping Phase - Focus Group Study	Nov.2015 - Jan.2016	Improving the design of SPATIAL-AR toolkit from subject matter perspective
Screening with two experts	Nov.2015 - Dec.2015	
Continuous analysis	Nov.2015 - Dec.2015	
Revising Software	Nov.2015 - Jan.2016	
Revising Tasks	Nov.2015 - Jan.2016	
Revising Booklet	Dec.2015 - Jan.2016	
Prototyping Phase - Walkthrough Study	Feb.2016 - Apr.2016	Improving the design of the SPATIAL-AR toolkit from students' perspective and conjecturing expected practicality for target students
Walkthrough with two seventh graders	Feb.2016 - Mar.2016	
Continuous analysis	Feb.2016 - Mar.2016	
Revising Software	Feb.2016 - Apr.2016	
Revising Tasks	Feb.2016 - Apr.2016	
Revising Booklet	Feb.2016 - Apr.2016	
Prototyping Phase - Micro-evaluation Study	Apr.2016 - Jan.2017	Finding out possible contributions of intervention to seventh grade students with the SPATIAL-AR toolkit in terms of spatial ability and learning environment.
Practicing with eight seventh graders	Apr.2016 - Jun.2016	
Continuous analysis	Apr.2016 - Jun.2016	
Final analysis	Jun.2016 - Jan.2017	

In the following sections, phases of the research, research design of iterations, participants of the iterations, data collection tools, and procedures are described in detail. An outline of time schedules of the phases is given in Table 3.1.

3.2.1. Preliminary Research Phase

Before designing a prototype of SPATIAL-AR toolkit, it is important to understand related studies about improving spatial ability models and suitable technological tools. The goal of this phase was to find out factors to be considered in order to design and develop a SPATIAL-AR toolkit that includes set of spatial tasks and a mobile AR interface to foster spatial understanding of seventh grade students, and to develop a prototype accordingly. Review of the literature constituted a base framework for this study and revealed needed principles to design a prototype.

First of all, literature review revealed that students had some problems in identifying three dimensional objects from their representations on textbooks which are two dimensional objects and only permit orthographic or perspective representation modes. These difficulties were referred as cognitive filter by Alcaniz and colleagues (2010). The negative effects of the cognitive filter on spatial understanding of students can be eliminated by training students to improve their spatial ability. However, although researchers stated that spatial ability could be trained by using concrete manipulative materials or by using digital materials in school mathematics (Olkun, 2003; Sundberg, 1994) most of the manipulatives are static and more of them are not changeable without breaking. As for the display based computer technology, our world is not two dimensional as projected on screens. Thus, even if students use computers, tablets or mobile phones in common ways as a supplementary for educational contents, they have still dealt with the cognitive filter caused from two dimensional projections of our three dimensional world on screens of devices and indirect manipulation of virtual objects (Shelton & Hedley, 2004). This might be the biggest limitation in providing real life experiences to students for educational contents via computer screens. It was seen that this limitation could be overcome with AR technology. In addition, previous studies stated that AR provides an enhancement of shared learning environment which provides learners to see other learners' actions and interactions in learning environment as well as contribute them by interacting virtual objects and other learners in natural ways which interactions play a key role for their learning while working with virtual objects (Park, 2012; Youniss & Damon, 1992). Therefore, AR technology can enhance interactions with virtual objects as well as with other learners through interface which is difficult with desktop based technology since in instructional environment based on desktop based technology, a disconnection exists between the task space and display space (Billinghurst & Kato, 2002). Thus, the AR interface may help to enhance students' spatial understanding by interacting with virtual objects and each other. Consequently, needed design principles for such ARLE, AR interface and spatial contents were derived from literature in order to form a framework to design and develop such AR interface to foster students' spatial abilities.

In short, the literature review guided this research to find out a complex problem as identifying two dimensional representations of three dimensional objects, and possible solutions for it as forming a model for spatial contents and a framework with design principles for designing AR interface to foster students' spatial ability in ARLE. Consequently, the preliminary research phase lead to a draft of model for improving spatial ability with AR (MISAR) which specifies spatial contents for tasks, design principles for ARLE and key elements of a mobile AR interface.

3.2.1.1. Draft Model for Improving Spatial Ability with Augmented Reality

Two objectives related with spatial ability of the seventh grade mathematics curriculum were chosen as the instructional unit. These objectives are (a) to draw two dimensional views of three dimensional objects from different directions, and (b) to build constructions of which views from different directions are given (MoNE, 2013). The recommended duration for these objectives were stated as five lesson hours in curriculum. In Turkey, one lesson hour is 40 minutes for middle school level. However, it is hard to build new virtual three dimensional objects in the coded AR interface from thin air with existed source codes and scripts. Therefore, students were limited to explore pre-designed virtual objects and they cannot create new virtual objects. This factor stands technological limitations of this study. Therefore, the objective (b) has been discarded from this research and only focus was given to identifying two dimensional representations of three dimensional objects, and to understand spatial relations both within an object between multiple objects.

In preliminary research phase, some models and characteristics about spatial contents for tasks have been determined. These models and characteristics lead forming of a draft MISAR. Firstly, the characteristics of spatial contents for tasks were derived from models of spatial operational capacity (SOC) (Sack, 2013; Sack & van Niekerk, 2009; Sack & Vazquez, 2013) and training spatial ability (TSA) (Martin-Gutierrez, et al., 2010; Perez-Carrion & Serrano-Cardona, 1998). The original model of TSA involves six sequential levels (Perez-Carrion & Serrano-Cardona, 1998) and the modified one involves five sequential levels (Martin-Gutierrez, et al., 2010). Additionally, spatial contents suggested by Wiesen (2004, 2015) were also considered while determining characteristics of spatial tasks. The draft MISAR was explained in the previous chapter in detail and presented in table 2.2. The draft MISAR includes five sequential levels and spatial tasks for ARLE were designed in accordance with this model. Moreover, virtual objects for these tasks were also prepared suitable with this model.

3.2.1.2. Draft Design Principles for Augmented Reality Learning Environment

In literature review, it was revealed that AR interface has the potential to enhance students' interactions with virtual objects and each other more than a desktop-based system, since students have the opportunity to use either partner-centered attributions or egocentric attributions to define spatial descriptions of a thing (Schober, 2009). Moreover, it was emphasized that learning pairs have higher level of critical thinking than independently working individuals (Johnson & Johnson, 1989) because studying with small groups provides opportunities for students to make discussions and take responsibility for their own learning as well as others. Therefore, in order to provide these opportunities in an ARLE, three main draft design principles for ARLE were derived from studies about collaborative learning and AR interface to cover all aspects of the design and development processes of SPATIAL-AR toolkit for fostering spatial ability of seventh grade students. These design principles, which were explained in the previous chapter in detail, were summarized as follows.

First of all, in ARLE, learners should be supported with unique interactions. To do this, they should be provided the opportunity of physical and natural way of interactions like moving virtual objects or walking around these virtual objects so that they should explore virtual objects by seeing each other and cooperate in natural way (Billinghurst & Kato, 2002; Smith & MacGregor, 1992; Szalavari et al., 1998; Vygotsky, 1978). Secondly, learners should be engaged in an active process for learning in ARLE since they could build ideas about geometric shapes better through active participation, rather than passive observation (Smith & MacGregor, 1992; Sundberg, 1994). Active participation in ARLE could be provided through challenging and gamified tasks. In addition to this, they should have the opportunity to move freely in environment and to control own independent viewpoints for virtual objects so that control of environment does not belong to a specific learner; hence, this eliminates other students being passive observer (Smith & MacGregor, 1992; Sundberg, 1994; Szalavari et al., 1998). Thirdly, in ARLE, AR interface should also provide some opportunities to teachers. AR interface should provide different type of tasks so teachers can choose, determine and administer spatial tasks for linking new information to prior one by providing opportunities for current situations of learners (Billinghurst & Dünser, 2012). Moreover, AR interface should also allow teachers to provide necessary information about learners' progress with feedbacks about their works just-in-time (Wu, Lee, Chang & Liang, 2013). Since these principles interrelate with both ingredients of spatial tasks and AR interface, these principles are in need of spatial tasks and AR interface to perform their design purposes.

AR interface was designed and developed considering a list of key elements of an AR interface with Unity 3D and Vuforia SDK. Two basic key elements which define a coded interface as AR were derived from literature in terms of key elements of AR interface. These key elements are virtuality and augmentation. Firstly, virtuality principle states that three dimensional objects do not have to be physically in the real environment since, even if they do not exist in the real environment, they should be viewed and examined via virtual objects in the real environment by AR tools (Kaufmann, 2003; 2004; Szalavari et al., 1998). Secondly, augmentation principle states that objects physically existed in the real environment can be augmented with virtual elements so dynamic information and variation of new parts for an existing object should be superimposed on this real objects via virtual annotations (Azuma, 1997; Szalavari et al., 1998).

As stated before, these key elements were regarded as basic starting point for design principles of AR interface since these principles were inseparable parts of the programming of an AR interface. In other words, the logic of AR is about augmentation of a real environment with virtual objects which do not exists physically in this environment (Azuma, 1997). Moreover, these principles are necessity to provide students making natural way of interactions with virtual objects freely in order to examine same objects with their own viewpoints and collaborate with partners by seeing each other (Kaufmann, 2004). In this study, other essential principles for an AR interface and ARLE were also conjectured through iterations.

3.2.1.3. Design and Development of the First Prototype

A prototype for SPATIAL-AR toolkit was designed and developed in light of these design principles and the draft MISAR. As stated before, the SPATIAL-AR toolkit was main instructional tool for intervention in ARLE for this research. The SPATIAL-AR toolkit was composed of a student's booklet which includes set of spatial tasks and target images for virtual objects, and an AR interface to visualize these virtual objects. The first prototype of SPATIAL-AR toolkit was designed and developed to provide students the opportunities of natural ways of interactions with virtual objects and each other as well as being active participants of the process of learning in order to foster their spatial ability levels in accordance with draft design principles for ARLE, key elements of a mobile AR interface and draft MISAR (Figure 3.3).

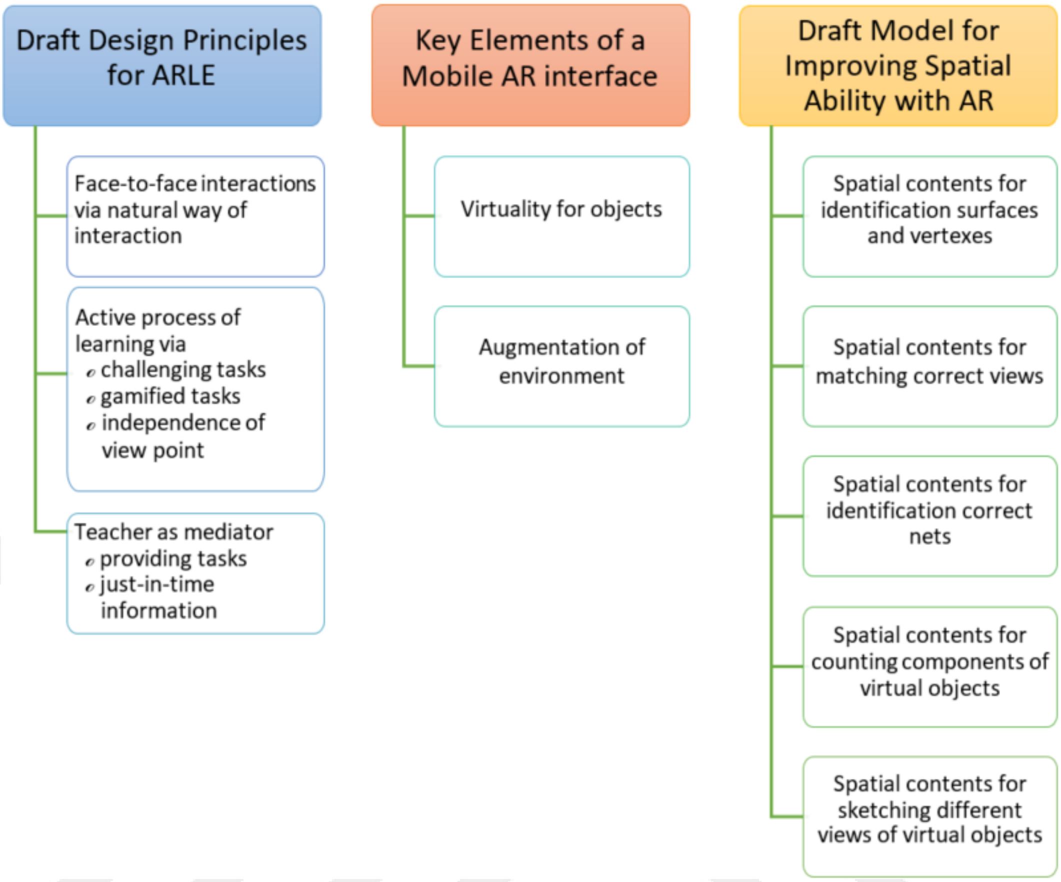


Figure 3.3. Characteristics to design and develop SPATIAL-AR toolkit within ARLE

First of all, spatial tasks in this student's booklet were prepared in accordance with the draft MISAR as in five sequential parts. In this phase, a pool for spatial tasks and virtual objects was prepared which included 73 spatial tasks and 111 related virtual objects (Table 3.2).

The reason of designing this pool was to provide a rich number of spatial tasks and virtual objects for focus group study in the first iteration of prototyping phase in which two mathematics education experts evaluated these numerous tasks and virtual objects' relevancy to seventh grade mathematics curriculum. So that, they could choose suitable tasks and virtual objects from this pool. These tasks and target images for virtual objects were printed on student's booklets.

Table 3.2. The pool for spatial tasks regarding the draft MISAR

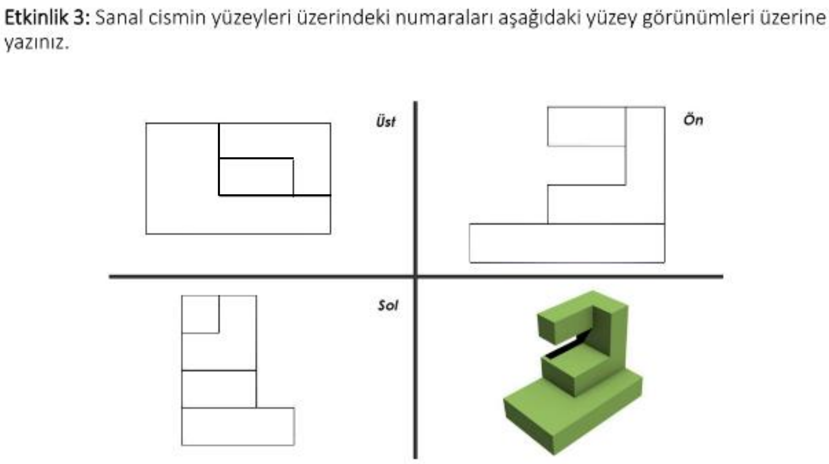
Parts	Spatial Contents	Virtual Objects	Spatial Tasks
Part 1: Surfaces & vertices	Identification of surfaces on orthographic views	10	10
	Identification of surfaces on perspective views	10	10
	Identification of vertices on projective views	10	10
Part 2: Matching Correct Views	Determining semiotic descriptions from organized orthographic views	10	2
	Determining semiotic descriptions from disorganized orthographic views	20	5
Part 3: Developments	Identification of nets of three dimensional objects	21	6
Part 4: Counting	Counting the number of objects in touch with given part of an object	10	10
Part 5: The Second Dimension - Sketches	Sketching missing orthographic views	10	10
	Sketching all orthographic views from three directions	10	10

As stated above the spatial tasks in the SPATIAL-AR toolkit came into existence based on the draft MISAR. In accordance with the draft MISAR, spatial tasks were designed in five sequential parts in the same line with AR interface which was also explained in the end of this section. The contents of spatial tasks were explained as follows.

Surfaces & vertices. The first part for spatial tasks was surfaces & vertices. Spatial tasks included tasks about identifying parts of three dimensional objects. This part was planned to involve three spatial contents for spatial tasks. These spatial contents were identification of surfaces on orthographic views, identification of surfaces on perspective views, and identification of vertices on both orthographic and perspective views.

Identification of surfaces on side-views. This spatial content refers spatial tasks which involves identifying specific surfaces on three dimensional objects and tasks about marking these specific surfaces on orthographic views of objects. In accordance with this spatial content, virtual three dimensional objects were developed as having numbers to signify specific surfaces (Figure 3.4). In addition, student's booklet was designed to involve orthographic views of the virtual objects with blank areas in order to mark the numbers of the specific surfaces, and perspective views without numbers on them in order to give a glance of these virtual objects to students (Figure 3.5).

Figure 3.4. Sample for numbered surfaces on a virtual object



[Activity 3: Write the numbers on surfaces of the virtual object onto orthographic views.]

Figure 3.5. Sample task for orthographic views of a virtual object to identify numbered surfaces

Identification of surfaces on projective views. This spatial content of this part refers to spatial tasks which is about identifying specific surfaces on orthographic views of three dimensional objects and tasks about marking these specific surfaces on perspective projections of objects. In accordance with this spatial content, virtual three dimensional objects were developed to be used only a reference in order to investigate and recognize which surface on orthographic views could be where on the perspective view (Figure 3.6). In addition, the prototype booklet involved orthographic views of the virtual objects with the numbers of the specific surfaces and perspective views of the virtual objects in order to mark these numbers of specific surfaces (Figure 3.7).

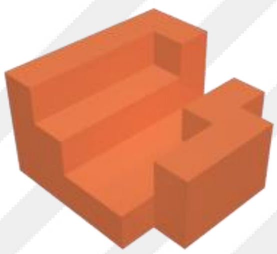
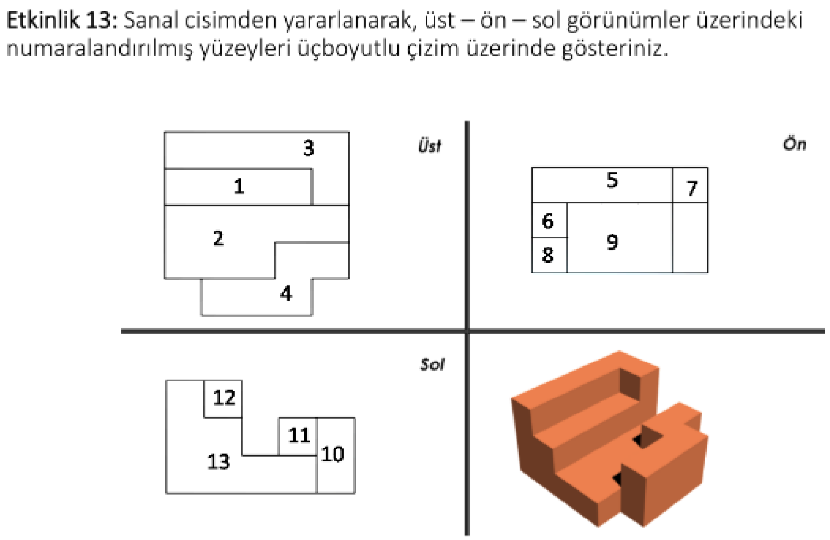


Figure 3.6. A sample virtual object to be used as reference to identify numbered surfaces



[Activity 13: Mark the numbers of surfaces on orthographic views onto perspective view via investigating virtual object.]

Figure 3.7. Sample task for orthographic views of a virtual object with numbered surfaces

Identification of vertices on side-views. This spatial content refers to spatial tasks about identifying vertices on three dimensional objects and tasks about marking specified vertices on orthographic views and perspective views of objects. Virtual three dimensional objects were designed to have numbers on some of their vertices (Figure 3.8). In accordance with this spatial content, the prototype booklet involved orthographic views and perspective views of the virtual objects in order to mark these numbers of specific vertices (Figure 3.9).

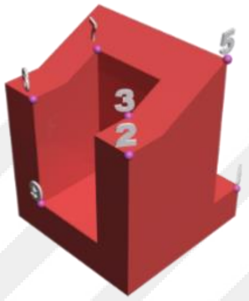
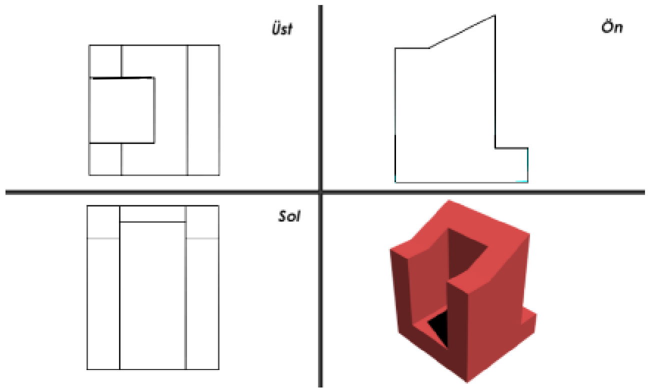


Figure 3.8. A sample virtual object to identify numbered vertices

Etkinlik 21: Sanal cismin numaralandırılmış köşelerini aşağıdaki üst – ön – sol görünümler ve üçboyutlu çizim üzerinde gösteriniz.



[Activity 21: Mark the numbered vertices on virtual object onto orthographic views and perspective projection.]

Figure 3.9. Sample task for orthographic and perspective views of a virtual object to identify numbered vertices

Matching Correct Views. The second part for spatial tasks was about understanding side views of three dimensional objects. This part involved two spatial contents for spatial tasks. These spatial contents were determining correct orthographic views from organized and disorganized lists of orthographic views. Moreover, two types of virtual objects were designed which were virtual objects composed of complex shapes like prisms and pyramids, and composed of unit-cubes.

Determining side views from organized orthographic views. This spatial content refers to spatial tasks which involves determining which orthographic views within organized list belong to which virtual three dimensional objects. In accordance with this characteristic, multiple virtual three dimensional objects were designed as formed from both with unit-cubes and complex shapes for every scene, and they were placed on a single scene in groups (Figure 3.10). In addition, prototype booklet was designed to involve orthographic views from three sides of these virtual objects presented in organized lists by name of these sides (Figure 3.11).

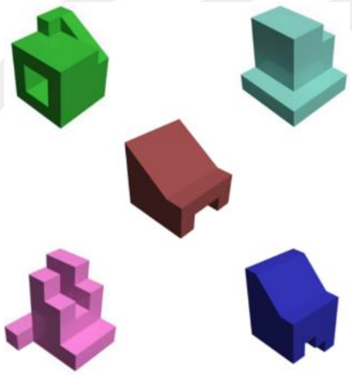
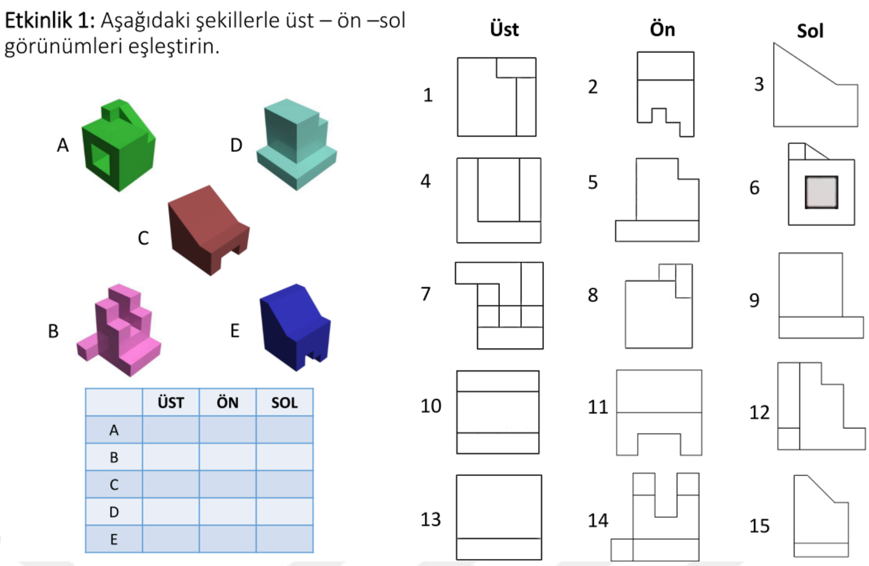


Figure 3.10. Sample for multiple virtual object in a scene



[Activity 1: Match side-views with objects.]; [Üst: Top, Ön: Front, Sol: Left]

Figure 3.11. Sample task for organized orthographic views of virtual objects in categories

Determining side views from disorganized orthographic views. This spatial content refers to spatial tasks which involve determining disorganized orthographic views belong to which virtual three dimensional objects. It could look like similar to first spatial content but this content was about disorganized list of orthographic views of objects without categories like top view, front view or left view. Similar to the first one, multiple virtual three dimensional objects were designed for every scene (Figure 3.12). In addition, the booklet was designed to involve orthographic views from three sides of these virtual objects without categories (Figure 3.13).

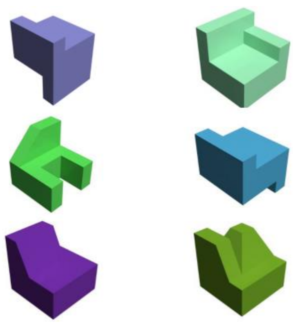
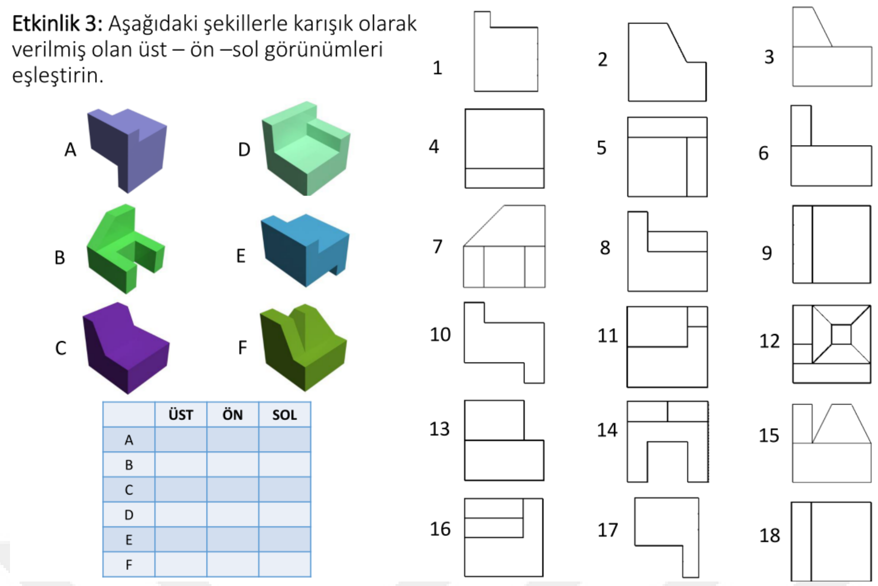


Figure 3.12. Sample for multiple virtual object in a scene

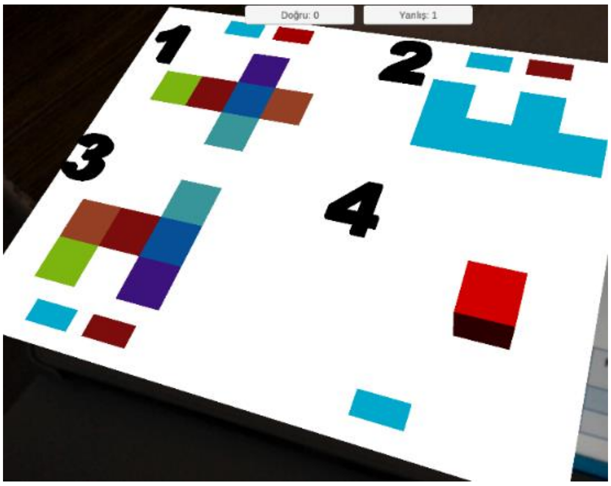


[Activity 3: Match side-views which listed without categories.]; [Üst: Top, Ön: Front, Sol: Left]

Figure 3.13. Sample task for disorganized orthographic views of virtual objects without categories

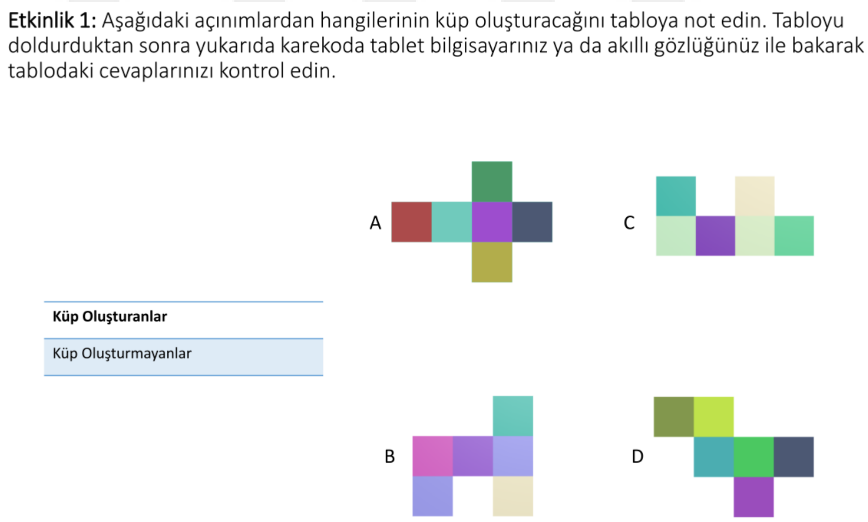
Nets. The third part for spatial tasks was nets. Spatial tasks for this part included tasks about identifying nets of virtual three dimensional objects. So this part involved one type of spatial content for simple geometric shapes such as cube, prisms and pyramids.

Identification of nets of three dimensional objects. This spatial content is about selecting correct and incorrect nets of geometric shapes. The spatial tasks involved correct and incorrect nets of cube, rectangular prism, square prism and square pyramid. In accordance with this spatial content, multiple correct and incorrect nets of geometric shapes were designed for every scene as gamified learning activity which give opportunity of immediate feedback (Figure 3.14). In addition, prototype booklet was designed to involve tables for noting correct and incorrect nets (Figure 3.15).



[Doğru: Number of Right Answers; Yanlış: Number of Wrong Answers]

Figure 3.14. Sample for multiple virtual object in a scene



[Activity 1: Investigate developments tablets or smart glasses to determine and take notes on table about which nets can form a cube and which not.] [Küp Oluşturanlar: Nets Can Form a Cube, Küp Oluşturmayanlar: Nets Cannot Form a Cube]

Figure 3.15. Sample task for nets of cube

Counting. The fourth part for spatial tasks was counting. Spatial tasks were about counting the number of objects in touch with given component of an object.

Counting the number of objects in touch with given object. This spatial content refers to spatial tasks which involves counting of objects in touch with given component of a virtual three dimensional objects. In accordance with this spatial content, virtual three dimensional objects, which were formed from rectangular prism bricks, were designed (Figure 3.16). In addition, student's booklet was designed to involve perspective views of these virtual objects and a table to write the number of bricks which are in touch with titled bricks (Figure 3.17).

Figure 3.16. Sample virtual object formed from bricks in a scene

Etkinlik 4: Yukarıda yer alan karekoda tablet bilgisayarınız ya da akıllı gözlüğünüz ile bakarak sanal cisimdeki harflendirilmiş tuğlaların kaç tane farklı tuğlayla yanyana olduğunu tablolara yazın.

[Activity 4: Write the number of bricks which are in touch with titled bricks.]

Figure 3.17. Sample task for counting activities about bricks of virtual three dimensional object

The Second Dimension – Sketches. The fifth and last part for spatial tasks was about sketching different orthographic views of objects by investigating virtual three dimensional objects. The sketching tasks involved two spatial contents. These spatial contents were sketching missing orthographic views and sketching all orthographic views from three directions. Similar to the second part of the draft MISAR, two types of virtual objects were designed for this part.

Sketching missing orthographic views. This spatial content refers spatial tasks which involve sketching missing orthographic views of virtual three dimensional objects. In accordance with this content, virtual three dimensional objects were designed as formed from both with unit-cubes and complex shapes (Figure 3.18). In addition, student's booklet was designed to involve orthographic views from two sides and plotting paper area to sketch missing one (Figure 3.19).

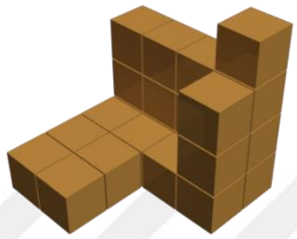
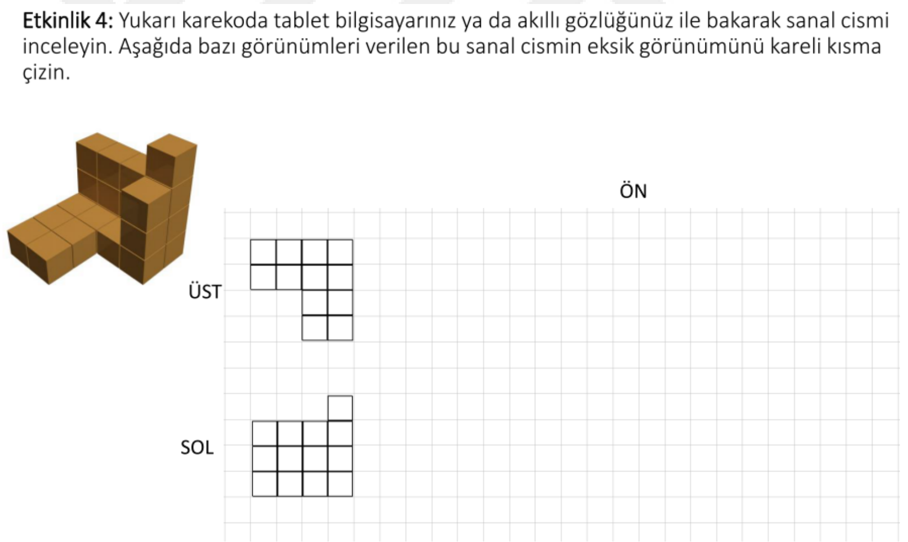


Figure 3.18. Sample virtual object formed from unit-cubes



[Activity 4: Investigate virtual object via tablet or smart glasses. Sketch missing side-view of the virtual object.]; [Üst: Top, Ön: Front, Sol: Left]

Figure 3.19. Sample task for sketching missing orthographic views

Sketching all orthographic views from three directions. This spatial content is similar to the one mentioned above with a little difference. These spatial tasks involved sketching all orthographic views from three directions of virtual three dimensional objects. In accordance with this spatial content, virtual three dimensional objects were designed as formed both with unit-cubes and complex shapes (Figure 3.20). In addition, student's booklet was designed to involve plotting paper area to sketch orthographic views of virtual three dimensional objects (Figure 3.21).

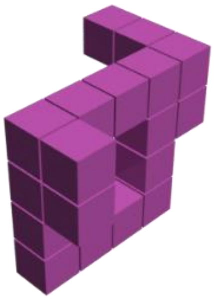
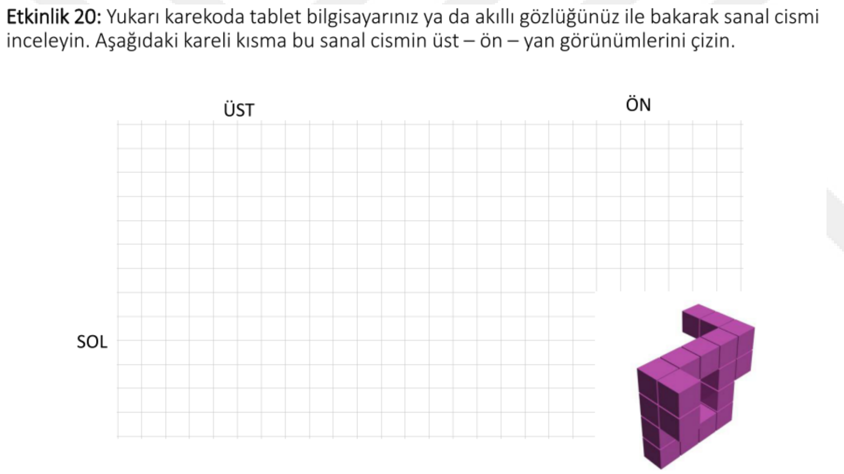


Figure 3.20. Sample virtual object formed from unit-cubes



[Activity 20: Investigate virtual object via tablet or smart glasses. Sketch top-front-left side-views of the virtual object onto plotting area.]; [Üst: Top, Ön: Front, Sol: Left]

Figure 3.21. Sample task for sketching all orthographic views from three directions

AR interface was another component of the SPATIAL-AR toolkit. The AR interface was written, coded and compiled as including the virtual objects for spatial tasks. First of all, there are some software development kits (SDKs) and developer platforms to code an AR interface. In this study, Qualcomm Vuforia SDK and Unity 3D developer platform game engine were used to code AR interface since both of them can be used free of charge with some little limitations such as watermark on screen in every launch of application. Moreover, Autodesk 3DS Max graphing designing software was used to design of the graphics of three dimensional objects. The graphics of three dimensional objects were integrated scenes in the AR interface with Unity 3D game engine in developmental processes.

Five scenes were coded with Unity 3D (Figure 3.22) for every part of the draft five-parted MISAR. In addition, some C# scripts were written to enable interactions for needed scenes (Appendix H). These scenes and scripts were compiled for Android OS since the study was conducted via tablets and smart glasses with Android OS.

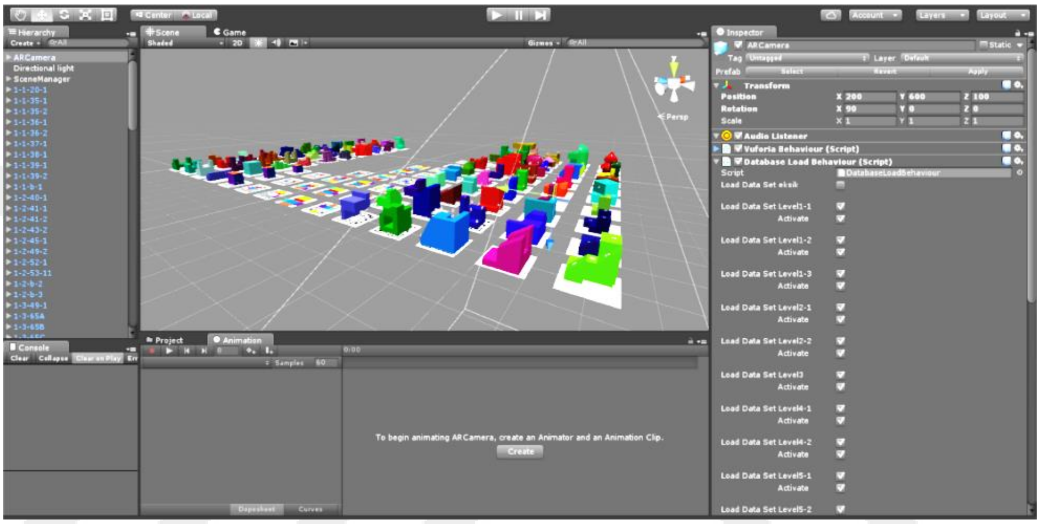


Figure 3.22. Unity 3D design screen for the first version of AR interface

The AR interface coded for this research needs target images in order to visualize virtual objects. Therefore, a student's booklet was designed to hold both spatial tasks and target images specified for each spatial task. Working principle of the target-based AR interface was demonstrated in figure 3.23.

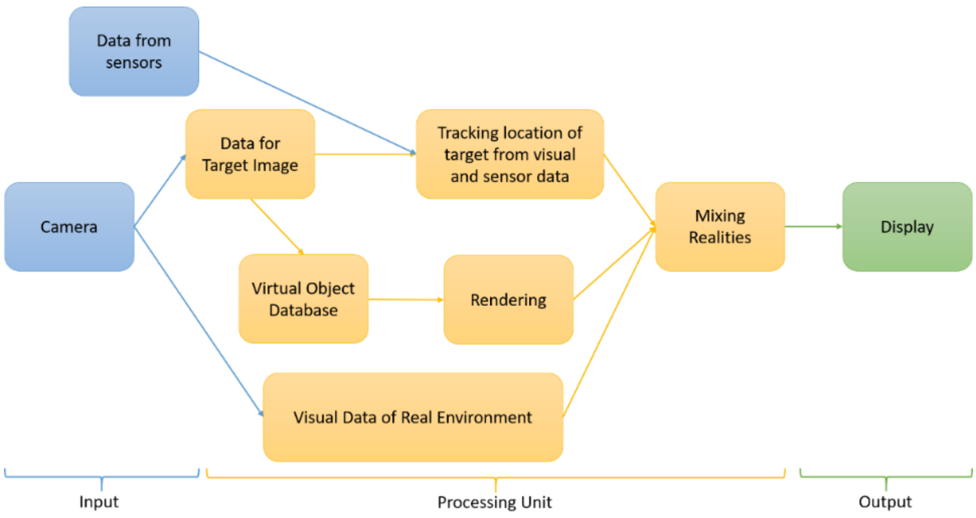


Figure 3.23. Working principle of target-based AR interface of the research

The AR interface needs a camera in order to process real environment visual data, and detect and track target images. Sensors of tablets or smart glasses could also be used as a tracking source if target has already been detected. Thus after detection of target, both camera and sensors can provide data for tracker unit. After detection of target image has been accomplished, the AR interface compares database so as to identify specified virtual object for this target image. In the meantime, visual data of real environment, which have been captured from camera, is processed in order to mix virtual objects and real environment. Computed location of target image, virtual object and visual data of real environment are merged as a single video stream as a final step for this loop. This merged video stream is routed to display and finally real environment is augmented. This loop repeats itself 18 - 24 times in a second within the AR interface of this study. The quality of visual output depends on quality of camera device, lighting of environment and quality of display. Similarly, reliability of detection and matching correct virtual object with correct target image also depends on quality of camera and lighting of environment. As above mentioned, if detection has been accomplished correctly, AR interface can track target image without direct visual data but with data from sensors.

In this study, qr-codes were used as target images. Because, their credibility of detection with the AR interface had been pointed as higher as possible by Vuforia SDK detection tools than other type of target images. By the way, any two dimensional and some three dimensional visual data can be used as target image within this SDK. Since these series of studies were conducted classroom environments which may not have direct sun lights and good lighting always, qr-codes were used as target images in order to provide the least buggy environment for detection of target images.

As mentioned above, the first version of student's booklet was designed to include both target images needed for the AR interface and contents of spatial tasks with A4 size pages. Within this booklet, pages were organized as containing landscape pages with target images above and spatial task below (Figure 3.24).

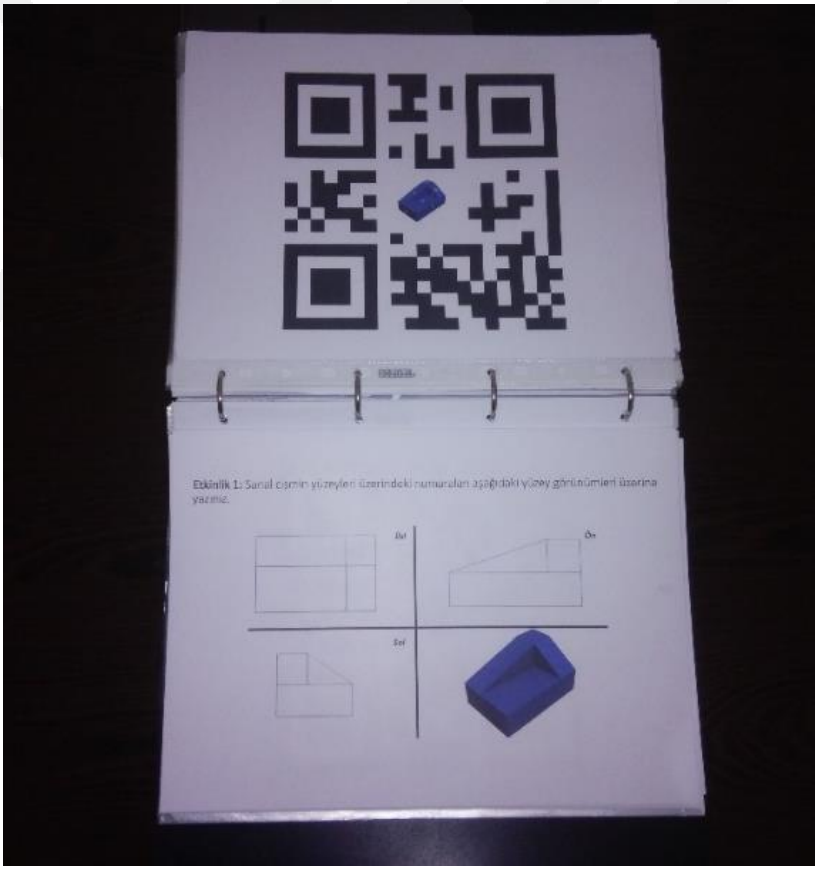


Figure 3.24. A sample page for the first version of student's booklet

3.2.1.4. Summary of Preliminary Research Phase

The draft five-parted MISAR, the draft design principles and key elements of an AR interface were unified in accordance with their relations in order to form framework to design and develop an AR-based intervention for improving spatial ability of middle school students in an ARLE. In other words, in order to form solid and coherent prototype for fostering spatial ability in ARLE, these principles should be mixed or related in accordance with their relevance. Therefore, the spatial tasks in SPATIAL-AR toolkit were designed to allow active process of learning with natural ways of interactions of students and challenging and gamified tasks via spatial tasks. Moreover, teacher can collaborate learning by providing these set of tasks and just-in-time information for students' progresses through this toolkit. Thus, the SPATIAL-AR could make students to engage in interactions with each other while sharing their thinking with others by representing a part of an object or describing an object with verbal and written statements.

In short, the first prototype of SPATIAL-AR toolkit was composed of these components:

- A mobile device application, AR interface, which contains virtual three dimensional objects and animations.
- An augmented booklet that provides target images for the AR interface to visualize virtual three dimensional objects and related spatial tasks for students.
- Android OS devices: Tablets or Smart Glasses.

A Qr-code to download a demo AR interface of the final prototype of SPATIAL-AR toolkit can be found in Appendix A. This prototype was formatively evaluated in prototyping phase and serve as instructional tool in iterations of the following phase.

3.2.2. First Iteration of the Prototyping Phase: Focus Group Study

The goal in the focus group study was to guide and improve the design of SPATIAL-AR toolkit from subject matter perspective. This goal lead to the following research questions:

- To what extent does the SPATIAL-AR toolkit embody the design principles?
- To what degree is the SPATIAL-AR toolkit relevant to intended curriculum?

For the purpose of answering research questions, it was necessary to gain in-depth knowledge about how the participants interact with SPATIAL-AR toolkit. In addition, feedbacks from them as experts were considered to find out necessary adjustments in design of SPATIAL-AR toolkit in order to make it more suitable to seventh grade mathematics curriculum. Therefore, the descriptive and exploratory nature of qualitative research was particularly appropriate for the present iteration (Yin, 1994).

In general, this focus group study provided useful information about bugs, other problematic and wrongly designed characteristics of the developed first prototype of SPATIAL-AR toolkit. Hence, with this information refinement in the draft five-parted MISAR and the design principles of ARLE were performed. Moreover, a new set of design principles for booklets was conjectured as well as programming AR interface.

3.2.2.1. Participants of the Focus Group Study

Participants in the focus group study were two mathematics educators who have at least MS degree in mathematics education and research assistants at public universities in Central Anatolia region of Turkey. Moreover, these participants have also teaching experiences at middle school level of mathematics at least three years. These participants were aware of AR technology but they had not used any AR tool until this research. On the other hand, they had conducted one or two research about learning tasks with three dimensional geometry concepts. In their research, they had developed three dimensional learning tasks with dynamic geometry software like GeoGebra 3D and Cabri 3D. Therefore, they had experiences with designing and administering learning tasks by using virtual three dimensional objects without AR technology.

Table 3.3. Participants' characteristics in focus group study

Participants	B.Ed.	MS	PhD
Bilge	Elementary Mathematics Education	Elementary Mathematics Education	Elementary Education
Rıza	Elementary Mathematics Education	Elementary Mathematics Education	Elementary Education (continuing)

These participants were purposefully selected since the focus of this iteration was to discover, understand and gain an in depth understanding about participants' interaction with SPATIAL-AR toolkit to find out necessary adjustment for updating toolkit and to make the spatial contents more suitable to seventh graders mathematics curriculum in accordance with their feedbacks. While deciding on the participants of the focus group study, the main concern was to eliminate as many obstacles as possible to make more stable and more appropriate SPATIAL-AR toolkit to Middle School Mathematics Curriculum (MoNE, 2013) and to understanding level of seventh graders. In order to preserve the personal rights of the participants, pseudonyms were used to each participants as Bilge and Rıza (Table 3.3).

Previous studies have indicated that mathematics and spatial ability have a strong relationship (Battista, 1990; Clements & Battista, 1992; Olkun, 2003). Therefore, mathematics educators were considered to be aware of the value of spatial ability, and they could be expected to have a reasonable spatial ability level. These factors could help them know what were expected from them while they carrying out spatial tasks in ARLE. In addition, these factors helped the researcher to collect efficient data so as to make proper adjustments for the SPATIAL-AR toolkit.

3.2.2.2. Procedure for the Focus Group Study

The focus points of this iteration are the participants' works, and their feedbacks about appropriateness of the SPATIAL-AR toolkit to seventh grade students. The participants were provided with the first prototype of SPATIAL-AR toolkit. The first prototype of SPATIAL-AR toolkit, designed and developed in the preliminary research phase as explained before, was used as a learning material.

Since the overall study was conducted with two different devices, as tablets and smart glasses, the participants used the devices that they preferred. The participants were asked to carry out the activities and express their way of thinking. They were also asked to clearly explain difficulties they had encountered while making explorations with spatial tasks. Moreover, they evaluated convenience of virtual objects and spatial tasks for seventh grade level and mathematics curriculum. For this reason, they were provided a checklist about relevancy of virtual objects and spatial tasks to seventh grade mathematics curriculum and students' levels of understanding (Appendix B). After they finished all spatial tasks in each part of the draft MISAR, they used other remaining device and repeated the spatial tasks with this device. This focus group study was conducted with one participant at a time in a researcher's office in faculty. Therefore, each participant was observed at a time in detail. Two lesson hours were given to participants to complete the spatial tasks for each part with both of tablets and smart glasses. This focus group study was carried out in the first semester of 2015 – 2016 academic year and it was lasted approximately three weeks included with interview sessions.

In the preliminary research phase, the first prototype of SPATIAL-AR toolkit was designed to include 111 different virtual three dimensional objects and 73 spatial tasks. These virtual objects and spatial tasks constituted a pool for spatial tasks, as mentioned before. Since the recommended duration for the objectives of instructional unit has been stated as four to five lesson hours in seventh grade mathematics curriculum, it was also discussed with participants that seventh grade students can accomplish each part of tasks in one lesson hour with which spatial tasks and virtual objects. Therefore, according to their comments on the checklists, some of the virtual objects and spatial tasks had been discarded from the SPATIAL-AR toolkit.

3.2.2.3. Data Collection in the Focus Group Study

Participants' feedbacks and comments as well as data collected from other sources were considered to make the SPATIAL-AR toolkit more appropriate to seventh grade mathematics curriculum and more stable to use in ARLE. In this iteration, data were collected through observations while participants were carrying out the spatial tasks, checklist provided for tasks, discussion sessions at the end of each day, screen video captures of devices, and their notes on booklets. In addition, task based interview sessions during the implementation and retrospective interview sessions after the implementation were conducted. Sample questions for the retrospective interview are described in table 3.4.

The task based and retrospective interviews were held by the researcher. During the interview sessions, it was expected from participants to talk about what they were thinking about each exercise of spatial tasks for each part. If their explanations were not enough or not clear, the researcher asked additional questions in order to clarify their statements. Moreover, while video camera is recording ARLE, the participants' point of views to virtual objects were captured by screen videos of AR interface. Therefore, the participants' nonverbal expressions like physical movements and what they see at that time in ARLE were collected for further analyses if needed. Hence, video recordings and screen captures were tried to be synchronized to understand what participants see in the process and how they react. In addition to these, the drawings, answers, and notes on booklets were collected to see their works and responses. However, because of some technical difficulties like overloading performance of devices with more than one recording processes, some of video recordings were corrupted. In order to overcome these technical difficulties, data from other sources like audio recording, observation notes and discussion notes were also used as backups.

Table 3.4. Sample questions for the retrospective interview

Issue	Questions
Appropriateness to curriculum	*What do you think about feasibility and suitability of this SPATIAL-AR toolkit for seventh grade mathematics curriculum?*
	Has the SPATIAL-AR met the objectives about spatial visualization in seventh grade mathematics curriculum?
Timing	*Which virtual objects might stay and which ones might be removed to satisfy one hour time limitation for each levels of activity?*
Bugs in programming	*Have you encountered any glitch during activities either about programming or virtual objects?*
Difficulties	*What kinds of difficulties or problems occurred during the spatial tasks?*

The task based and retrospective interviews as well as other logs were analyzed through content analysis. This analysis method is defined as “a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use” (Krippendorff, 2012, p.18). The analysis was made according to AR interface, booklets and spatial tasks.

3.2.3. Second Iteration of the Prototyping Phase: Walkthrough Study

The goals of this walkthrough study were to guide and to improve the design of SPATIAL-AR toolkit through seventh graders’ experiences in the ARLE and to conjecture expected practicality of this toolkit with representative of target students. These goals lead to the following research questions:

- Is the SPATIAL-AR toolkit valid and relevant with the intended curriculum?

In order to answer these research questions, qualitative research methodology was considered since it is necessary to gain in-depth knowledge about finding out how the students interact with the SPATIAL-AR toolkit. Because, Johnson (1995) suggests that researchers, who studies education with technology, "engage in research that probes for deeper understanding rather than examining surface features" (p.4). Moreover, he noticed that qualitative methodologies of inquiry are powerful and useful tools for enhancing ones’ understanding of teaching and learning processes.

3.2.3.1. Participants of the Walkthrough Study

Two participants were chosen for this iteration. These participants were chosen from 7th graders at a public middle school in Kırşehir. Participants were chosen in accordance with their scores in Spatial Ability Test (SAT) among 66 seventh grade students. The SAT was developed in time period between the first iteration and this iteration in accordance with spatial contents in the MISAR in order to provide an assessment tool for ARLE with the MISAR. Two 7th graders were chosen as participants from ones having higher scores in the SAT scores out of fourteen (Table 3.5). In order to establish confidentiality of participants, pseudonyms were used.

Table 3.5. Participants' characteristics in walkthrough study

Participants	Gender	SAT Score (out of 14)
Meva	Female	14
Elif	Female	13

Since this iteration was still about designing, developing and updating the second prototype of SPATIAL-AR toolkit, students who have a reasonable spatial ability level were considered appropriate for this iteration.

3.2.3.2. Instrument in the Walkthrough Study

First of all, as a reminder, the SAT was only used for selecting participants in this iteration but used to measure spatial ability at the following iteration. As mentioned above, a SAT was developed by researcher, according to the draft MISAR. The aim of this test development process was to develop a proper assessment test for intervention with spatial tasks designed along with the MISAR, and to find out spatial ability of students and at what level the SPATIAL-AR toolkit might provide the improvement in spatial ability. This test was piloted before the walkthrough study in order to check its reliability, appropriateness, clarity and discrimination of the items. The test and the pilot study were described below.

Content of the SAT was tried to be accomplished in the same line with the MISAR. The first version of SAT includes 15 multiple-choice questions. These questions were checked for their appropriateness by four researchers with doctoral degree in the field of Mathematics Education. According to their feedback some changes were made in the items of the SAT before pilot study. Participants of pilot study of the SAT were 132 seventh graders from Kırşehir. These students were selected conveniently. According to the results of the pilot study, item difficulty, discrimination index for each item and point-biserial correlation coefficient were calculated as in Table 3.6.

A good and reliable classroom test were defined as having reasonable item difficulty which was recommended as greater than .20, item's discrimination index which was also recommended as greater than .20 (Matlock-Hetzel, 1997; Varma, 2006; Zimmaro,

2003) as well as reasonable point-biserial correlation coefficient which was stated as greater than .25 (Varma, 2006). As seen on table 3.6, the SAT satisfy these condition except item 9, therefore, this test can be considered as a good classroom test with exclusion of item 9 (Matlock-Hetzel, 1997; Varma, 2006; Zimmaro, 2003). After this pilot study, the final version of SAT was formed with reordered items based on item difficulty values in table 3.6.

In this study, the final SAT included 14 multiple-choice items. Scoring of the SAT was handled by giving one point for each correct answer. Therefore, the maximum score for students was 14 and minimum was 0. Moreover, students' spatial ability were categorized as low spatial ability for 0 to 5 scores, average spatial ability for 6 to 10 scores and high spatial ability for 11 to 14 scores.

Table 3.6. Item difficulty and item discrimination index for the SAT

Item	Item Difficulty	Item discrimination index	Point-biserial correlation
1	0,59	0,61	0,55
2	0,62	0,57	0,47
3	0,59	0,45	0,36
4	0,52	0,49	0,42
5	0,48	0,79	0,63
6	0,39	0,58	0,48
7	0,71	0,26	0,21
8	0,52	0,85	0,70
9*	0,56	0,09	0,14
10	0,73	0,62	0,60
11	0,61	0,56	0,51
12	0,50	0,55	0,47
13	0,56	0,75	0,56
14	0,79	0,37	0,35
15	0,58	0,56	0,40

*: *not satisfied criteria*

To sum up, item 9 was excluded from test since it did not fit the criteria. Therefore, the final version of SAT involves 14 multiple choice items (Appendix C). Item difficulty of the SAT was calculated as 0,58 and discrimination index was calculated as 0,46. In addition to this findings, the Cronbach Alpha reliability coefficient was calculated as 0,73, for the pilot study, in fact, this value indicates high reliability.

3.2.3.3. Procedures for the Walkthrough Study

The focus of this second iteration is to improve the design and development of the SPATIAL-AR toolkit as well as to find out expected practicality of this toolkit from students' experiences in the ARLE to inform the following iteration. In the walkthrough study, the participants were provided with the second prototype of SPATIAL-AR toolkit.

For the prototype of SPATAIL-AR toolkit, according to findings in the focus group study in the first iteration, some revisions and additions were made in terms of draft design principles as well as the draft MISAR. For example, third part of the draft five-parted MISAR which was about nets was excluded since the spatial tasks in this part were decided as not suitable for the seventh grade mathematics curriculum. With this change, some of characteristics of design principles for ARLE were also changed. For example, gamified tasks characteristic was excluded since the spatial tasks about the third part of the draft MISAR were only designed tasks related to this characteristic. Moreover, the order of parts in the draft MISAR was change with regard to feedbacks of the participants of the focus group study.

With all modifications after focus group study, the draft MISAR became a four-parted model and the second prototype of SPATIAL-AR toolkit was designed considering these revisions. This revised toolkit was used as learning materials in this walkthrough study. This prototype toolkit included approximately 44 different virtual three dimensional objects and the student's booklets included 36 spatial tasks and target images for these virtual objects (Table 3.7).

Table 3.7. Spatial Tasks for each part of the revised four-parted MISAR

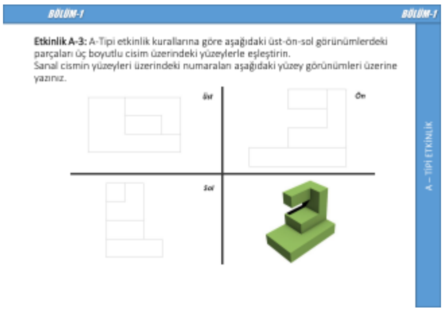
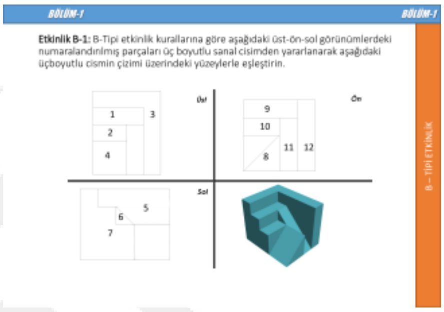
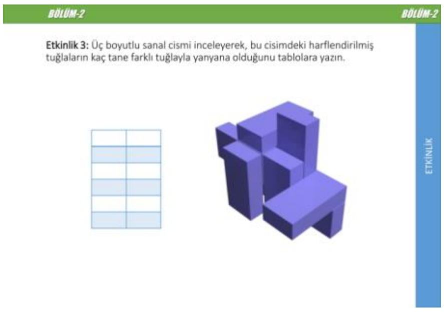
Parts	Characteristics	Example Tasks
Part 1: Surfaces & vertices	Identification of surfaces on orthographic views	
	Identification of surfaces on perspective views	
	Identification of vertices on both orthographic and perspective views	
Part 2: Counting	Counting the number of objects in touch with given part of an object	

Table 3.7. (Continued)

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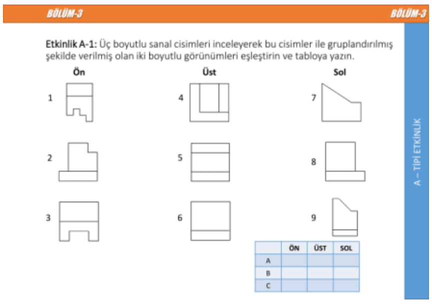
<td>Part 3: Matching Correct Views</td>
<td>Determining side views from organized orthographic views</td>
<td>
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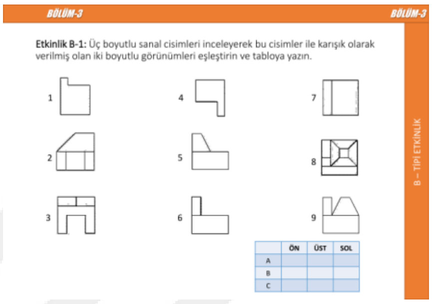
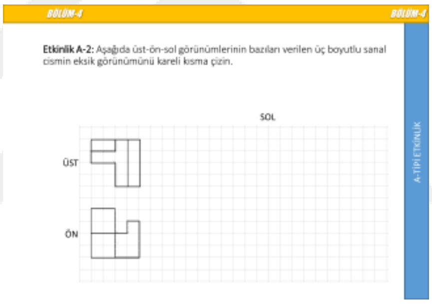
<tr>
<td></td>
<td>Determining side views from disorganized orthographic views</td>
<td>
</td>
</tr>
<tr>
<td>Part 4: The Second Dimension - Sketches</td>
<td>Sketching missing orthographic views</td>
<td>
</td>
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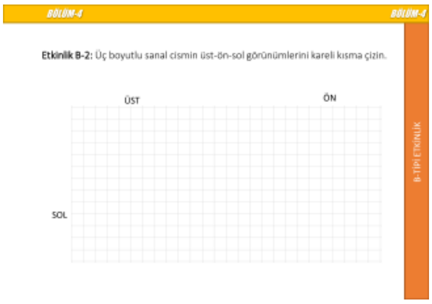
<tr>
<td></td>
<td>Sketching all orthographic views from three directions</td>
<td>
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</table>

This table summarizes the revised four-parted MISAR for this walkthrough study. In accordance with these modifications, spatial tasks were redesigned in four parts.

There were two different types of device similar to focus group study, and these devices were tablets and smart glasses. The participants used the devices whichever they preferred since this iteration has been still about guiding and improving the design and development of the SPATIAL-AR toolkit. One of the participants completed all tasks with tablet while other participant completed with smart glasses (Figure 3.25).

Figure 3.25. Students were working on the spatial tasks

In this iteration, the participants worked together in computer laboratory of a public middle school in Kırşehir. Participants were asked to carry out the spatial tasks via their preferred devices. They were expected to give comments about the SPATIAL-AR toolkit and to help developing stable version of it. One lesson hour was given to participants to complete the spatial tasks in the booklets for each part of the revised four-parted MISAR. Since this was students' first encounter with the AR technology, it was briefly explained what is augmented reality technology. In addition, how they can use tablet and smart glasses along with SPATIAL-AR toolkit were introduced to students. After that, the participants tried to explore spatial relationships between objects and their projections by following directions in spatial tasks.

In the beginning of walkthrough study, the content of the study was introduced to participants. In addition, some explanations about spatial tasks were given to them if any need occurred. After that the participants started to explore virtual objects with spatial tasks via preferred device at hand. The walkthrough study was carried out in the second semester of 2015 – 2016 academic year and conducted over two weeks. This study was exploratory in nature, and also it provided developmental assessment for possible usefulness, advantages and disadvantages of SPATIAL-AR toolkit for seventh graders level. Therefore, according to findings of this iteration, some revisions and additions were made to the SPATIAL-AR toolkit and so design principles as well as the MISAR, and revised versions of them were prepared to use in following iteration.

3.2.3.4. Data Collection in Walkthrough Study

The information needed to understand students' progresses while using the SPATIAL-AR toolkit could be gained through probing participants' experiences during interviews and observing them during spatial tasks. This walkthrough study provided helpful data to enhance tasks in order to make suitable and solid to use at third iteration as well as to develop a proper and practical SPATIAL-AR toolkit for the ARLE. Gathering information about students' interactions in the ARLE was obtained by observations with video recording of environment and screens of devices, task based and retrospective interview sessions. Sample questions for the retrospective interviews are described in table 3.8.

Table 3.8. Sample questions for the retrospective interview

Issue	Questions
Distracting aspects	*Was there anything that distracts your attention throughout the tasks?*
Difficulties	*What kinds of difficulties or problems did occur during the tasks?* *with respect to device* *with respect to tasks*
Bugs in programming	*Have you encountered any problems during activities about observing virtual objects?*

To sum up, in this walkthrough study, there were data from interviews, observations, video records for instructional process, and screen captures of AR interface. Data analysis was done to reshape and to inform the planning and development of the SPATIAL-AR toolkit, and to understand what would be happening in learning phases in ARLE in order to reshape design principles if needed. The data from interviews, observations, video and audio records were also documented. Similar to the first iteration, the analysis was made according to AR interface, booklets and spatial tasks. Findings in the walkthrough study reshaped the SPATIAL-AR toolkit as more proper for seventh grade level.

3.2.4. Third Iteration of the Prototyping Phase: Micro-evaluation Study

The goal of this micro-evaluation study was to find out possible contributions of intervention with the SPATIAL-AR toolkit in terms of spatial ability and learning environment. This goal lead to following research questions:

- Is the SPATIAL-AR toolkit practical in learning environment with mobile devices?
- How effective is the SPATIAL-AR toolkit in improving spatial ability and enhancing learning opportunities?

Qualitative research was used to find out the answers of research questions for this iteration. The explanatory nature of qualitative research method was employed. According to Yin (1994), the function of an explanatory study is to explain how or why about cases. Thus, it could be understood whether the seventh grade students might transfer their practices and spatial understandings with mobile AR devices into paper and pencil environment.

The researcher focused on a selected number of participants in groups, to be described later, in order to allow an in-depth examination and obtain detailed data of how students approached and interacted with the SPATIAL-AR toolkit. Along with the quantitative information, the qualitative research method allowed the researcher to probe deeper into explaining how students of varying in spatial ability interacted with the SPATIAL-AR toolkit through spatial tasks in order to express possible contributions of this toolkit in the ARLE for seventh graders.

3.2.4.1. Participants of the Micro-evaluation Study

This micro-evaluation study was conducted with eight seventh grade students from a public middle school in Kırşehir since due to technical limitation of the study and in order to supply all students a device, the participants were chosen purposefully from 26 students in terms of their spatial ability levels. There were four tablets and four smart glasses for the study. Participants were grouped in accordance with their pretest scores in the SAT. As mentioned before, this SAT was developed by the researcher for this study in accordance with the revised MISAR. This test and pilot study about it were explained in the previous iteration.

As mentioned above, the SAT was used as an indicator of students' spatial abilities. In this iteration, four students were supplied with smart glasses and other four students with tablets. Therefore, the study groups constituted tablet based ARLE and smart glasses based ARLE. All device based groups included two students with variety of spatial ability levels in order to make ARLE suitable for emerging both partner-centered and egocentric spatial descriptions about virtual objects with diversity in groups (Table 3.9).

Table 3.9. Participants' characteristics in micro-evaluation study

Groups		Participants	Gender	Spatial Ability
Group 1	Smart Glasses	Ahmet	Male	High
		Ömer	Male	Average
Group 2	Tablet	Enes	Male	High
		Ümit	Male	Average
Group 3	Smart Glasses	Nurgül	Female	Low
		Erhan	Male	Average
Group 4	Tablet	Şebnem	Female	Low
		Sare	Female	Average

In order to establish confidentiality for participants, pseudonyms were used as in table 3.9. These students were selected since they constituted representative cases from low, average and high levels of spatial ability, and since it was aimed to develop a toolkit to foster spatial ability which is suitable to all students from any spatial ability level and supports both ability-as-enhancer and ability-as-compensator hypotheses.

3.2.4.2. Procedure for the Micro-evaluation Study

The focus of this iteration was to develop an understanding about students' progresses within this ARLE in order to find out possible contributions of the design, and to give final shape to the SPATIAL-AR toolkit, the design principles and the MISAR, if needed revisions.

In this iteration, the participants were provided the third prototype of SPATIAL-AR toolkit. In accordance with findings of the previous iteration, design principles and the MISAR were reshaped. For example, it was seen that seventh grade students needed sample demonstrations about each type of spatial tasks in the walkthrough study. Therefore, sample tasks were prepared with an introductory page for each part of the student's booklet. The third prototype of SPATIAL-AR toolkit was redesigned in accordance with the results of the walkthrough study and used as a learning tool in this micro-evaluation study. This third prototype of SPATIAL-AR toolkit included 47 different virtual three dimensional objects for 33 spatial tasks and 6 example tasks (Table 3.10).

The table 3.10 summarizes the revised MISAR and so spatial tasks for this micro-evaluation study. Thus, the last version of student's booklets for spatial tasks consisted of four parts as Surfaces & vertices (Appendix D), Counting (Appendix E), Matching Correct Views (Appendix F), and The Second Dimension – Sketches (Appendix G).

Table 3.10. Virtual objects and spatial tasks for each part of the four-parted MISAR with examples

Parts	Spatial Contents	Virtual Objects	Spatial Tasks	Example Tasks
Part 1: Surfaces & vertices	Identification of surfaces on orthographic views	6	5	1
	Identification of surfaces on perspective views	6	5	1
	Identification of vertices on both orthographic and perspective views	4	3	1
Part 2: Counting	Counting the number of objects in touch with given part of an object	4	3	1
Part 3: Matching Correct Views	Determining side views from organized orthographic views	8	2	1
	Determining side views from disorganized orthographic views	7	3	1
Part 4: The Second Dimension - Sketches	Sketching missing orthographic view	6	6	0
	Sketching all orthographic views from three directions	6	6	0

The participants were divided into two groups as tablet based ARLE (Figure 3.26) and smart glasses based ARLE (Figure 3.27). In the micro-evaluation study, the participants worked in groups of two students in an unused room of a public middle school in Kırşehir. The participants were asked to carry out the spatial tasks via their devices. Similar to the second iteration, one lesson hour was given to participants to complete the spatial tasks in the student's booklets for each part of the revised MISAR. Moreover, at the beginning of the study, AR technology, usage of both tablet and smart glasses in an ARLE, and content of the study were briefly explained to participants in a classroom. The researcher was an observer, a technical assistant and a teacher in these groups.

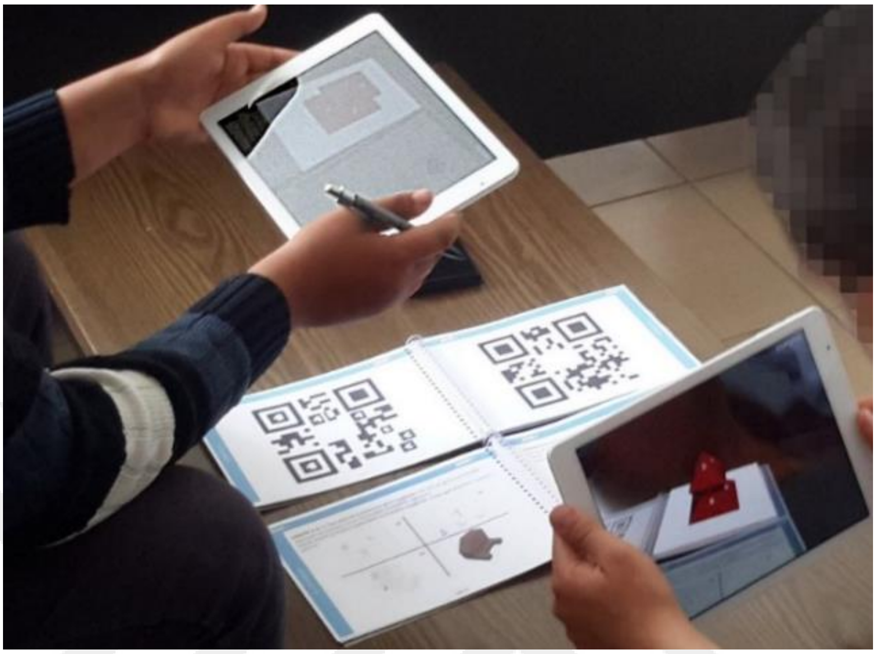


Figure 3.26. Students were working on spatial tasks with tablets

Figure 3.27. Students were working on spatial tasks with smart glasses

Before the study, the SAT was administered to the participants as pretest in order to see their preliminary spatial ability levels. This test was also administered as posttest to all of the participants in order to analyze possible gain in spatial ability. In order to restrict analytical processing during solving spatial ability questions, Bodner and Guay (1997) limited time to administer their spatial ability test which was Purdue Spatial Visualization Test (PSVT). Similar to the PSVT, time allotted for administration of the SAT was also limited to 20 minutes to complete test.

In sum, according to results of the both focus group and walkthrough studies, the SPATIAL-AR toolkit was purified from its bugs and unsuitable characteristics, then it was used in this micro-evaluation study. This micro-evaluation study was carried out in the second semester of 2015 – 2016 academic year and this iteration lasted five weeks.

3.2.4.3. Data Collection in Micro-evaluation study

In this iteration, both quantitative and qualitative data were collected. The SAT was administered to the participants as pretest before intervention and as posttest after intervention in order to provide some possible indicators for fostering spatial ability. The qualitative data were collected through video recordings of both environment and screen of devices, observation notes and interview transcripts. The information needed to explain students' understanding and experiences while using the SPATIAL-AR toolkit can be gained through probing participants' experiences during retrospective interviews. Gathering information about their interactions in the ARLE were also obtained by observations and video recordings of their ongoing interactions while they were dealing with spatial tasks. Their works on booklets were also considered as data sources.

In the micro-evaluation study, retrospective interviews were conducted after posttest administration of the SAT in order to ask what they envision about objects while solving pretest and posttest of the SAT. Sample questions for the retrospective interviews were described in table 3.11. In addition, video records of the students provided data about both students' interactions in the ARLE and their point of view via device screen while in discussions, so the participants' nonverbal expressions like body movements and what they see at that time in the ARLE were also considered as data.

Table 3.11. Sample questions for the retrospective interview

Issue	Questions
Envisioning	*What did you envision about spatial tasks and objects during pretest and posttest administrations of the test?*
Strategies	*How did you explain your works in tasks?* *What were your starting points in tasks?*
Distracting things	*Was there anything that distracts your attention throughout the tasks?*
Difficulties	*What kinds of difficulties or problems did occur during the tasks?* *with respect to device* *with respect to tasks*
Bugs in programming	*Have you encountered any problems during activities about observing virtual objects?*

The qualitative data analysis was done in order to understand what would be happening in learning with AR interface and to explain students' experience with the SPATIAL-AR toolkit in order to provide an insight into practicality and possible effectiveness of this toolkit.

To sum up, the data from interviews, observations, video and audio records, the SAT and students works on booklets were documented and analyzed. The analysis was made according to SPATIAL-AR toolkit, indicators of spatial ability and learning opportunities in parallel with research questions. Results of this iteration were also used to give final and solid shape to the SPATIAL-AR toolkit, the design principle and the MISAR as well as revealing possible contributions of the toolkit.

3.3. Data Analysis through Educational Design Research

In this section, data analysis procedures for all iterations of this EDR study were explained. As in the nature of the EDR study, data analysis had started with preliminary research phase and continued until the end of the study in a continuous way until the prototype has reached a completed product. In other words, since findings reshaped the prototype and prototype shaped the study in cycles of EDR, data collection and data analysis continued until obtaining a stable and solid prototype (Nieveen & Folmer, 2013; Plomp, 2013).

As stated before, this study was conducted in three iterations. In general, results of each iteration formed and reshaped prototype in the following iterations. Hence, outputs of each iteration became input for the following ones. Moreover, these iterations included several micro-cycles. Therefore, continuous analyses of data were required within each iteration so that if any problematic issue or remarkable point about the SPATIAL-AR toolkit has arrived in an implementation session of any iteration, the researcher analyzed related data and reshaped the toolkit or design principles in accordance with the findings at the end of the each implementation session. Hence, the issues were tried to be eliminated before proceeding to study.

The data were collected through several different sources such as interview sessions, video records of learning environment, screens' video captures of devices, worksheets, audio records, and observations logs. First of all, audio records of interview were documented in text forms which is a starting point to analyze (Creswell, 2009). Moreover, video records and screen video captures of devices were synchronized in order to understand the participants' nonverbal interactions with virtual objects and each other like pointing, gesturing, gazing or relocating. In addition, worksheets of participants and observation notes were also added to data pool in order to increase credibility of findings by triangulating (Merriam, 1995) and to complete missing or damaged points of electronically stored data.

In order to proceed data analysis and to create meaningful categories from these data, the documented data, observation notes and worksheets were read several times to deduce and comprehend what happened throughout the study (Creswell, 2007). At the meantime, synchronized video records were also watched several times in order to understand participants' ways of interactions and possible glitches about programming of AR interface. These documenting audial data, synchronizing visual data and analyzing these data were applied in MAXQDA software. After these reading and watching processes, relevant and useful data were disassembled from all the other data in order to focus important factors related with research questions and aims of the iterations (Glaser & Straus, 1967). Moreover, other data sources like videos were also analyzed in order to extract visual and nonverbal units of data as well as if exist to verify and validate founded units of data from written sources with visual ones. After extracting units of data, they were roughly separated and coded in accordance with their relation. Similar or related codes were grouped together to form tentative categories.

Definitions of the codes and categories were noted on their names in the MAXQDA software in order to prevent confusion through data analyses process (Creswell, 2007). When all relevant codes were matched with these categories, it was seen that categories were consistent with their included codes and there was no remaining idle code as a result of constant comparison (Taylor & Gibbs, 2010). Finally, these categories were grouped and related with pre-determined themes in accordance with respect to research questions and aims of the iterations. Hence data analyses focused on three main themes, as issues regarding the AR interface, regarding booklets and tasks which were components of the SPATIAL-AR toolkit, for the first two iterations, since these iterations were about to design, develop and improve the SPATIAL-AR toolkit and so the mobile AR interface, students' booklets and spatial tasks (Table 3.12).

Table 3.12. Coding categories regarding to improvement of the prototype

Themes	Categories	Criteria
AR Interface	Issues about recognition of qr-codes Issues about projection of virtual objects	Issues about recognition about target images or / and superimposing of virtual object on these target images were considered.
	Interacting with interface	Interactivity opportunities or deficiencies about usage of interface were considered.
	Determining orientation for objects	Mimicking reality issues were considered.
	Issues about pure programming	Pure programming which can prevent stable usage of interface were considered.
Booklet	Usability of booklet in ARLE	Opportunities or deficiencies for affective interactions with virtual objects were considered.
	Directions about tasks	Clarity of tasks and directions of them were considered.
Tasks	Timing	Needed time to complete tasks were considered.
	Appropriateness of tasks	Relevancy of tasks to curriculum were considered.
	Adaptation of students to ARLE	Whether students get used to ARLE.

This table summarized themes and emerged categories from data in content analysis of the first and second iterations' data from observation notes, interviews' transcripts, checklists and video logs. On the other hand, for the last iteration, data analyses were handled over two themes as contribution to spatial ability and contribution to learning environment in accordance with research questions and aims of this iteration (Table 3.13).

Table 3.13. Coding categories regarding to spatial ability and learning environment

Themes	Categories	Criteria
Spatial Ability	Find a reference object	Students find some reference surfaces, vertices or components to accomplish tasks
	Follow a path on objects	Students follow some kind of paths or routes across objects to accomplish tasks
	Count objects	Students count components of object
	Estimate objects	Students estimate size or other physical properties of object
	Draw outline for objects	Students sketch views through general outline
	Transfer to test	Students show signs about transferring their learning to paper and pencil test
Learning Environment	Physical Interactions	Students interact with objects or each other physically
	Verbal Interactions	Students interact with each other verbally
	Shared Learning	Students share their viewpoints for objects or thoughts
	Guidance through learning	Students need guidance for tasks

This table summarized themes and emerged categories from data sources in terms of indicators of spatial abilities and opportunities in learning environment for data analysis about findings of the third iteration. Moreover, difference between students' scores in the pretest and posttest administrations SAT were analyzed through Wilcoxon signed-rank test since, sample size was small.

To sum up, the data gathered through this EDR was analyzed in line with research questions and aims. Therefore, the data analysis processes firstly focused on improving the design of the SPATIAL-AR toolkit for experts' and students' perspective, and then focused on revealing possible contributions of this design to spatial ability and learning environment. Based on these focuses, emerged categories and codes were grouped and explained at the following chapter.

3.4. Trustworthiness

Because of the subjective nature of qualitative research, researchers have looked to develop ways in which trustworthiness can be applied to this type of research (Merriam, 1995). The aim of trustworthiness is to support the argument that the research's findings are "worth paying attention to" (Lincoln & Guba, 1989). Moreover, it is important in research in education, social work, counseling and administration since the trustworthiness affects practices of these fields. Also, these practices directly influence individuals' life, their choices and lifestyles (Merriam, 1995).

In any qualitative research, some criteria for trustworthiness demand attention. For this study, validity issues were discussed in terms of credibility (internal validity) and transferability (External Validity). Moreover, consistency of data analysis was discussed in terms of dependability (reliability) in detail at the following sections.

3.4.1. Validity

Validity meant "truth", is "interpreted as the extent to which an account represents the social phenomena to which it refers" (Hammersley, 1990, p. 57; as cited in Silverman, 2002). Firstly, researchers should convince themselves that "findings" of their research are based on critical investigation of all data segments. It other words, they do not depend on a few well-chosen examples. Then, they should also convince audience for scientific credibility of our data (Silverman, 2002).

3.4.1.1. Internal Validity

The internal validity searches an answer for the question of that "How congruent are one's findings with reality?". Therefore, internal validity is the notion of "reality (truth)". There are two views of reality. In positivists believe, reality is fixed and stable and in naturalists' view (qualitative research believe) reality is constructed and interpreted (Merriam, 1995). In qualitative research, it is assumed that truth is constructed, multi-dimensional and ever-chancing, so that there is no such thing as a single and solid reality which waits to be observed and measured. Therefore, it is assumed that there are interpretations of reality (Merriam, 1995). To strengthen the internal validity of qualitative research there are some strategies. These strategies were explained in the context of this study.

First strategy is *triangulation.* It refers to the use of multiple investigations, different data sources or multiple-methods. In this strategy, using multi-ways investigating situations or findings and combining them to get a true on these situations or findings are employed to reach the truth (Fraenkel & Wallen, 2006; Silverman, 2002). Therefore, in this study, a variety of data sources was used, for example, in order to reveal truth of a phenomena which revealed in an interview by investigating the truth in observation notes, documented interviews data or video captures of screens as well as ARLE.

Comprehensive data treatment refers to analyze and compare all data until results refer to every single case or situation of relevant data that were collected. Comprehensive data is not same for qualitative research as in quantitative research. For example, in survey research, researcher satisfies this condition by reaching significant and non-spurious correlations. That is, it is enough to show nearly all data and support hypothesis in quantitative study. However, in qualitative study, this is achieved when generalization of the study should apply every single pieces of data (Silverman, 2002). In this study, categorization of asserted codes were continued until no single idle code remained.

Peer / colleague examination refers to asking peers / colleagues to examine the data in terms of plausibility of emerging findings (Lincoln & Guba, 1985; Merriam, 1995). As an example, in this study, design and development process of spatial tasks and the SPATIAL-AR toolkit were handled with two mathematics experts. In addition, one educational technologist and an expert from mathematics education contributed in a continuous process of analysis of data about design principles and findings from iterations.

Persistent observation refers to identify most relevant characteristics and elements to a situation and to focus on them in detail (Lincoln & Guba, 1985). Therefore, a continuous process of observing the participants was applied throughout the all iterations of this study.

3.4.1.2. External Validity

The goal of qualitative inquiry is to understand the particular in-depth rather than finding out what is generally true of many. In qualitative research, generalizability is provided with to degree of transferability of findings to other situations (Merriam, 1995). Therefore, transferability could be mentioned rather than generalizability as in quantitative inquiry.

There are at least three alternative conceptions of transferability in qualitative inquiry. First conception is *working hypothesis*. Cronbach (1975) stated that, generalizing is not the priority, it is about working hypothesis or guiding practice, not a conclusion. Research should appraise a practice / proposition in it is own settings. Second conception is *concrete universals*. Erickson (1986) stated that the general lies in the particular; what is learned in a particular situation is applied to similar situations encountered. The third way of viewing external validity is *reader and user generalizability*. In this view, generalizability is determined by people in these situations. They speculate how a research's findings can be applied to other settings (Merriam, 1995). Therefore, ones wanted to design and developed an ARLE or implement an AR tool to foster spatial ability can derive results of this study in their circumstances.

3.4.2. Reliability

Reliability refers to the degree of consistency in data analysis while assigning codes, categories and asserting findings by different observers or by same observer or different occasions (Hammersley, 1990 as cited in Silverman, 2002). In social sciences, notion of reliability / replication is somewhat problematic. Since we deal with human and human behavior is never static. We can never get the exact same results. However, we may reach different interpretations of the same phenomenon. In qualitative research, we seek not exactly same results, but consistency over replications (Merriam, 1995; Silverman, 2002). For strengthen the consistency, two proposed strategies by Merriam (1995) were utilized.

Triangulation is nearly similar with the given triangulation in validity section. It is about using multiple methods of data collection, it can lead to consistency. As mentioned before, in this study, a variety of data sources was used in data analyses procedure.

Peer / colleagues examination is about to examine the same dataset to understand whether the emerging results appear to be consistent. In this study, one mathematics education expert helped data analyses and coding procedures.

3.5. Assumptions and Limitations of Study

Through this study, some assumptions were made. First of all, it was assumed that all the participants including two mathematics educators gave necessary attention to the spatial tasks. Secondly, at the third iteration, the participants contributed in collaborative learning environment with their partners. Thirdly, even if the AR was a new technology for the participants, the participants could use the AR interfaces without any technical problem for usage. In addition, the novelty of AR interfaces as a supplement to learning environment could not remain after the participants became accustomed to it, as stated by Dunleavy, Dede and Mitchell (2009).

Because the AR technology is relatively new technology and devices like smart glasses are too expansive, the results of this study are limited to a small number of participants. Therefore, findings of this study is limited to similar environment and students have similar characteristics. Moreover, the spatial tasks and the MISAR developed throughout this study can be applicable to similar environment in such possessed similar technological potential.

3.6. Researcher Role

The researcher had different roles in this study. First of all, mobile AR interface was designed and developed based on design principles for ARLE and key elements of a mobile AR interface by researcher. The Unity 3D software was used as a developer environment. Vuforia SDK provided a basis for designing and developing this mobile AR interface. Moreover, the researcher also wrote some key scripts in order to provide interactivity layers for touch and pointer events only for matching side views tasks, and gamified experiences through scoring students' works only for nets of three dimensional objects tasks. Additionally, the virtual objects and spatial tasks were designed and developed, in accordance with design principles for ARLE and spatial contents for MISAR, by researcher. The Autodesk 3ds Max was used to design virtual three dimensional objects. The SAT was also designed by researcher based on the spatial contents for MISAR in order to provide an assessment tool for spatial ability in accordance with spatial tasks based on the MISAR. Furthermore, the booklets for spatial tasks and target images were also designed and printed by researcher by considering design principles for booklets. Lastly, in the iterations, the researcher was facilitator of the SPATIAL-AR toolkit in implementation sessions. So that, the researcher had also teacher role throughout the iterations. On the other hand, if students needed assistance for usage of tablets and smart glasses or they had problems with the AR interface, the researcher had also a technical assistant role throughout this research in order to provide assistance to students for using their devices and AR interface without serious problems.

In general, in this study, the researcher was designer, developer and facilitator of intellectual learning experiences for participants. Therefore, the researcher had mediating role for the learning environment as well as designer of this environment.

CHAPTER FOUR

FINDINGS

The main focus of this study was to form needed design principles in order to set up an effective, feasible and applicable augmented reality learning environment (ARLE) and to design a mobile augmented reality (AR) interface for fostering spatial ability of students in line with these design principles. This focus lead study to two main aim. Firstly, it was aimed to guide and improve the design of spatial augmented reality (SPATIAL-AR) toolkit which included a mobile AR interface and series of spatial tasks. Secondly, it was aimed to find out possible contributions of intervention to seventh grade students with this SPATIAL-AR toolkit in terms of spatial ability and learning opportunities.

As a result of these aims, this chapter provided formative evaluation of design principles in order to improve the design by explaining ingredients of this development process and articulated a model for improving spatial ability in AR (MISAR) in order to provide a way to put theory into practice. Moreover, possible contributions of the SPATIAL-AR toolkit to spatial ability and learning environment were brought into view.

4.1. Design and Development Processes of SPATIAL-AR toolkit for Augmented Reality Learning Environment

In this part, findings about design and development processes of the SPATIAL-AR toolkit with a mobile AR interface and set of spatial tasks were described in terms of needed characteristics of ARLE, mobile AR interface and spatial tasks. These characteristics guided the whole design, development and implementation processes of the SPATIAL-AR toolkit for an ARLE. Therefore, reasons of revising prototypes of SPATIAL-AR toolkit in order to make more suitable and stable prototypes for ARLE were explained in accordance with findings from the iterations.

4.1.1. Iteration I: Focus Group Study

The focus group study was conducted with two mathematics educators. Both participants carried out tasks with two devices namely tablets and smart glasses, interchangeably. In this focus group study, data was collected through observations' notes, task based interviews during the implementation, retrospective interviews after the implementation, discussion's sessions at the end of each day, audio records and video captures of screens of devices. Data were analyzed in order to answer research questions which were given at the previous chapter.

Results of this focus group study were used to explain reasons for modifications in the first prototype of SPATIAL-AR toolkit. The first prototype of SPATIAL-AR toolkit was composed of a mobile AR interface and a student's booklet. This toolkit was designed and developed in line with characteristics of draft design principles for ARLE, key elements of a mobile AR interface and the draft five-parted MISAR which had been derived from literature in the preliminary research phase (see Figure 3.3). These characteristics were considered as initial draft principles for designing of a mobile AR interface, spatial tasks and learning environment in this iteration.

According to the characteristics of initial draft design principles and draft MISAR, 111 different virtual three dimensional objects were designed and coded into an AR interface, and 73 spatial tasks were developed in order to foster spatial ability of seventh grade students. With all of these virtual objects and spatial tasks, a pool of tasks was formed for the SPATIAL-AR toolkit. Within this focus group study, relevance of this pool of tasks to seventh grade mathematics curriculum evaluated formatively as well as AR interface with regard to findings of this iteration. Thus, the responses of participants and findings from logs were explained into two sections that were the mobile AR interface and student's booklet as components of the SPATIAL-AR toolkit.

4.1.1.1. *Findings about Augmented Reality Interface on Focus Group Study*

Some software glitches and bugs were expected naturally since the first mobile AR interface was a draft prototype. Since findings revealed that participants faced some issues with the mobile AR interface, key elements of a mobile AR interface and draft design principles for ARLE were needed some revisions for making prototype more relevant to intended curriculum, more consisted in design and providing more opportunities for learning environment.

First of all, observation notes revealed some technical issues in the first version of mobile AR interface. One of them was recognition issue. This interface included over 100 virtual objects and their target images within a single software. Firstly, as seen on observation notes and screen capture logs, this interface mingled some target images and projected wrong virtual objects or wrong locations on these target images in some situations. For example, Bilge and Rıza encountered this issue at first day of the implementation (Figure 4.1 & Figure 4.2).

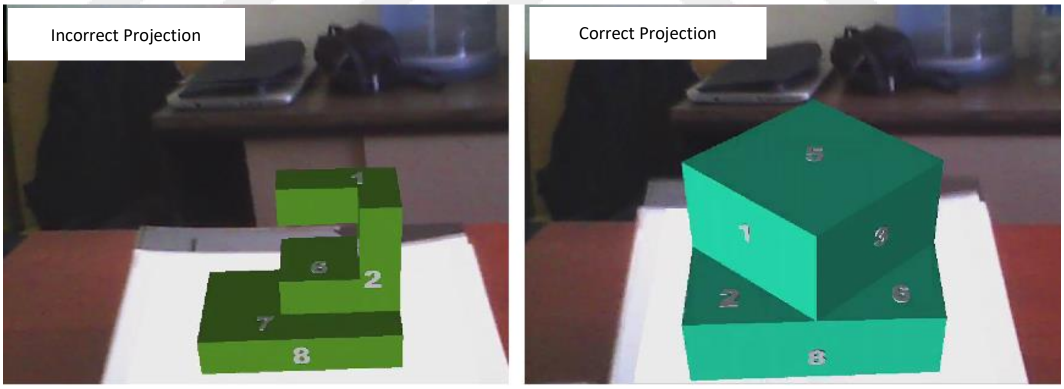


Figure 4.1. Screen capture of Bilge when recognition issue arose to demonstrate incorrect and correct projections of virtual object on a target image.

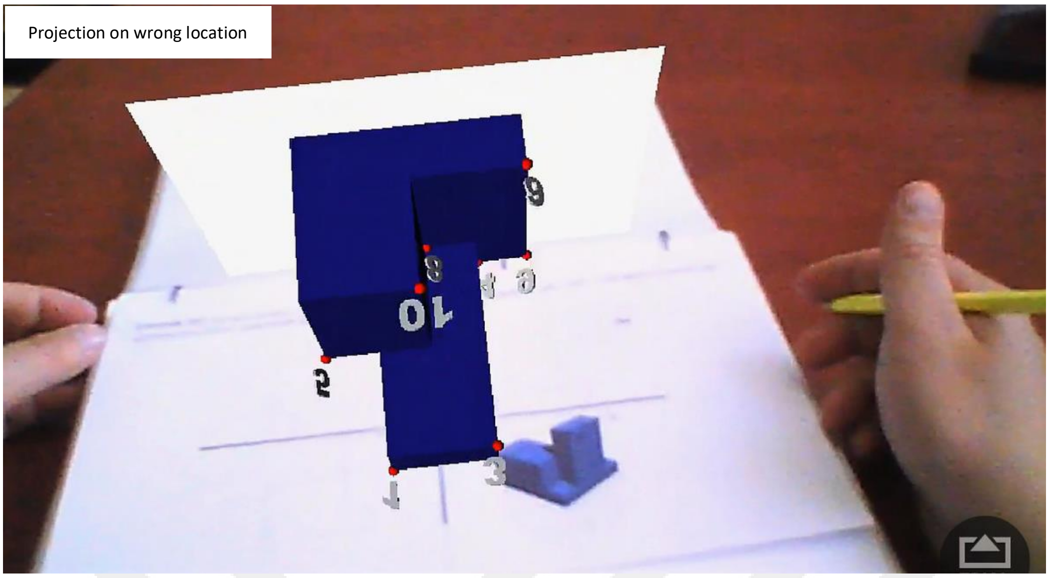


Figure 4.2. Screen capture of Rıza when recognition issue arose to demonstrate projection on wrong location for virtual object on a target image.

Reason of this issue was revealed after trials for some debugging and recoding the mobile AR interface. This issue was caused due to logic of recognition target images of interface. Even qr-codes were used as target images, the Vuforia SDK, which constituted a base layer for the AR interface, recognizes all used two dimensional target images as pictorial data. Moreover, the Vuforia SDK does not require to capture the whole target image to project objects. Even if, visual data of one third of any target image is captured, this SDK processes this data and projects objects on virtual plane. Since, generally qr-codes have big squares as position markers and small squares as alignment marker on corners, they seem similar to each other in one third ratio (Figure 4.3). This issue arose another problematic situation for the study since qr-codes are alike each other visually.

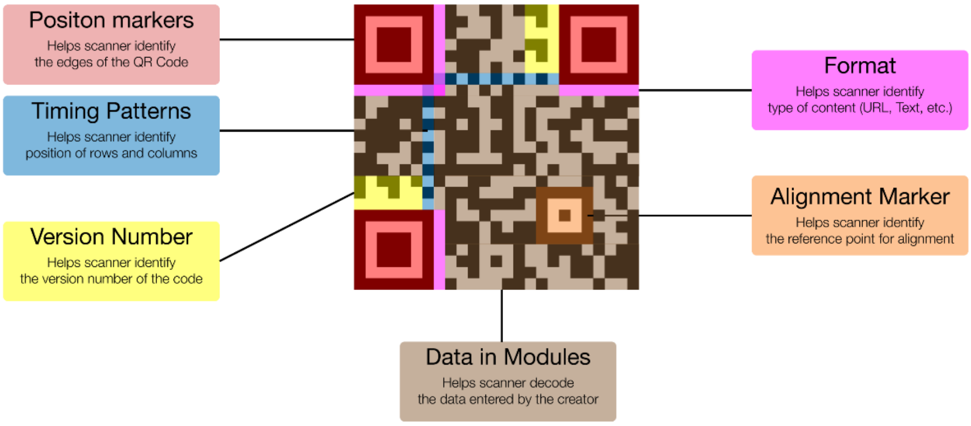


Figure 4.3. Identifiers for every qr-codes ("How QR Codes Work?" n.d.)

Since the Vuforia SDK treats qr-codes as pictorial data and they seem similar to each other visually, this interface mingled target images and sometimes projected wrong virtual objects or two different virtual objects on a single target images. In order to overcome with this difficulties, some qr-codes were changed to make them as easily recognizable without confusing software (Figure 4.4). Thus, the mobile AR interface was recoded and recompiled with this change about target images after the first day of implementation.

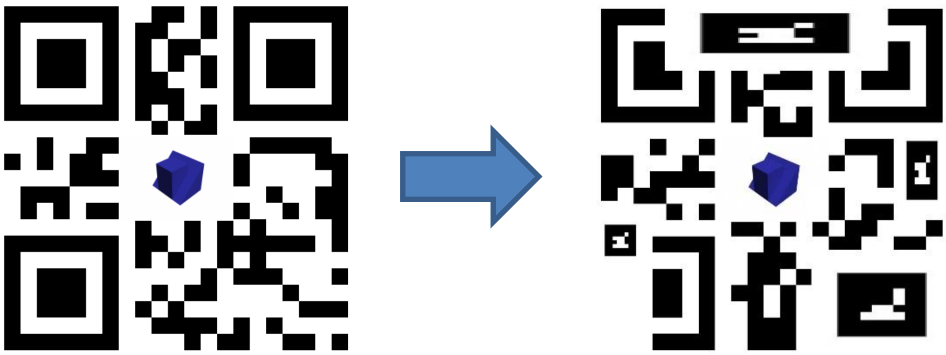


Figure 4.4. Modification in target images in order to make them more recognizable

After this revision in the AR interface, target images on booklet also had to be changed and the revised student's booklet was reprinted. At the second micro-cycle in following day of the implementation, it was seen that this modification solved the difficulty in recognition of target images, at the least.

On the other hand, in task based interview session of the first implementation day, Rıza stated another issue about some delays in recognition of target images and projecting virtual objects, frequently. Technically speaking, it was discovered from software logs that this issue was caused from integrated large database. In this database, there were data of a large number of target images in a single software and the mobile AR interface compares data of recognized target images with data of over 70 target images. Therefore, this designed mobile AR interface could not process these numerous target images smoothly. In order to shorten the time of delay in recognition target images, the AR interface was divided into five separated software, related to parts of draft MISAR such as interface for “Part 1: Surfaces & vertices”, interface for “Part 2: Matching Correct Views”, interface for “Part 3: Nets”, interface for “Part 4: Counting”, and lastly interface for “Part 5: The Second Dimension – Sketches”. Since, with this modification, database were also divided into five relatively small databases, duration of comparing data of target images was also relatively decreased. These modified mobile AR interface was tested with Bilge and Rıza, and it was seen that delay of recognition was minimum in implementation on the second day.

Similarly, findings showed that some issues related to projection of virtual objects had also been encountered. This issue was failure of projection virtual objects while participants were trying to investigate virtual objects from relatively exact top, front, back, left and right sides. For example, observation notes showed that because of this issue, Bilge had confused while examining virtual object with cylindrical component in figure 4.5. Orthographic view of this component of the virtual object from exact front side should look like a rectangle. However, Bilge insisted on that this part did not look like a rectangle, and stated that front view should be changed as his drawing on Figure 4.6.

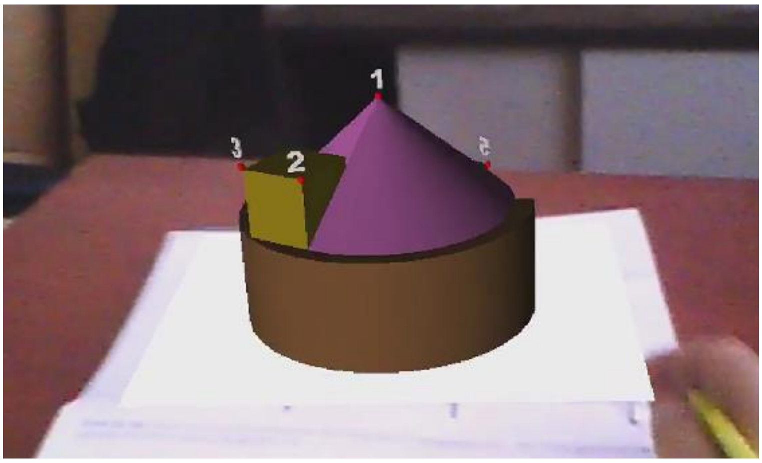


Figure 4.5. Bilge screen capture about virtual object with cylindrical component and his point of view at the time

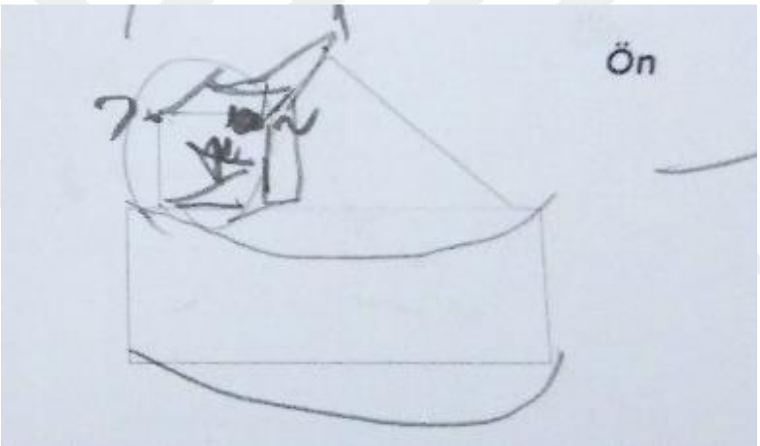


Figure 4.6. Bilge tried to correct views by misleading information from projection of virtual object

As seen on these figures, if the AR interface does not visualize virtual objects correctly, learners cannot carry out spatial tasks as expected. This issue was also found in retrospective interview’s transcripts. For instance, Bilge stated this issue as a difficulty which they encountered during implementation.

> “*I think software cannot detect qr-code from exact front viewpoint (Bilge, retrospective interview)”.*

Rıza also commented on the same issue:

> *“Technical difficulty? It was hard to restore view of object if it was disappear, and software could fail to detect view (project virtual object) from sides, frequently (Rıza, retrospective interview)”*.

The participants commented to change altitude of projection layer from ground in order to solve this issue in the interviews. For example,

> “*I cannot look exact front (of object) … Exact front, for instance if I hold this (qr-code) and lift up … look object has gone (Camera cannot get sufficient data of qr-code). … Can you lift up (virtual) object a bit? With this way, I think, we have enough viewpoint to see both qr-code and object. … Yeah. Since, I suppose that I could get down (viewpoint) somewhere about here, I am trying to investigate objects with this viewpoints. May be you can lift objects from one or two units above. I mean little higher than this point. They can be placed on air, right? (Rıza, task based interview)*”

> “*To arrange objects a little higher point can make viewpoint of user more efficient. If objects start (are projected) on very top of qr-code (Bilge, retrospective interview)*”

This issue was caused by recognition logic of the mobile AR interface because the interface requires to catch at least 1/3 portion of target image to project virtual data on top of it. While participants were trying to see and examine virtual objects from exact perpendicular view point, the interface losses required visual data of target images and could not project any virtual data via using insufficient visual data. With regard of the issue about examining objects from exact front, back, top and sides, virtual object was placed a little higher point from base plane as seen on figure 4.7. On the third micro-cycle of the implementation, the AR interface was recoded and recompiled with this modification and tested by the participants.

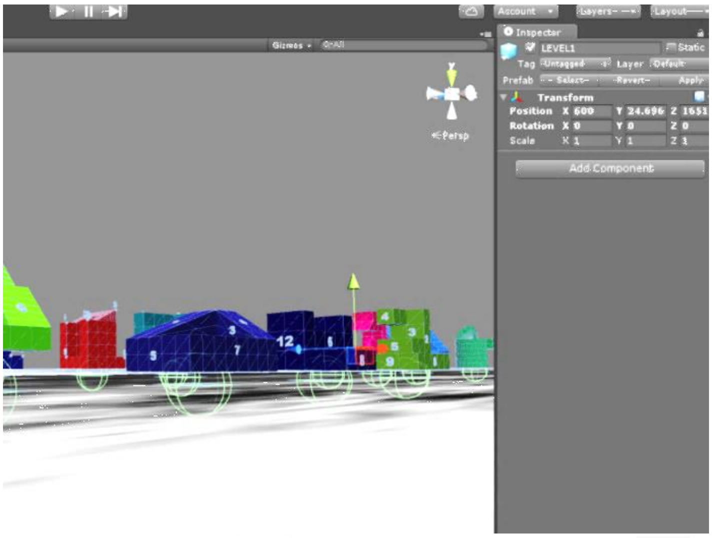


Figure 4.7. Revisions about vertical location of virtual objects

After this revision for the mobile AR interface, according to observation notes, this issue was not encountered again at the following implementation day. This little revision about vertical location of virtual objects has solved the issue related to projection of objects. Although virtual objects were lifted up somewhat on shared virtual space, users could not notice the difference since a white plane below each object also was added and lifted up, accordingly. Therefore, the white plane hided the gap between qr-code and virtual objects from viewpoints of users.

Furthermore, the last category related to issues about the mobile AR interface, in the focus group study, was about some kind of a deficiency of the mobile AR interface. This deficiency came in sight from feedbacks of the participants about consistency of the prototype SPATIAL-AR toolkit with draft design principles for ARLE. For instance, it was asked to participants find side views of virtual objects from organized or disorganized lists of side views on spatial tasks about matching side views. The nature of these tasks requires comparing multiple objects. Therefore, all compared virtual objects were designed to be seen and examined on a single scene (Figure 4.8).

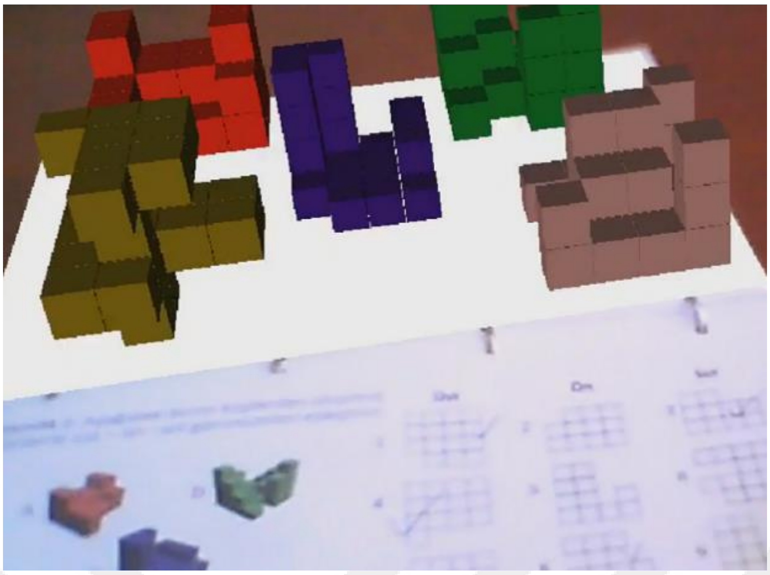


Figure 4.8. Screen capture of Rıza during spatial tasks about matching side views

However, the participants stated some difficulties while comparing objects in task based interviews. For instance,

> *"It can be good if we examine these shapes (virtual objects) one by one. Now, I see all of them together, but it is hard to examine, how they look like from top or side. … Because, looking both this (virtual plane) and this (task) at the same time increases workload (Bilge, task based interview)."*

> *"You might make them (virtual objects) interactive (such that) object make thing (expand and hide others) (when) we touch on top of them. … examining (them) could be much easier and also students can compare all and examine one-by-one (Rıza, task based interview)"*

As seen on these transcripts, if the AR interface included some kind of interactivity layers, students may have the opportunity to compare and examine virtual objects in both multiple view and singular view. Therefore, a new touch or pointer control C# script was written and added to interface after completion of the implementation. With this modification, the mobile AR interface became having some opportunities for interactivity via touch for tablets or pointer for smart glasses. By the way, it was conjectured that this modification could also support the ARLE by providing some opportunities to increase interactions between students by allowing students to talk, share and discuss multiple objects and compare them.

4.1.1.2. Findings about Booklet of Spatial Tasks on Focus Group Study

Findings about relevancy of booklet of spatial tasks to seventh grade mathematics curriculum and consistency in design have been summarized into two themes as revisions of booklets and revisions of spatial tasks.

_i._ Revisions of Booklets

The first version of student's booklet was designed as a single booklet which contained both spatial tasks and related target images in landscape pages as seen on figure 3.24 in the Chapter 3. While designing this first version of student's booklet, it had been conjectured that designing a single booklet, which includes both target images and spatial tasks, might be usable for participants to handle the booklet easily and use AR interface effectively. However, in this focus group study, some issues related to portability of booklet were emerged. For instance, this was noted on observation notes as following:

> "*Bilge could not understand one of the virtual objects in a task while working with smart glasses. He travelled around target image in order to see every angle of object. However, he could not see exact sides view of the object. Therefore, he tried to hold booklet but it was not efficient way for examining object and writing down notes on task at the same time since task and target images were on same booklet. Thus, target image for this task was cut from booklet and it was asked him to hold this page of target image separately (Observation notes about Bilge's works)*".

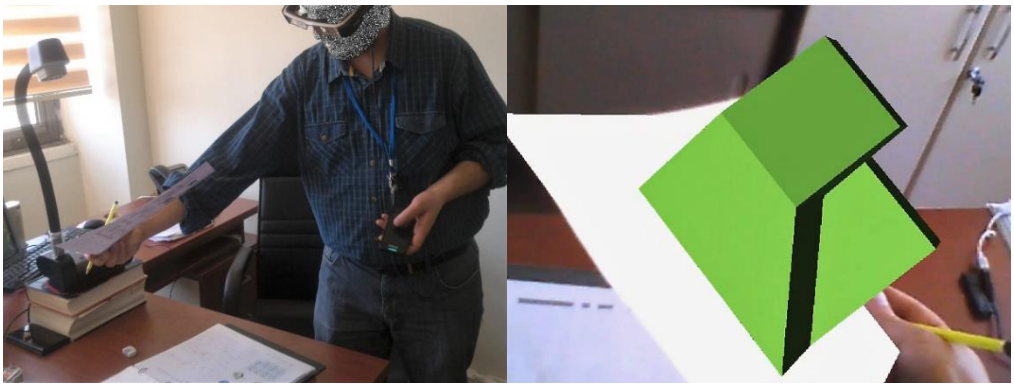


Figure 4.9. Bilge was holding qr-code page at hand to examine virtual object from sides and his point of view at that time.

Following dialogue from task based interview session was about Bilge’s feedbacks after this issue – solution process described in the previous observation’s log.

> *Researcher: Look, let’s take this (target image page) at your hand and examine object in this way.*
>
> *Bilge: Hah, yes, in this way, this (side view) suddenly appears. So, if this booklet might have been thinner it was so easy … examining like this is quite effective and comfortable (see Figure 4.9).*
>
> *Researcher: If you want, you can take qr-code pages at your hand.*

Considering this issue – solution process, it was conjectured that booklet could be prepared by separating into two parts such as booklet of spatial tasks and booklet of qr-codes in order to provide easiness in portability for booklets in ARLE since the participants could examine objects easier than the draft design of student’s booklet. Hence, ARLE could become an environment which possesses more opportunities to students for natural way of interactions and mobility.

This modification caused a need for consistency in design for multiple booklets. Since the booklet was thought to be divided into two, as the booklet of spatial tasks and the booklet of qr-codes, there occurred a need to make progress on these two booklets cohesively in order to prevent confusion to match target images with spatial tasks. For this reason, in order to perform a compatible way of design on multiple booklets, some design principles for booklets were conjectured to provide consistency among multiple booklets (Figure 4.10).

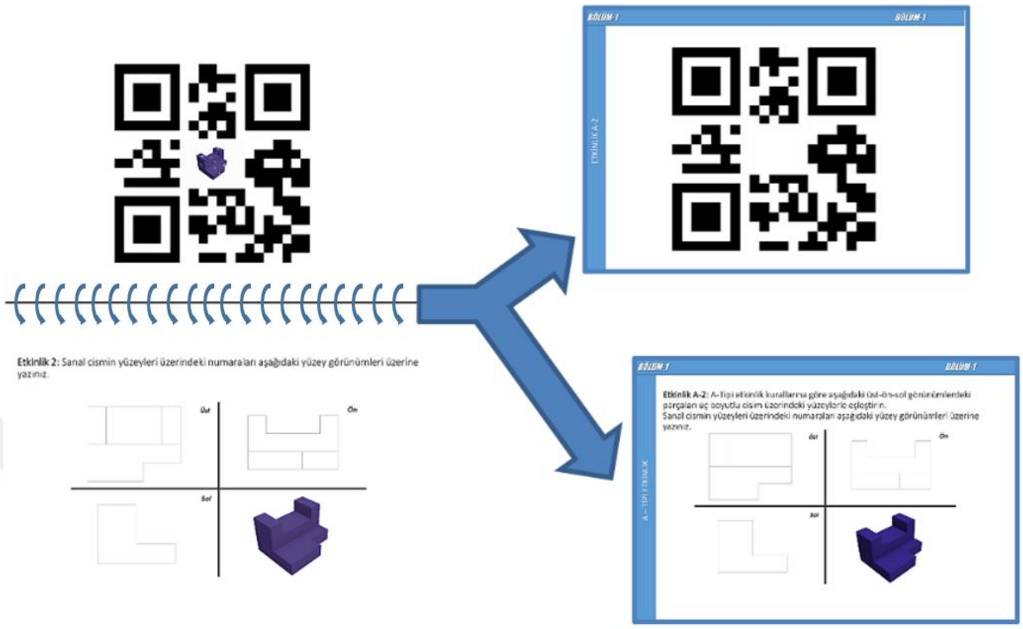


Figure 4.10. Modifications in design of booklets

These conjectured design principles for booklets existed due to a need. While preparing the first version of student's booklet, a basic design was employed since it was a draft version. Therefore, no design principle was needed in order to perform this draft version. In the focus group study, some issues emerged about usability of SPATIAL-AR toolkit in terms of this draft booklet during implementation sessions. Findings from the focus group study showed that firstly there was a need for some predetermined characteristics for design of booklet in order to provide more solid learning experience in ARLE. Characteristics for this design were decided with an instructional technologist with Ph.D. degree in the field of instructional technology, who served as expert for these design issues of booklet. This conjectured design principles included the following characteristics;

- If an augmented reality task is presented on worksheet and this task requires exploration of virtual objects at multiple points of view, target image of virtual objects and task should be given on separate pages in order to provide mobility. Size of pages should be suitable to hold booklet with one hand easily.

- If separated pages for augmented reality tasks and target images are needed to be used, these pages should be designed to be discriminated by some visual cues for identification of different types of tasks in order to make students' progresses concurrent among these multiple worksheets and target images without causing distraction for learning tasks.
- If separated pages for augmented reality tasks and target images are needed to be used, these pages should be designed in the same manner by using the same design styles to make students' progress in a synchronous way while working with multiple books.
- If separated pages for augmented reality tasks and target images are needed to be used, these pages should be designed in the same manner by presenting related target image and task at the same page number among different booklets in order to find the target image of a specific tasks from their page numbers easily.

These conjectured design principles for booklets were decided in a discussion with this expert so as to provide a consisted way for progressions of students using multiple booklets. In this study, the visual cues were given with colors in page design of multiple booklets. These given visual cues and titles of tasks were consistent and design to be same through on both target image booklets and spatial tasks booklet. Moreover, spatial tasks and their related target images were numbered similarly throughout multiple booklets (see Figure 4.10). Hence, separated student's booklets were rearranged with this modification and presented to the participants for their approval for consistency to these conjectured design principles. The booklets were designed with A5 size pages.

ii. Revisions of Spatial Tasks

As mentioned before, the first prototype of SPATIAL-AR toolkit contained 73 spatial tasks within five parts. These spatial tasks were prepared based on the draft five-parted MISAR. The first version of student's booklet has over 140 pages since all spatial tasks in the pool of tasks were used with their related target images. In order to answer the research questions about relevancy of spatial tasks to seventh grade mathematics curriculum and consistency of these tasks to the draft MISAR, the participants were asked to evaluate relevancy and consistency of them in discussion sessions which were held at the end of each implementation day. Since the recommended duration for the spatial contents has been suggested as four to five lesson hours in seventh grade mathematics curriculum (MoNE, 2013), it was also discussed with the participants that whether seventh grade students could accomplish each task types at most in one lesson hour with which spatial tasks and virtual objects. A checklist was provided to the participants to evaluate tasks and virtual objects in these discussion sessions (see Appendix B). According to their comments and feedbacks, some virtual objects and spatial tasks had been excluded from the first prototype of SPATIAL-AR toolkit. While deciding on objects to be excluded, the main criteria was to eliminate virtual objects similar to each other in terms of their views or their complexity for seventh graders. These revisions and the participants' feedbacks were summarized below in terms of five parted MISAR for spatial tasks.

a. Surfaces & vertices.

Surfaces & vertices tasks were the first level of the draft five-parted MISAR and included three type of spatial tasks. Ten spatial tasks and ten related virtual objects were designed for each task type of the surfaces & vertices part (Table 4.1). According to comments of the participants, some tasks and their virtual objects were excluded from the study.

Table 4.1. Surfaces & vertices part and number of tasks with virtual objects

Spatial Contents	Virtual Objects	Spatial Tasks
Identification of surfaces on orthographic views	10	10
Identification of surfaces on perspective views	10	10
Identification of vertices on projective views	10	10

In general, the participants stated that the three different task types of the surface and vertices could make easy to adapt to logic and usage of the mobile AR interface with spatial tasks. It is important to note that, this study was the first time for the participants to use a tablet for this purpose as well as to meet and use smart glasses. Even so, observation notes and their comments in task based interview sessions revealed that they were easily adapted the logic of AR technology during working on these spatial tasks of the surfaces & vertices without noticing which devices they used such tablets or smart glasses. For instance,

> *"I think, I have got used to (the AR) since 15th task ... Now I can predict (surfaces of) some objects without examining in detail. ... For some parts (surfaces of objects) I need to look in detail but for others, for example, I don't (Bilge, task based interview in the first day with smart glasses)"*

> *"One gets used to augmented reality after a while. ... Now, I don't feel that I deal with a different technology (Rıza, task based interview in the first day with tablet)"*

The surfaces & vertices part was actually designed to make the usage of AR easy so that users should look and examine all possible viewpoints of virtual objects. Thus, according to these findings, it was revealed that the spatial tasks in this first part fitted its designed purpose. Nevertheless, some of the spatial tasks and their virtual objects were excluded from the study in order prevent waste time in vain.

According to participants' evaluations in the checklists, in order to satisfy one hour time limitation for this level of tasks, five or six spatial tasks for the first and second task types could be enough to make seventh graders get used to usage of the SPATIAL-AR toolkit without getting bored with the task type. However, according to findings on the checklists, the third task type could require more time from other two for seventh graders. Therefore, three or four spatial tasks were conjectured to be enough for this task type. According to these findings, the student's booklets were redesigned as having six spatial tasks for each of the first and second task types and three spatial tasks for the third task type of the surfaces & vertices part (Table 4.2).

Table 4.2. The revised Surfaces & vertices part with number of tasks and excluded virtual objects.

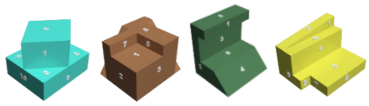
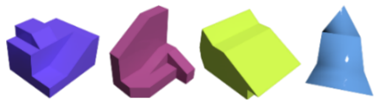
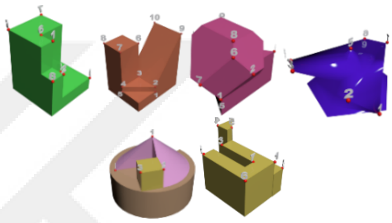
Spatial Contents	Virtual Objects	Spatial Tasks	Excluded Virtual Objects in Discussion Sessions
Identification of surfaces on orthographic views	6	6	
Identification of surfaces on perspective views	6	6	
Identification of vertices on projective views	4	4	

Table 4.2 summarizes revisions in the surfaces & vertices part. As a result of these revisions, sixteen spatial tasks and sixteen related virtual three dimensional objects for three task types were remained. These remained tasks were also organized from easy to hard as virtual objects with vertical or horizontal planar surfaces to virtual objects with inclined planar surfaces by the participants in the checklists. At last, since these required revisions were only about time management, any change in contents of the draft five-parted MISAR was not needed for this surfaces & vertices tasks.

b. Matching Correct Views

Matching correct views was the second level in the draft five-parted MISAR and it included two task types. These spatial types and number of tasks with virtual objects were summarized in Table 4.3.

Table 4.3. Matching correct views part of the spatial tasks and number of tasks with virtual objects

Spatial Contents	Virtual Objects	Spatial Tasks
Determining side views from organized orthographic views	10	2
Determining side views from disorganized orthographic views	20	5

As seen on table 4.3, seven spatial tasks were designed with thirty different related virtual three dimensional objects in total. These spatial tasks were about determining side views of multiple three dimensional virtual objects from both organized lists of top, front and left views, and disorganized lists. Two different virtual object types were designed such as virtual objects formed by complex shapes and unit-cubes for these tasks.

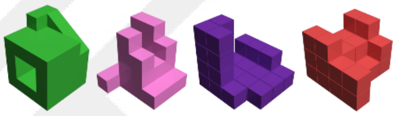
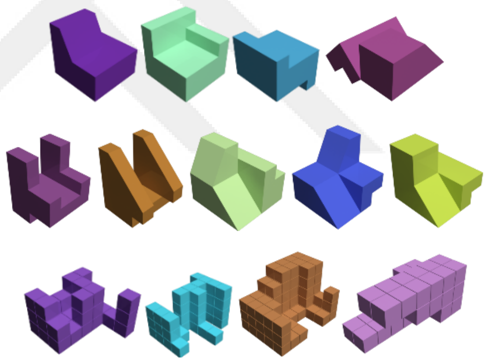
In order to satisfy one lesson hour limitation for implementing tasks of this part, according to findings in feedbacks of the participants and logs, some virtual objects and spatial tasks were excluded from the study. Firstly, observation notes showed that the participants found virtual objects composed of unit-cubes harder than virtual objects with complex shapes for these tasks. Rıza stated this as

> "*I have difficulty to count cubes, it's too complicated. ... for this object (with complex shapes) I can estimate its views (Rıza, discussion sessions)*".

Therefore, due to these findings it was conjectured that the spatial tasks about virtual objects formed by unit-cubes could be presented after spatial tasks about other virtual objects since unit-cubes would require more time.

According to comments on the checklists, some revisions about tasks were applied to make students complete tasks in one hour. First of all, there were five virtual three dimensional objects with complex shapes and five with unit-cubes in the first task type. According to comments of the participants, two virtual objects with complex shapes and two virtual objects with unit-cubes were excluded from the tasks. Moreover, there were five spatial tasks with fourteen virtual three dimensional objects with complex shapes and six with unit-cubes. Similarly, according to findings, it was conjectured that at most three virtual objects could be enough for each spatial tasks. Therefore, nine virtual objects composed of complex shapes and four virtual objects composed of unit-cubes were removed. The number of tasks and excluded virtual objects were given in table 4.4.

Table 4.4. The revised Matching correct views part with number of tasks and excluded virtual objects.

Spatial Contents	Virtual Objects	Spatial Tasks	Excluded Virtual Objects in Discussion Sessions
Determining side views from organized orthographic views	6	2	
Determining side views from disorganized orthographic views	7	3	

As a result of these modifications, there remained thirteen three dimensional virtual objects within five spatial tasks. These spatial tasks were organized from easy to hard as virtual objects with complex shapes to virtual objects with unit-cubes with regard to the participants’ feedbacks in checklists. Lastly, similar to the modifications in the first level of the MISAR, these modifications were only about time management and purifying virtual objects from similar or harder ones. Thus, there was no contextual revision within the draft five-parted MISAR related to these tasks.

c. Nets

The third level in the draft five-parted MISAR was about nets. The tasks related with one spatial content which was about identification of nets of virtual three dimensional objects. Thus, these tasks were about finding correct and incorrect nets of basic virtual three dimensional objects such as cube, rectangular prism, square prism and square pyramid. Findings about participants' feedbacks in the checklists indicated that these tasks were not related with the spatial contents for seventh grade mathematics curriculum since the objectives about this spatial content were not included in seventh grade mathematics curriculum. Therefore, these spatial tasks were excluded from booklets and also the draft MISAR were revised in accordance with these comments. Actually, this part was not completely disregarded from this AR study. Since the objectives related with these tasks are included in the fifth grade mathematics curriculum (MoNE, 2013), a new study was conducted about these tasks with fifth graders. This study and report of findings can be found in paper of Özçakır, Çakıroğlu and Güneş (2016). With this exclusion, the five-parted MISAR became a model with four sequential parts. Moreover, a characteristic, gamified tasks, in design principles for ARLE was also excluded since this excluded level was the only level including gamified tasks characteristic.

d. Counting

The fourth level of the five-parted MISAR was about counting tasks. The counting tasks included tasks about counting the number of components in touch with given components of a virtual object.

Firstly, in accordance with findings in the checklists, it was seen that these spatial tasks required more time than other tasks since it required participants to examine not only virtual object as a whole but also component by component from all possible angles. For instance, Rıza stated this as

> *"This part might require more time since we have to look from every angle in order to see relations".*

Thus, some virtual objects and their spatial tasks were excluded from the study in accordance with the participants' feedbacks. In order to satisfy time limitation about each level in one hour, seven spatial tasks and their virtual objects were excluded from the study with regard to feedbacks of the participants about complexness of the virtual objects for seventh graders in the checklists (Table 4.5).

Table 4.5. The revised counting part with number of tasks and excluded virtual objects

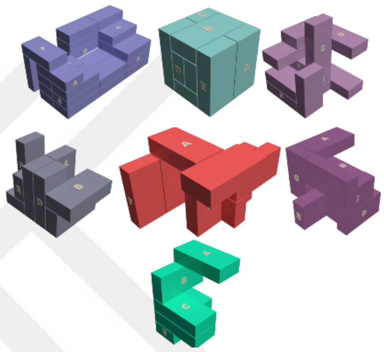
Spatial Contents	Virtual Objects	Spatial Tasks	Excluded Virtual Objects in Discussion Sessions
Counting the number of objects in touch with given part of an object	3	3	

Table 4.5 summarizes tasks after revisions for time management. In consequence of this revision, there remained three virtual objects and their spatial tasks for this part.

In addition, a revision was also applied for sequential order of the draft MISAR. According to findings, it was seen that these tasks were helpful to become familiar with the usage of the AR interface since the participants looked and examined every possible points of view for virtual objects in order to find bricks in touch with each other, similar to the first level, which was about surfaces & vertices tasks (Figure 4.11).

Figure 4.11. Bilge was investigating a virtual object for counting tasks

Therefore, it was conjectured that these tasks could also be helpful students to get used to logic of AR technology and so this level was placed between “surfaces & vertices” and “matching correct views” levels in the draft MISAR.

e. The Second Dimension – Sketches

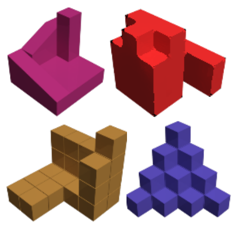
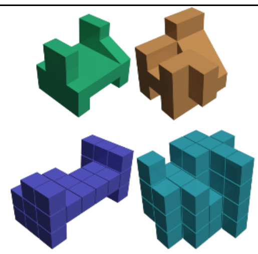
The last level of the draft five-parted MISAR was the second dimension – sketches. This level included two task types. These task types and number of tasks with virtual objects were given in Table 4.6. Twenty spatial tasks with twenty different virtual three dimensional objects were designed for tasks in this level. Similar to matching correct views level, the virtual objects were constituted from two types of objects such as virtual objects with complex shapes and virtual objects with unit-cubes. According to findings in checklists, some of the virtual objects and their spatial tasks were excluded from the study in terms of their complexity for seventh graders and similarity to other objects or in its orthographic views.

Table 4.6. Sketches part of the spatial tasks and number of tasks with virtual objects

Spatial Contents	Virtual Objects	Spatial Tasks
Sketching missing orthographic views	10	10
Sketching all orthographic views from three directions	10	10

Firstly, in contrast to findings about the second level of the draft five-parted MISAR, this time, the participants found virtual objects with unit-cubes much easier than other objects in terms of sketching. As a reminder, they had found the objects with unit-cubes harder than other objects for matching tasks. Moreover, it was seen that three virtual objects with complex shapes and three virtual objects with unit-cubes could be ideal for each task type of this level in order to complete these tasks in one hour. Therefore, four three dimensional virtual objects were excluded from each task type in accordance with feedbacks of the participants in the checklists (Table 4.7).

Table 4.7. The revised second dimension – sketches part with number of tasks and excluded virtual objects.

Spatial contents	Virtual Objects	Spatial Tasks	Excluded Virtual Objects in Discussion Sessions
Sketching missing orthographic views	6	6	
Sketching all orthographic views from three directions	6	6	

This table summarizes the revisions related to limiting number of spatial tasks. With these revisions, six virtual objects were remained for each task type. These remained spatial tasks were ordered from easy to hard as objects with unit-cubes to objects with complex shapes in accordance with participants' feedbacks. Similar to the first and second levels of the draft five-parted MISAR, these revisions were only about time management and excluding complex virtual objects or virtual objects which were found having similar views with others.

4.1.1.3. Summary of Findings from Focus Group Study

In this section, reasons for revising the first prototype of SPATIAL-AR toolkit in terms of experts' perspective were given with their evidences in order to provide more relevant contents for seventh grade mathematics curriculum and more consistent design for SPATIAL-AR toolkit throughout the Iteration I.

New characteristics were added for key elements of a mobile AR interface about recognition and projection, division in design and interactivity opportunities. First of all, in the preliminary research phase it had been conjectured that qr-codes might make precision of recognition of target images stronger. However, it was revealed that the Vuforia SDK provides a runtime in order to recognize all two dimensional target images via using pictorial data. Hence, the designed mobile AR interface mingled some qr-codes in the implementation. Moreover, the participants had some difficulties in examining virtual objects from viewpoint of exact sides of them. Therefore, all of the virtual objects were relocated to a higher layer from base plane in order to solve this projection issue. In addition to these, some revisions were also made about draft design principles for ARLE since it was conjectured that adding an interactive interface to allow shift scene between comparing multiple objects to examining a single object in detail could allow students interact each other to share their thoughts and discuss about single and multiple objects. In other words, the participants encountered a workload about exploring side views of multiple virtual objects in a single scene and a suggestion for exploring virtual object one by one had arisen. Therefore, a script was written in order to change scene from displaying multiple objects to displaying single object. Similarly, the displayed object can change user to user in accordance with their choices so that it was also conjectured that students could have the opportunity to describe and discuss their own different point of view for virtual objects to other students.

Moreover, a pool for spatial tasks was presented to the participants in order to evaluate and select appropriate ones to the seventh grade mathematics curriculum. In accordance with their evaluations in the checklists, some spatial tasks and virtual objects were discarded from the booklets. Additively, the five-parted MISAR was revised in according to the findings of this focus group study and it was refined in a four-parted MISAR which included four sequential levels.

The revisions for characteristics of the draft design principles for ARLE, key elements of a mobile AR interface and spatial contents in the draft MISAR were revised as the following manner in Table 4.8, Table 4.9 and Table 4.10, respectively.

Table 4.8. Conjectured Design Principles for Augmented Reality Learning Environment

Revisions	Characteristics	Design Principles	Rationale for emergence / consistency / exclusion
Emerged Principles	Sharing and Comparing	ARLE should provide students a way to observe and compare multiple virtual objects or explore one of them in detail within a same scene in order to provide more opportunities for interactions with the objects and each other if multiple objects are in use.	It was conjectured that students could examine virtual objects in tasks included comparisons of multiple objects without confusion if they have the opportunity of choosing specific object to be examined among many. Moreover, they could also have more opportunities to interact with their pairs by sharing their viewpoints, in this way.
Consistent Principles	Natural Way of Interaction	ARLE should support multi-user interactions and natural interactions, as in real world with real objects, to provide more opportunities for students’ interactions with virtual objects and each other.	It was seen that the participants were able to interact with virtual objects, as in real world with real objects. Therefore, it was conjectured that students could interact both with virtual objects and with each other as in real world by natural interactions like talking, pointing, gazing, etc.
	Challenging Tasks	In ARLE, students should be provided with challenging tasks in order to engage in an active process for learning.	It was seen that the participants completed tasks without boring or undistracted. Therefore, it was conjectured that students could complete these challenging tasks as active learners.
	Independence of Viewpoint	In ARLE, students should be provided with an opportunity of moving freely by controlling and choosing own independent viewpoint for inspected virtual objects in order to engage in an active process for learning.	It was seen that the participants were able to act freely in environment or move freely virtual objects. Moreover, since they had control of environment by choosing their own independent viewpoints, they were active participants. Therefore, it was conjectured that students could also be active participants of the environment by these opportunities.
	Providing Tasks	In ARLE, teachers should have the opportunity of choosing and administrating suitable tasks for students’ current situations within AR tools.	The learning tasks were reorganized from easier to harder ones in accordance with checklists. Therefore, it was conjectured that the toolkit included learning tasks for each spatial ability level.
	Just-in-time information	In ARLE, teachers should have the opportunity of supporting students with feedbacks about their works and progresses just in time so that teachers should collaborate students’ works with his/her AR interface.	In ARLE, researcher was able to see and collaborate the participants any time necessary throughout tasks by his tablet. Therefore, it was seen that AR interface was support a third person interaction in background.
Excluded Principle	Gamified Tasks	In ARLE, students should be provided with gamified tasks included scoring systems or/and fail states so that they become more active and ambitious to accomplish tasks	The spatial tasks in the third level of the draft five-parted MISAR were designed to include scoring systems and animations showing right and wrong answer. However, this level was excluded from this study. Therefore, gamified tasks characteristics for active process of learning was also excluded from design principles.

Table 4.9. Revised Design Principles about Key Elements of a Mobile Augmented Reality Interface

Revisions	Characteristics	Design Principles	Rationale for emergence / consistency
Emerged Principles	Interactivity via Touch / Pointer	AR interface should be designed to provide students a way to interact interface in order to observe and compare multiple virtual objects or explore one of them in detail within a same scene.	It was seen that the participants were confused while investigating multiple virtual objects in matching tasks. Hence it was conjectured that students could examine multiple virtual objects easily and without confusion if AR interface provides a way to choose specific object to be examined among many with touch events or pointer selections.
	Recognition and Projection	Target images should be assigned or chosen as recognizable as possible for AR interface if AR interface is programmed as requiring target images to superimpose virtual objects. Moreover, if target images are in use, AR interface should be programmed as projecting virtual objects at relatively higher positions from base layer in order to visualize virtual objects in more accurate way.	It was seen that, if visually similar target images were used, the AR interface mingled target images and projected wrong virtual objects. Therefore, it was conjectured that using visually different target images can increase recognisability of them and prevent mingling for AR interface. Moreover, locating virtual objects at base layer of virtual space, which refers on very top of target image in real world, made hard to see exact front, left and other sides for the participants. Therefore, replacing virtual objects at higher points could make see these sides easy for students.
	Division in Design	AR interface should be programmed and compiled as separating in parts if target images database and number of virtual objects are higher in order to prevent delay issues for searching related visuals in database.	It was seen that the AR interface had some delay issues during recognition of target images. Therefore, it was conjectured that dividing AR interface into parts for lighter database could make recognition time interval minimum, and student could use this divided AR interface without any problem.
Consistent Principles	Virtuality for Objects	AR interface should superimpose virtual objects in the real world by mimicking some properties of real objects like length, depth, height and others.	This characteristic is a must for an interface to be an AR interface. Moreover, it was seen that the designed AR interface successfully superimposed virtual objects on real objects.
	Augmentation of Environment	AR interface should enhance reality by augmenting real objects with virtual annotations and elements.	This characteristic is another must for an interface to be an AR one. Moreover, it was seen that the designed interface successfully enhanced designed augmented book with virtual elements.

Table 4.10. Revised Model for Improving Spatial Ability in an Augmented Reality Environment

Revisions	Parts	Spatial Contents	Rationale for consistency / exclusion
Consistent Tasks	Surfaces & Vertices	Spatial tasks should start with identifying components of virtual objects in order to make students adapt an ARLE. These tasks are recommended to include spatial contents about identification of surfaces & vertices on orthographic and perspective views.	It was seen that the participants easily adapted the ARLE even this study was their first meet with usage of AR in education while they were working on spatial tasks about surfaces & vertices. Therefore, it was conjectured that students could also adapt the ARLE with these tasks easily.
	Counting	Spatial tasks should be followed by tasks about counting components of virtual objects in order to eliminate novelty effects of an ARLE. These counting tasks are recommended to include spatial content about counting specific components with their relation to others, i.e. in touch with others.	It was seen that the participants worked like exercising their adaptation and having more experiences with the ARLE while they were counting bricks in touch with others within a virtual object. Therefore, it was conjectured that these tasks could be helpful for students by eliminating novelty effects of these newly adapted technology for them. Hence, this level was replaced as second level in the MISAR.
	Matching Correct Views	Spatial tasks should include matching correct and incorrect side views in order to make spatial relations recognizable by students. These tasks are recommended to include spatial contents about matching side views from organized lists and disorganized lists.	It was seen that the participants worked fluently in these tasks and made transition of spatial information from three dimensional virtual objects to two dimensional views. Therefore, it was conjectured that these tasks could provide students some opportunities to put in process their spatial ability as well as recognize spatial relations.
	The Second Dimension – Sketches	Spatial tasks should include sketching activities for students in order to provide them opportunities to make use of their spatial ability as well as spatial relations within virtual objects. These tasks are recommended to include spatial contents about sketching missing side view and all side views from different directions, i.e. from front, side and top.	It was seen that the participants used their spatial ability and spatial relations within virtual objects while they were working on these tasks in order to sketch correctly. Therefore, it was conjectured that students could make use of their spatial ability and spatial relations within objects by making transitions between three and two dimensional spatial information on these tasks.
Excluded Tasks	Nets	Spatial tasks should include folded and unfolded nets of virtual objects. These tasks recommended to include spatial contents about finding correct and incorrect unfolded nets of basic three dimensional objects, i.e. cube, rectangular prism, rectangular pyramid and others.	It was revealed that the participants did not found these tasks relevant to seventh graders curriculum. In fact, they related these tasks to fifth graders curriculum. Therefore, these tasks were excluded from current design.

Lastly, the student's booklet was divided into two separated booklets for users to examine virtual objects easily and freely with the SPATIAL-AR toolkit. Hence, a need for consistency among multiple booklets was arisen. Therefore, in order to provide a coherent way for progress among multiple booklets, some characteristics for design of booklets were conjectured. The design principles for booklets referred to key characteristics to provide a suitable way of design in order to make progress for multiple pages cohesively. These principles were summarized in the following table.

Table 4.11. Conjectured Design Principles for Booklets

Characteristics	Design Principles
Mobility	Target images and tasks should be given on separated pages in order to provide mobility if an AR task is presented on worksheet and this task requires exploration of virtual objects at multiple points of view. Size of pages should allow mobility easily with one hand.
Visual Cues	If separated pages for an AR task and target image are needed to be used, these pages should be designed to be discriminated by some visual cues for identification of different types of tasks in order to make students' progresses concurrent among these multiple worksheets and target images without causing distraction for learning tasks.
Consistency among Multiple Pages	If separated pages for augmented reality tasks and target images are needed to be used, …
• In design	… these pages should be designed in the same manner by using the same design styles to make students' progress in a synchronous way while working with multiple books.
• In page numbering	… these pages should be designed in the same manner by presenting related target image and task at the same page number among different booklets in order to find the target image of a specific tasks from their page numbers easily.

With explained revisions made about these all design principles, the mobile AR interface and booklets were redesigned. With all these revisions, the second prototype of SPATIAL-AR toolkit was designed and developed in order to serve as instructional tool at the Iteration II.

4.1.2. Iteration II: Walkthrough Study

The walkthrough study was conducted with two seventh grade students from a public middle school in Kırşehir. Findings from the data sources were analyzed in order to seek answers for research question in order to reveal relevancy of tasks to seventh graders' understanding level and conjecture expected practicality of the SPATIAL-AR toolkit for seventh graders. That is, in this walkthrough study, testing of the SPATIAL-AR toolkit was performed in terms of seventh graders' feedbacks and experiences within implementation.

Results of this walkthrough study shed light on further needed revisions in the second prototype of SPATIAL-AR toolkit in terms of seventh graders' works, feedbacks and challenges through the Iteration II. The responses of these participants were explained into two sections in terms of components of the SPATIAL-AR toolkit that was the mobile AR interface and the student's booklets.

4.1.2.1. Findings about of Augmented Reality Interface on Walkthrough Study

Second prototype of SPATIAL-AR toolkit was redesigned in accordance with findings of the Iteration I. Therefore, most of the technical issues about programming level of AR interface were eliminated. Moreover, design principles for ARLE and key elements of a mobile AR interface, and spatial contents of the MISAR were also modified in accordance with the findings of the first iteration. Even so, the walkthrough group faced some technical issues about determining directions of virtual objects visualized by AR interface and switching different applications for parts of the tasks.

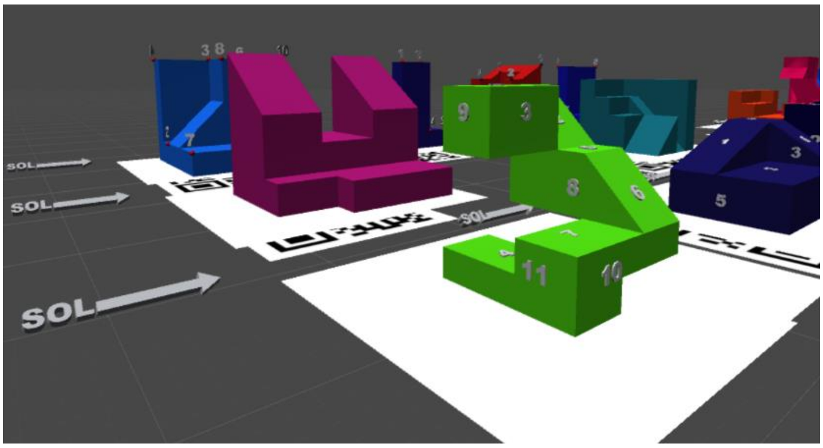
First of all, Elif and Meva (pseudonyms) encountered the issue of directions at the first day of the implementation. For instance, while they were working on the first level of the spatial tasks, Elif asked about

> "*How can we find the directions? For example, do we think left direction as our left?*".

Similarly, Meva explained her difficulty about directions in retrospective interview session as the following manner.

> *"... I had this issue, opposite side ... you know, you can look form that side (she pointed front side) and also from opposite side. That's why ... We can look from here or there (she pointed two opposite directions of a thing in front of her) if we hold something in our hands. Point of view I meant ... For example, we don't know this side is the front, or in fact I even don't know which side is the back. Sometimes, while I am examining the views (of objects from different directions), I go wrong and then I realize that I was looking from back direction (Meva, retrospective interview)"*

In fact, in the preliminary research phase and the first iteration of prototyping phase the researcher did not think that students might confuse about directions since, as stated before, the AR is a technology which give us a unique opportunity to mimic real object with virtual one. Similarly, the participants of the first iteration were not confused about directions of virtual objects during implementation. In other words, they could discriminate views from left, right, front, and back directions for virtual objects without confusing directions. In order to eliminate this issue, an orientational clue by giving a sign to show only one direction was added to design of AR interface, thereby it was thought that students could need to think about and find other directions spatially (Figure 4.12).



[Sol: Left]

Figure 4.12. Modification about direction as pointing only one side

This direction pointer was designed and located on a relatively outer point so that the pointer could be seen only by looking from front side. By this way, students may manage to find other directions by themselves by using this reference direction.

Another issue observed during this walkthrough study was about switching to different software for each level of the spatial tasks since the mobile AR interface was divided into four separated software in terms of the four-parted MISAR in order to make database of target images relatively light to overcome delay issues in recognition target images which was observed in the first iteration. However, according to observation notes, it was difficult for students to switch one application to another during the study and it was distracting for them from learning goals. Therefore, a solution was tested which was about uniting interface again in one single software while keeping target image database light. In fact, the software remained as separated, but a script was written to make this switching between parts easier for students. To be more specific, this script creates a menu to switch between software without exiting interface so that students might switch one software to another easily (Figure 4.13).

[Bölüm: Part; Başlat: Start]

Figure 4.13. Menu for switching between applications for parts

Finally, the mobile AR interface was recoded and recompiled in accordance with these modifications to be used in the second day of implementation. In the following day of implementation, Elif and Meva used this modified version of the mobile AR interface during working on spatial tasks, and no issue was observed about neither directions of virtual objects nor switching applications for the parts. Hence, these revisions and conjectures were added to the design principles.

To sum up, in the light of these findings, these conjectures could be made that AR interface should include some reference information about orientational clues in order to help students' adaptation process for logic of AR, and unity in design of interface should be preserved in order to make easy to switch between different scenes for students without distracting their attentions from learning goals.

4.1.2.2. Findings about Booklets on Walkthrough Study

In the walkthrough study, aims of the iteration were about improving the design of the SPATIAL-AR toolkit from students' perspective and conjecturing expected practicality for target students. Since the issues about the AR interface were tried to be explained, now this section focused on other component of the SPATIAL-AR toolkit which was the booklet. Issues about the booklets were analyzed and findings were summarized into two themes as modifications for booklets and modifications for spatial tasks.

i. Modifications for Booklets

Findings of the first iteration directed us to design booklets in a coherent way if multiple booklets were used. First of all, according to observation notes in this walkthrough study, it was seen that the conjectures about mobility with this design of booklets completely fulfill their design purposes (Figure 4.14). In other words, as seen on the observation notes, any issue about design of booklets was not encountered during the walkthrough study.

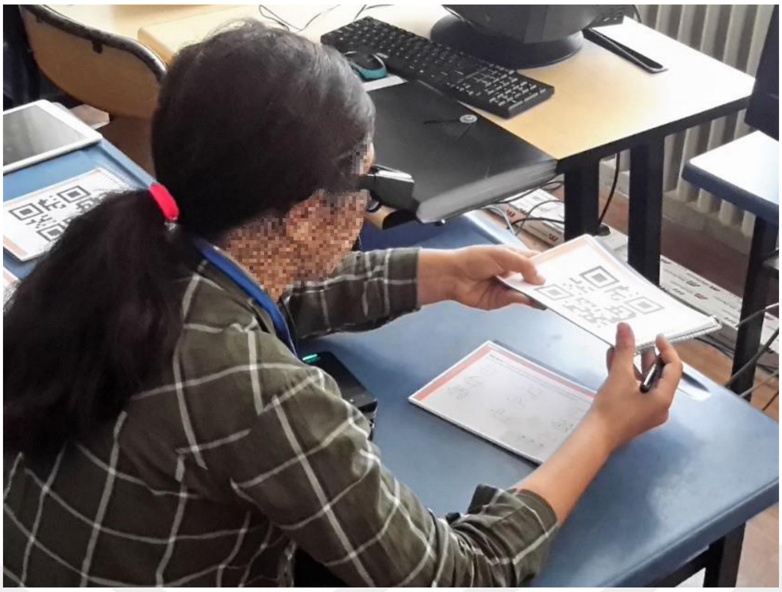


Figure 4.14. Meva can move and turn booklet freely.

However, it was observed that the participants did not pay attention to descriptions of task located on pages. Due to this issue, Elif went wrong on the second task type of the matching side views tasks. For instance, she could not notice that matching side views tasks had two different task types and these tasks differ in given lists. Therefore, she treated the second task type, which was about matching side views of objects from disorganized list of side view, as the previous one, which was about matching side views from organized list. She tried to match side views with virtual objects as thinking that these side views were listed in order of top, front and left like the previous tasks. Therefore, she made a mistake and confused about matching after a while.

The issue of disregarding descriptions of tasks was asked them on retrospective interview session. Meva and Elif stated as

> "*I paid attention but read only bold statements (Meva, retrospective interview)*",

> "*I did not read these writings until … something went wrong … some difficulties (Elif, retrospective interview)*".

In order to find a solution this issue, some visual clues about descriptions of task with sufficient and clear instructions were planned to be presented as a sample task for each task type (Figure 4.15) and an introductory page for every levels (Figure 4.16). Moreover, it was conjectured that, these additions could help a teacher demonstrate and inform students about task and what is expected from them in order to prevent time consuming and to not face similar issues in an ARLE.

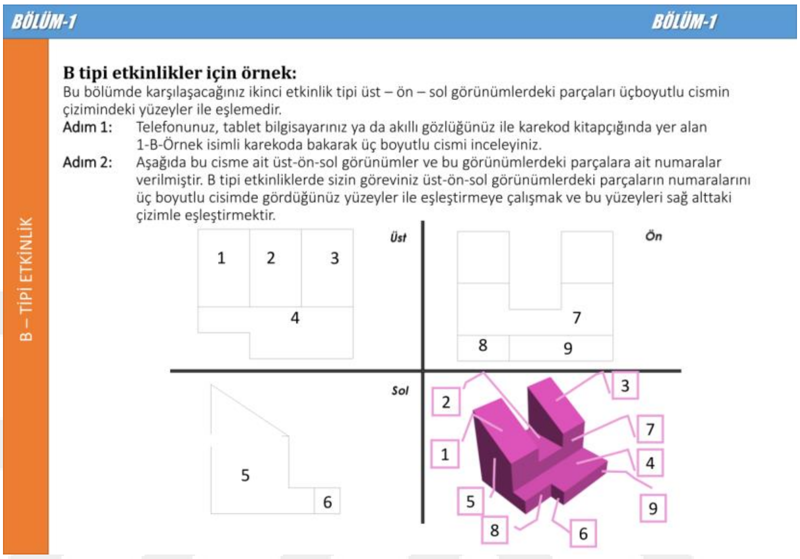


Figure 4.15. Example task about third subpart of the first part

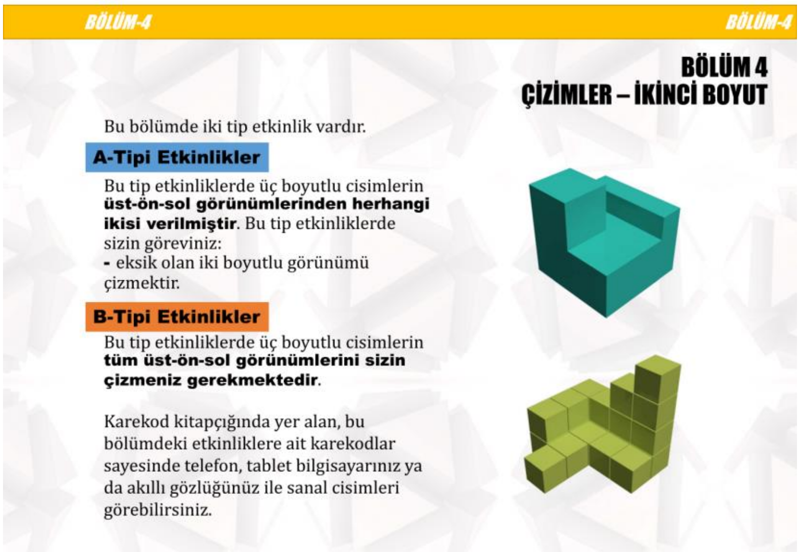


Figure 4.16. Introductory page for the last part

However, example tasks were not designed for the last part of the spatial tasks about sketching tasks since findings show that the first task type of the sketching tasks was already designed as demonstrating sketches of objects from two different directions so it was asked students to sketch other missing one. Therefore, it was seen that these tasks were helpful for students as preparation tasks for the following task type which was about sketching all side views of objects. Therefore, six sample tasks were designed for first three levels of revised four-parted MISAR since it was seen that the last level of the revised MISAR might not be required an example since it already provided opportunities of sample sketches within. Thus, the design principles for booklets and also the design principles for ARLE have been revised in line with these findings since these additions in booklets might also provide teachers a new type of just-in-time information if students confuse and need some helps.

ii. Modifications for Spatial Tasks

In the previous iteration, a pool for spatial tasks were presented to the mathematics education experts. According to their feedbacks and comments several virtual objects and spatial tasks were excluded from the study. Hence, the second prototype of SPATIAL-AR toolkit was designed including the remaining spatial tasks as in the revised MISAR.

During this walkthrough study, observation notes revealed that the spatial tasks and virtual objects were properly prepared for seventh grade mathematics curriculum since the participants Meva and Elif were not confused with any virtual object and spatial tasks. They could examine the spatial tasks smoothly and adapted logic of AR technology easily through these tasks. However, the duration of the whole four levels of the spatial tasks was lasted about three to four hours, in total. In fact, this duration seemed to be less than expected since these spatial tasks were revised in order to keep duration of implementation about four to five lesson hours in the focus group study.

The participants in this walkthrough study were chosen purposefully from high spatial ability students in accordance with their SAT scores. Therefore, it could be expected that students having high spatial ability levels can use holistic strategies to complete spatial tasks and so complete faster than students having average spatial ability (Glück & Fitting, 2003). Nevertheless, this timing issue could be important in working with bigger group of students, so students can diverge in spatial ability levels. Therefore, it was decided that using some of the excluded spatial tasks as extension could be more suitable to design an ARLE for every students. Hence, teacher have an opportunity to provide students extra tasks if some students finish tasks faster than others. In accordance with this decision, some of the virtual objects, which were excluded from the design, were chosen for these extension tasks. These extension tasks consisted of two spatial tasks, which included complex objects in accordance with the findings on the checklists from the previous iteration, for each type of spatial tasks. Because of this modification, "providing tasks" characteristic of the design principles for ARLE was revised as including providing extension tasks if students with higher spatial ability levels need.

4.1.2.3. Summary of Findings from Walkthrough Study

This section presented evidences and reasons of revisions in the design principles for ARLE, key elements of a mobile AR interface and booklets throughout the walkthrough study.

However, the spatial tasks, which were in line with the revised MISAR, were seen consistent through this iteration. Therefore, there was no revision about the revised MISAR. Moreover, it was revealed that the participants could manage to carry out activities smoothly. With some little revisions, the second prototype of the SPATIAL-AR toolkit was seen as practical as possible for seventh grade students. After these revisions, the revised design principles could be summarized as in the following manner Table 4.12 to Table 4.14.

Table 4.12. Revised Design Principles for Augmented Reality Learning Environment

Revisions	Characteristics	Design Principles	Rationale for revised / consistency
Revised Principles	Providing Tasks	In ARLE, teachers should have the opportunity of choosing and administrating suitable tasks as well as easily accessing extension tasks for students' current situations within AR tools.	It was seen that some students could complete given tasks faster than expected time. Hence, a need for some extension tasks could occur in an ARLE in order to keep these students' attentions for learning goals. Therefore, AR tools used in an ARLE could support teachers with extra tasks which could be made visible by only teacher for students in need.
	Just-in-time information	In ARLE, teachers should have the opportunity of supporting students with feedbacks about their works and progresses as well as demonstrations and extra information just in time if a need occurs so that teachers should collaborate students' works with his/her interface and provide sample demonstrations of tasks.	It was seen that students required some orientational clues and explanation about tasks. Therefore, teacher could be provided with such information through AR tools since some students could need sample demonstrations or some clues about tasks and virtual objects.
Consistent Principles	Natural Way of Interaction	ARLE should support multi-user interactions and physical or natural interactions as in real world with real objects in order to provide more opportunities for interactions with virtual objects and each other.	Previously, it was conjectured that students could interact with virtual objects and each other as in real world by natural interactions like talking, pointing, gazing and other. It was seen that the seventh grade students were able to interact with virtual objects as in real world with real objects.
	Sharing and Comparing	ARLE should provide students a way to observe and compare multiple virtual objects or explore one of them in detail within a same scene in order to provide more opportunities for interactions with virtual objects and each other if multiple virtual objects are in use.	Previously, it was conjectured that students could examine virtual objects in tasks included comparisons of multiple objects without confusion if they have the opportunity of choosing specific object to be examined among many. It was seen that, students were not confused while they working on multiple objects and they could observe both multiple objects and one of them in detail by focusing it.
	Challenging Tasks	In ARLE, students should be provided with challenging tasks in order to engage in an active process for learning.	Previously, it was conjectured that students could complete these challenging tasks as active learners. It was seen that the students completed tasks without boring or undistracted.
	Independence of Viewpoint	In ARLE, students should be provided with an opportunity of moving freely by controlling and choosing own independent viewpoint for inspected virtual objects in order to engage in an active process for learning.	Previously, it was conjectured that students could also be active participants of the environment by the opportunities of independence of viewpoints. It was seen that the students were able to act freely in environment or move freely virtual objects. Hence, they were active participants all the time.

Table 4.13. Revised Design Principles for Key Elements of Augmented Reality Interfaces

Revisions	Characteristics	Design Principles	Rationale for emergence / revised / consistency
Emerged Principles	Reference Information	AR interface should provide reference information in order to help students' adaptation process for logic of AR technology.	It was seen that if orientation of virtual object was important in tasks, students need some kind of orientational clues. Therefore, a pointer for direction could be helpful students to understand orientations for virtual objects projected by AR interface.
Revised Principles	Unity in Design (Formerly: Division in Design)	AR interface should be programmed and compiled as a single interface in order to use easily. On the other hand, if it requires to include numerous target images and virtual objects, in order to prevent delay issues for searching related visuals in database, it should be divided into parts by providing some kind of menu to make transition between parts as easy as possible.	Previously, it had been conjectured that dividing this AR interface into parts for lighter database could make delay in recognition minimum, and student could use this divided AR interface without any problem. This conjecture was partly applicable since this modification made delay in recognition minimum but students could not use this parted interface easily. Hence, a menu was designed so that students could make switching between parts of interface without making any extra effort other than learning goals.
Consistent Principles	Virtuality for Objects	AR interface should superimpose virtual objects in the real world by mimicking some properties of real objects like length, depth, height and others.	It was seen that the designed AR interface successfully superimposed virtual objects on real objects.
	Augmentation of Environment	AR interface should enhance reality by augmenting real objects with virtual annotations and elements.	It was seen that the designed interface successfully enhanced designed augmented book with virtual elements.
	Interactivity via Touch / Pointer	AR interface should be designed to provide students a way to interact interface in order to observe and compare multiple virtual objects or explore one of them in detail within a same scene.	Previously, it was conjectured that students could examine multiple virtual objects easily and without confusion if AR interface provides a way to choose specific object among many with touch events or pointer selections. This modification was seen consistent through this design.
	Recognition and Projection	Target images should be assigned or chosen as recognizable as possible for AR interface if AR interface is programmed as requiring target images to superimpose virtual objects. Moreover, if target images are in use, AR interface should be programmed as projecting virtual objects at relatively higher positions from base layer in order to visualize virtual objects in more accurate way.	Previously, it was conjectured that using visually different target images can increase recognisability of them and prevent mingling for AR interface. Moreover, it was also conjectured that replacing virtual objects at higher points could make see these sides easy for students. Through this design, these modifications were seen consistent.

Table 4.14. Revised Design Principles for Booklets

Revisions	Characteristics	Design Principles	Rationale for emergence / revised / consistency
Emerged Principles	Introductory for Tasks	Booklets should include introductory and sample tasks pages for each type of tasks to provide students helpful information about instructions about tasks and type of tasks.	It was seen that students could miss or ignore descriptions for task so that they could go wrong during tasks. Therefore, it was thought that providing some sample tasks and introductory pages for tasks could remind important aspects of tasks to students.
Consistent Principles	Mobility	Target images and tasks should be given on separated pages in order to provide mobility if an AR task is presented on worksheet and this task requires exploration of virtual objects at multiple points of view.	It was seen that the students' booklet provided mobility for students in ARLE.
	Visual Cues	If separated pages for an AR task and target image are needed to be used, these pages should be designed to be discriminated by some visual cues for identification of different types of tasks in order to make students' progresses concurrent among these multiple worksheets and target images without causing distraction for learning tasks.	It was seen that students were able to easily find related tasks and target images among multiple booklets.
	Consistency in Design	If separated pages for AR tasks and target images are needed to be used, these pages should be designed in the same manner by using the same design styles to make students' progress in a synchronous way while working with multiple books.	It was seen that students were able to easily find related tasks and target images among multiple booklets.
	Consistency in Page Numbering	If separated pages for AR tasks and target images are needed to be used, these pages should be designed in the same manner by presenting related target image and task at the same page number among different booklets in order to find the target image of a specific tasks from their page numbers easily.	It was seen that students were able to easily find related tasks and target images among multiple booklets.

These lists in tables pointed out the revised design principles. On the other hand, as mentioned before, however, the MISAR was not revised since it was observed that there was no need to differentiate content of spatial tasks and seventh graders could manage to carry out tasks without any difficulty. Therefore, the contents of the spatial tasks in the SPATIAL-AR toolkit remained same for the last iteration of the study. Some sample spatial tasks were designed for each task type except the last level tasks.

To sum up, the student's booklets were redesigned to include these sample tasks, and the AR interface was recoded to include an opening menu to switch between parts of spatial tasks and orientational clues. Thus, the third prototype of the SPATIAL-AR toolkit were prepared as instructional tools of Iteration III.

4.2. Possible Contributions of Spatial Augmented Reality Toolkit: Micro-evaluation Study

Micro-evaluation study was the last iteration of the overall study. The participants of this micro-evaluation study were eight seventh grade students from a public middle school in Kırşehir. These students were selected from 26 students and grouped two-by two in accordance with their scores in the SAT such as two groups of students with high and average or average and low spatial ability. Moreover, one of the main goal of this dissertation was is to find out possible contributions of intervention to seventh grade students with the SPATIAL-AR toolkit in terms of spatial ability and to learning environment, so in order to understand possible contribution of the toolkit on two types of mobile devices and with variety spatial abilities group of students, two tablet based groups of students and two smart glasses based groups of students were formed with students from different spatial ability levels (Table 4.15).

In this micro-evaluation study, the third prototype of the SPATIAL-AR toolkit, which was redesigned according to findings of previous studies, was used as learning tool. This micro-evaluation study was about finding out the contributions of the prototype of SPATIAL-AR toolkit to seventh graders and making final modification to reshape toolkit for final product if it was needed by seeking answers the research questions which were stated at the previous chapter.

Table 4.15. Groups of students in the Iteration III

Groups		Participants	SAT pretest score	SAT posttest score
Group 1		Ahmet	13	14
	Smart Glasses	Ömer	8	10
Group 2		Enes	12	14
	Tablet	Ümit	8	12
Group 3		Nurgül	3	7
	Smart Glasses	Erhan	6	8
Group 4		Şebnem	3	6
	Tablet	Sare	7	8

In this micro-evaluation study, the third prototype of the SPATIAL-AR toolkit, which was redesigned according to findings of previous studies, was used as learning tool. This micro-evaluation study was about finding out the contributions of the prototype of SPATIAL-AR toolkit to seventh graders and making final modification to reshape toolkit for final product if it was needed by seeking answers the research questions which were stated at the previous chapter. The findings were discussed into two sections in order to answer research questions in terms of SPATIAL-AR toolkit and possible contributions of this toolkit.

4.2.1. Findings about Spatial Augmented Reality Toolkit on Micro-evaluation Study

First of all, the findings shed light on that the modifications seemed enough to administer the SPATIAL-AR toolkit without any issue. Since the participants in this iteration did not encounter any technical difficulty about programming of the AR interface and design of the booklets, there was no need for further modification for the AR interface and design of booklets.

According to observation notes, the SPATIAL-AR toolkit was consistent in design and in the same line with the design principles. Moreover, the mobile AR interface was seemed practical for seventh graders since students worked with this interface fluently and without any bugs across tablets and smart glasses with this design. In addition to this, observation notes revealed that students did not get into trouble while using multiple booklets such as student's booklet of spatial tasks and student's booklet of qr-codes. Therefore, these student's booklets which were designed based upon design principles, were practical for seventh graders to be used in learning phase. Hence, they could use the AR interface along with booklets of spatial tasks and qr-codes without any issue neither using tablets nor smart glasses.

At last, according to findings, the third prototype of SPATIAL-AR toolkit exceled at implementation and this situation could be also an evidence of successfully revision and adaption of the design principles for current design. Therefore, according to findings, the AR interface and the student's booklets were composed of a practical final prototype of the SPATIAL-AR toolkit with their relevancy with learning goals and consistency through design, and also practical implementation of it in an ARLE.

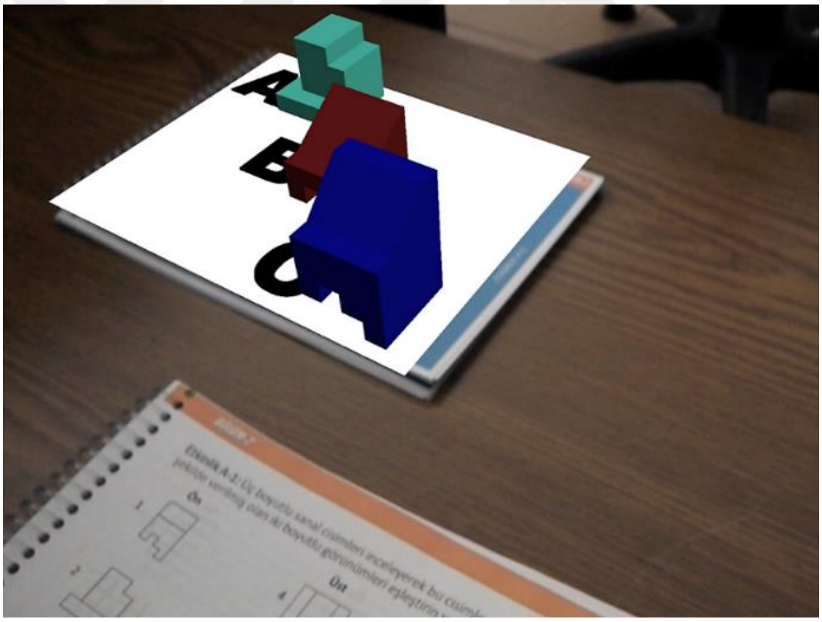


Figure 4.17. The virtual objects subjected to the dialogue on screen capture of Şebnem

Beside these results, a new characteristic has also emerged to provide extra opportunities for interactions of students but it was not from an issue. This characteristic was shown up from dialogs of Şebnem and Sare while they were working on spatial tasks about matching side views. For instance,

Şebnem: … hah, okay this (one of the side views) belongs to blue (virtual object named as C in figure 4.17).
Sare: This was blue (she meant this side view belongs to blue one). Look now the red (virtual object named as B).
Şebnem: … the red. This one (a side view) belongs to which, is it the blue?
Sare: Okay, write this also (she match a side view with the blue one) …

From this dialogue and similar dialogues to this one, Şebnem and Sare used colors of the virtual objects while talking among themselves. They did not use the letters belong to them and then they used their own terminology. Hence, although these virtual objects had not been designed in different colors for this purpose, after this finding it was conjectured that if multiple virtual objects appear in same scene, they could be given in different colors in order to increase their discernibility and provide students more opportunities to use their own terminology. Therefore, "colors of multiple objects" characteristic emerged in accordance with these findings of micro-evaluation study when students used their own terminology during explaining objects to partners via colors of them, and it was added to the design principles of key elements for a mobile AR interface in order to provide students more opportunities for using own terminology in interactions and support the ARLE.

In brief, the design principles for key elements of mobile AR interface were finalized with minor modifications about addition of "using colors to help distinguishing" descriptor to "virtuality for objects" characteristic. In the light of the findings, it was seen that the SPATIAL-AR toolkit exceled at its design purposes of providing spatial tasks as practical as possible in an ARLE. Therefore, according to findings explained in this subsection, it was seen as that final and stable version of SPATIAL-AR toolkit was implemented in this last iteration.

4.2.2. Possible Contributions of Spatial Augmented Reality Toolkit

The design processes of the components of the SPATIAL-AR toolkit, which were the mobile AR interface and the student's booklets, were shown throughout the prototyping phase. Moreover, the findings of this micro-evaluation study revealed that the prototype of the SPATIAL-AR toolkit became a completed product in order to be used in intervention for fostering spatial ability of students. Thus, this section was about revealing expected effectiveness of the SPATIAL-AR toolkit in terms of spatial ability and enhancing learning opportunities through findings from this micro-evaluation study. Findings about students' progresses, experiences and interactions while working on spatial tasks were analyzed in order to understand expected contributions of intervention. These findings were divided into two themes about spatial ability gains and learning opportunities through mobile AR interface.

4.2.2.1. Indicators of Spatial Ability

Findings reflecting how students understood spatial tasks and what strategies emerged while they were working on spatial tasks with the SPATIAL-AR toolkit were explained. Therefore, data obtained through retrospective interviews, video and observation notes, and student's booklets were presented to understand their strategies within the spatial tasks. In addition, visual data from screen captures were presented in order to show what they were seeing at time that they were explaining their solution' ways. Moreover, students' spatial ability could also be explained from their works on spatial tasks (Khoza & Workman, 2009; Strong & Smith, 2002). Thus, some information about students' current spatial ability level could be gathered from their works on student's booklets regarding the MISAR. Findings of this section were explained in terms of the four-parted MISAR which were (i) Surfaces & vertices, (ii) Counting, (iii) Matching correct views and (iv) The second dimension - sketches. In addition, the SAT was also administered as posttest to the all students before retrospective interview. Their scores on the SAT were presented on Table 4.15 at the previous section.

i. Surfaces & vertices

The first level of the MISAR was about identifying components of virtual objects such that these components were composed of surfaces & vertices of objects. In accordance with these components, three type of spatial tasks as identification of surfaces on orthographic views, identification of surfaces on perspective views, and identification of vertices on both orthographic and perspective views were prepared. These tasks were given in Surfaces & vertices level of spatial tasks' booklet as an entrance level since it was seen that these tasks were helpful for students to adapt usage and logic AR interface by examining virtual objects from all directions.

Firstly, the first task type was identification of surfaces on orthographic views. These tasks were designed to make students find and match numbered surfaces on virtual object with its orthographic views. Findings revealed that students used some spatial strategies while doing these tasks. For instance, Ömer stated his strategy in retrospective interview as

> *"I determined inclined and squared (horizontal) surfaces ... for instance, four is a square, six is inclined so does one (see object in Figure 4.18)".*

Another explained strategy was about selecting one of the components of virtual objects. This strategy was stated by Ahmet in retrospective interview. Ahmet stated that

> *"... this surface is one (he was pointing a surface on virtual object), and I wrote one (on this) ... then I continued with other nearby surfaces (Figure 4.18)."*

In addition, according to observation notes, other students also accomplished tasks via these strategies or similar strategies by locating some reference surfaces and following surfaces nearby. In general, these strategies used during this task type could be collected together in a general name such as "specifying a reference".

Figure 4.18. Screen capture and task page of Ahmet to illustrate his strategy

Another task type was about identification of surfaces on perspective views. These spatial tasks were designed to make students find and match numbered surfaces on orthographic views of a virtual object with perspective view, as reverse of the previous spatial tasks. Findings from transcripts of the retrospective interview and observation notes indicated students’ strategies and methods for performing tasks as follows. During the micro-evaluation study, Sare and Şebnem, who were students with average spatial ability and low spatial ability in a tablet based (TB) group respectively, had some difficulty in the second task type until they identify one of the surfaces from key features. When they identified one or some of the surfaces they continued the tasks fluently. Similarly, Erhan and Nurgül, who were students with average spatial ability and low spatial ability in a smart glasses (SG) group, had followed a similar method. For instance, while they were dealing with a cylindrical virtual object, they found and matched sixth surface on orthographic view from front in figure 4.19 and they compared location of this surface with surface four and five which were also in front direction of the virtual object (Figure 4.20).

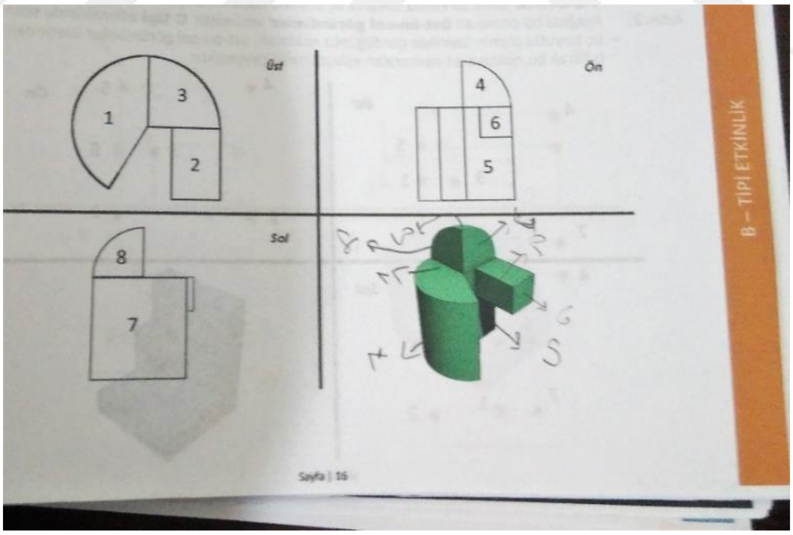


Figure 4.19. Works of Nurgül and Erhan at spatial a task about a cylindrical virtual object

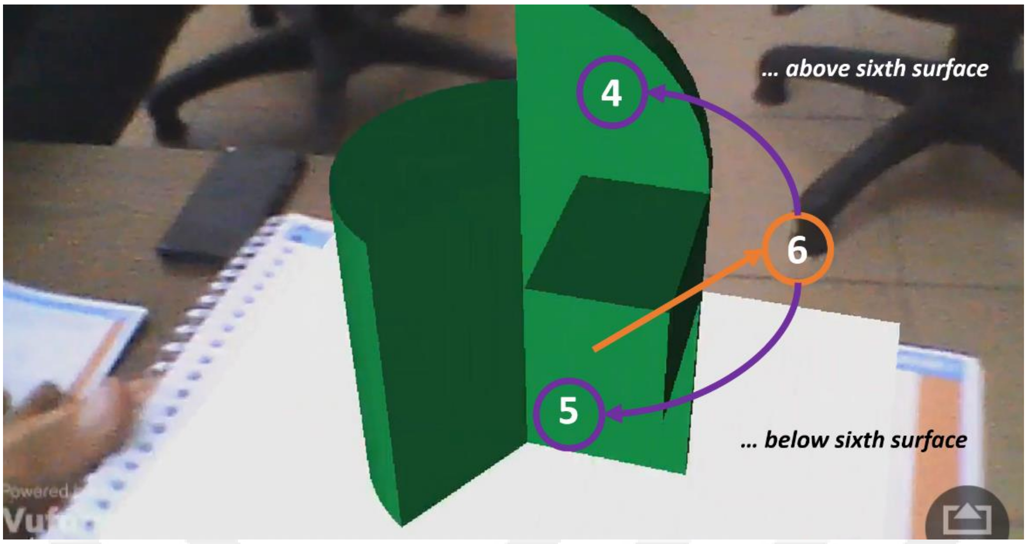


Figure 4.20. Viewpoint of Nurgül while performing her spatial strategy

In addition, a similar strategy showed up in retrospective interview with Ömer (Figure 4.21). He stated his strategy as

> "*If it (virtual object) went down as a stairway, I found the top surface and went down step by step*".

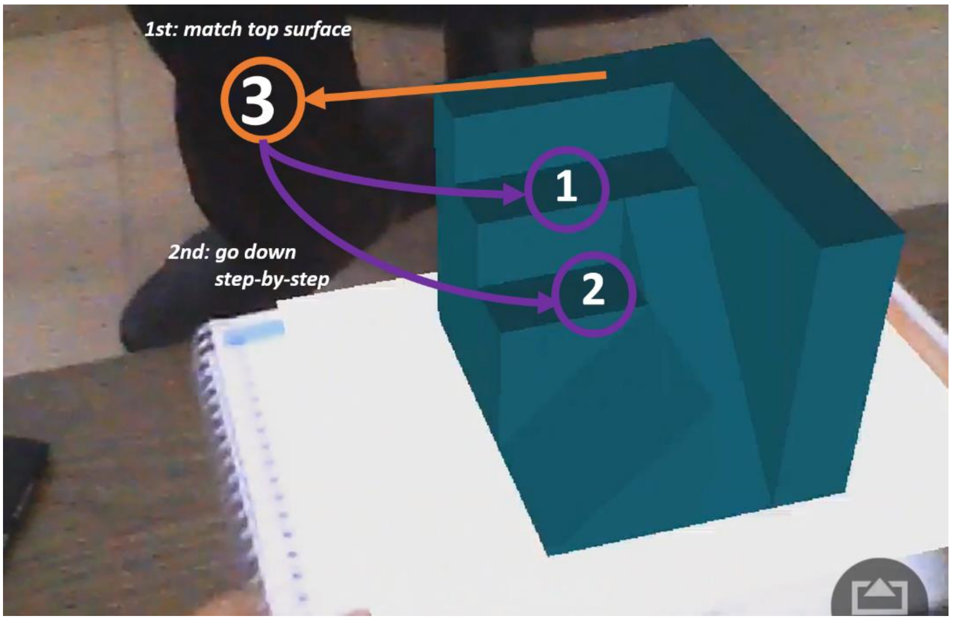


Figure 4.21. Viewpoint of Ömer while performing his spatial strategy

In short, since these strategies also included some key features of objects, these strategies were similar to emerged strategy at the first task type which was "specifying a reference". The "specifying a reference" strategy was also used as an analytic approach for spatial tasks at the above examples. In other words, it was seen that these students approached spatial tasks as analytical ways and solved tasks without using spatial relations within virtual objects.

Thirdly, the last task type was about identification of vertices on both orthographic and perspective views. These spatial tasks were designed to make students find and match numbered vertices on virtual objects with their both orthographic and perspective views. Observation notes revealed usage of some kind of a reference strategy similar to the ones mentioned above. This time, students specified some reference vertices and moved on others. For instance, they generally used phrases like "*above that*", "*below that*", "*opposite side of that*", "*on other corner*", and others. They described locations of vertices to their partners by referring and comparing a found vertex with spatial relations. Therefore, "specifying a reference" was used in these tasks but as a holistic approach.

Besides, another strategy was also identified in transcripts of the retrospective interview for this task type. Some students explained that they followed some kind of a path during these tasks. For example, Erhan and Ümit stated their strategies for the virtual object in figure 4.22 as

> "*… by determining ten at edge, four at edge, eight at edge … then found others … I found outer vertices then moved on inner ones (Erhan, retrospective interview)*".

> "*… I started with four … I followed (a path) from beginning (to end) orderly … in compliance with adjacencies of object like four, six, ten,* and others *(Ümit, retrospective interview)*".

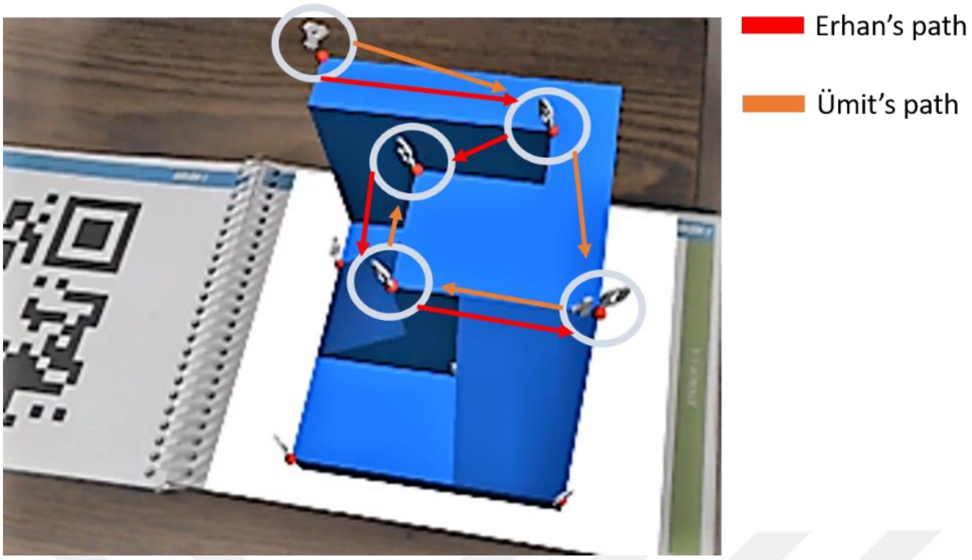


Figure 4.22. Strategies for following a path to find out vertices

Thus, they used a different strategy than using reference objects. This strategy could be named as "following a path". This strategy could be stated in analytic approach since students find out vertices systematically following a route around or on virtual objects.

Additionally, findings from transcripts of the retrospective interview and observation notes indicated that all students found the spatial tasks of the Surface & vertices level as easy. In the retrospective interview session, for instance, students stated *"(objects) having with numbers on (surfaces) were easy to me"*, *"they were easy since objects were simpler"*, *"easy because we can see numbers on them"*, and others. Moreover, although these students were not trained about usage of AR interface or logic of AR technology, they could accomplished all spatial tasks for this part without any confusion about virtual objects, spatial tasks and usage of AR interface.

In short, these spatial contents of the first level were thought and designed as easiest tasks in order to make student to adapt the SPATIAL-AR toolkit. As seen on the students' statements and observation notes, it could be said that these types of tasks were actually helpful to make students get used to the SPATIAL-AR interface and work in ARLE. These findings verified that this level of the MISAR should be considered as entrance level of tasks in order to make students easily adapt to work in ARLE.

ii. Counting

The second level of the four-parted MISAR was about the counting components of virtual objects tasks. These components were thought as bricks and virtual objects were composed of these bricks for this study. Some of these bricks were named to distinguish them and tasks were designed as counting components based on these named bricks. These tasks were given in this level of spatial tasks booklet as a subsequent to the first level since this task type was seen as helpful for students to adapt AR interface by exploring components of virtual objects from all available directions, too.

First of all, for spatial strategies, observation notes indicated that students firstly identified lettered bricks, and then located other bricks in touch with one of these lettered bricks (Figure 4.23). Hence, they simply counted bricks in touch with others, generally. This strategy could be named as "counting components" strategy.

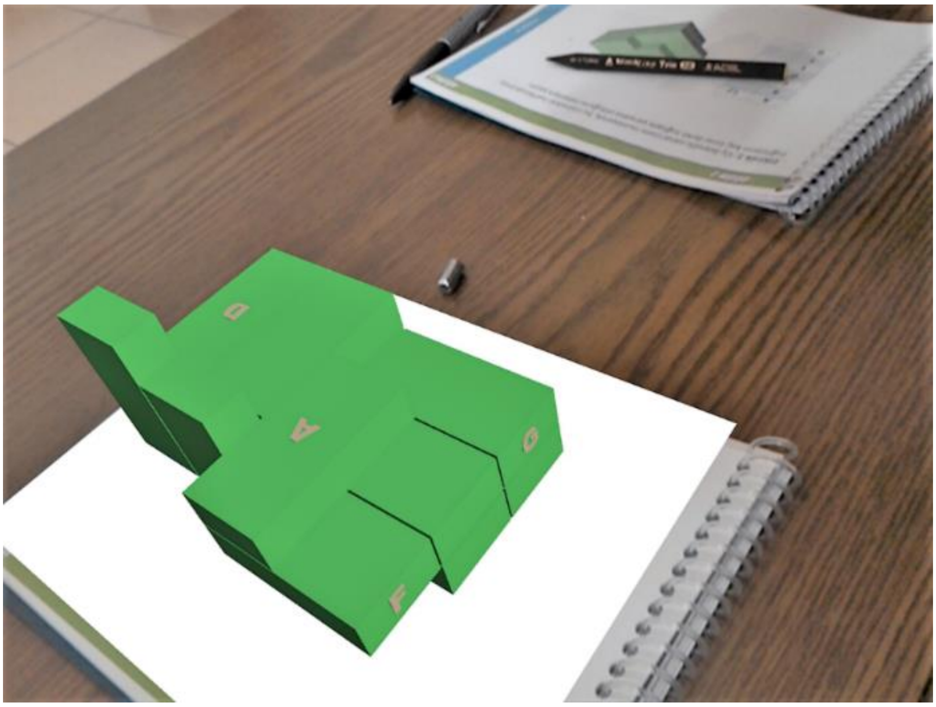


Figure 4.23. Screen capture for counting tasks

Moreover, observation notes have also revealed a similar strategy to specifying a reference object which was described in the previous level. To be more specific, during the implementation, it was observed that while some students were describing their points of view to their partners, they used some phrases like "*above that*", "*below that*", and others. This time they used another lettered brick rather than focused one, which was also a three dimensional object, as reference to describe bricks in touch with the focused lettered brick. Thus, it can be said that, students were able to use a three dimensional component as reference for other components with this type of spatial tasks, and they used spatial relations between these components to use this strategy in a holistic way.

In addition to these strategies, according to answers of students in tasks booklets, all students accomplished these tasks correctly. Therefore, it can be said that students realized spatial relationships within objects since these spatial tasks needed to reveal spatial relations between components within a virtual object. Moreover, these tasks were thought as a supplement for the first level in order to enhance students' usage of AR interface and works in ARLE. Findings from both observation notes and retrospective interview transcripts verified this conjecture since students did not have any difficulty and engaged these tasks with the AR interface as if they used the SPATIAL-AR toolkit like using a common learning tool. Hence, they explored the virtual objects designated to this level in every angle of views without any difficulty. Moreover, they stated this situation as *"(objects) with writings were easy"* or *"these (tasks) were easy"*, and others in the retrospective interview.

In the light of these findings, it was revealed that students were actually accustomed to logic of AR technology and working with the mobile AR interface as a common material. Therefore, the SPATIAL-AR toolkit have lost its novelty and become a common instructional material during this level.

iii. Matching Correct Views

Another level was of the four-parted MISAR was about matching side views for virtual objects. Two types of tasks were designed such as matching from organized and disorganized lists with full of side views of multiple virtual objects for this level. These tasks were presented before sketching tasks since these tasks could be helpful students to understand two dimensional representations of three dimensional objects.

Firstly, spatial tasks about matching side views from organized lists consisted of first task type of this level. These tasks were designed to make students discriminate and match correct side views from an organized list of top, front and left views with a virtual object among many. Secondly, the other task type was again matching side views with objects but, this time, side views were given as mixed in disorganized lists. Thus, students needed to understand directions of side views, discriminate virtual object of these views, match side views and virtual object during this task type.

Findings indicated some strategies were used in these spatial tasks. For example, some students counted unit-cubes, which were components of some virtual objects, in order to match their side views. This strategy was also seen at the above mentioned level for spatial tasks. Enes and Ahmet stated their strategies in the retrospective interview as

> *"… they (objects with unit cubes) were much better, you can count them (cubes) (Enes, retrospective interview)*".

> *"… objects with unit cubes were clearer and sharper then I can count like this one, two … (Ahmet, retrospective interview)*".

As seen on these statements and observation notes, this counting strategy was applicable to only matching side views of objects with unit-cubes (Figure 4.24).

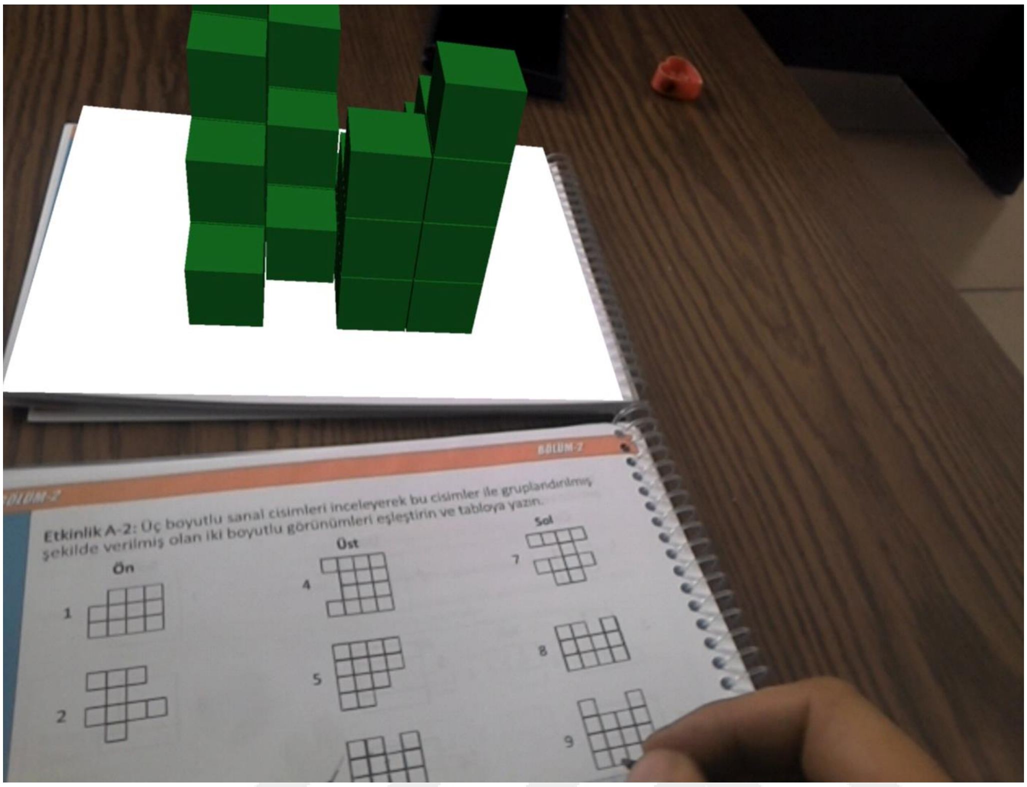


Figure 4.24. Screen capture for view point of Enes while he was counting cubes

For other objects, in addition to this, Ümit (Figure 4.25) and Ahmet explained their strategies as follows

> "*Normally, I looked this shape and if this has some inclined surfaces, I marked possible side views having surface like this so as that become clear from there (list of side views) (Ümit, retrospective interview)*".

> "*If objects seem like a stairway, I look that and match accordingly … like there is a rectangular surface, does down and a square (Ahmet, retrospective interview)*".

Figure 4.25. Screen capture for view point of Ümit while performing his strategy

They explained a similar strategy but in different ways. This strategy was similar to the "specifying a reference" which was also seen at tasks for the first level and the second level. Therefore, it was clear from these findings that students used formerly used strategies during these tasks such as "counting components" and "specifying a reference".

Moreover, all students accomplished these matching tasks correctly by using either analytic or holistic approaches. Therefore, it can be said that these students understood spatial relationship between objects and relationship between two dimensional spatial information and three dimensional one.

iv. The Second Dimension – Sketches

This level was the last level of the four-parted MISAR and about sketching different views of virtual objects tasks. Two types of tasks were design for this part which were about sketching a missing side view and sketching all side views of virtual objects.

Firstly, students engaged in spatial tasks about sketching missing side views of virtual objects. There were two types of virtual objects such as virtual objects with unit-cubes and virtual objects with complex shapes. For each object type, there were three tasks as missing side views from top, front and left sides. Secondly, the other task type was about sketching side views form all three directions as top, front and left sides. Similar to first task type, students engaged in spatial tasks about sketching side views of three virtual objects with unit-cubes and three virtual objects with complex shapes. These tasks were the final tasks of this study.

It was observed that generally students counted unit-cubes in order to sketch side views of the virtual objects with unit-cubes. In terms of counting, some students sketched side views via using unit squares. In other words, sketching side views was take placed by drawing square by square. It was discovered from their terminologies to describe objects to their partner such as

> "*... take this side as four unit squares (while Enes was explaining object to Ümit during implementation)*"
>
> "*No, look at this (object) ... that much unit cubes (while Ümit was showing his sketch to Enes during implementation)*"
>
> "*This (edge) four squares and that two squares (while Ahmet was explaining an object to Ömer during implementation)*".

As seen on these statements, students used both mathematical terminology for two dimensional geometry and three dimensional geometry. It was observed that they used "squares" while they were working on or giving information about two dimensional representations, and used "cubes" while they were working on or explaining from virtual three dimensional objects. This counting strategy was object-specific, so the students could use the "counting components" strategy with only virtual objects with unit cubes.

In retrospective interview, it was asked to students how they managed to sketch side views of virtual objects with complex shapes. Three different strategies were designated in their statements. One of them could be considered as a modified version of this counting components strategy. This strategy was about estimating size of components of virtual objects. For instance, Ümit and Enes who were groupmates in TB group summarized their methods as

> "*Firstly, I joined this lines (he meant crossing lines between components on Figure 4.26) on object. After that I sketched the remaining … I considered this smallest gap between edging things as one unit cube and calculate others based on these … by estimating (Ümit, retrospective interview)*".

> "*We estimated … for example, if this one is two (unit squares), we take that one as three (unit squares). But this was like estimation not accurate since I could not count (Enes, retrospective interview)*".

Figure 4.26. A virtual objects with complex shapes

It was observed that this "estimating components" strategy was utilized as sketching component by component similar to the above mentioned method for objects with unit cubes while they were sketching relatively easy and less complex objects as observed. However, if virtual objects were relatively more complex, they estimated size of virtual objects somehow and sketched firstly outline of side views of these objects then sketched inner lines to specify components. This strategy was similar to used and emerged strategy from previous works of students which was "following a path" since it was observed that generally students sketches these outlines by describing virtual objects to partners like a path or an address. For instance,

> "*It goes down four unit, (turns) then continues four unit… after three to above … (Ahmet, during implementation, see figure 4.27)*"

> "*We explained objects to each other like describing a route … go left three units then come upwards or go down (Enes, retrospective interview)*".

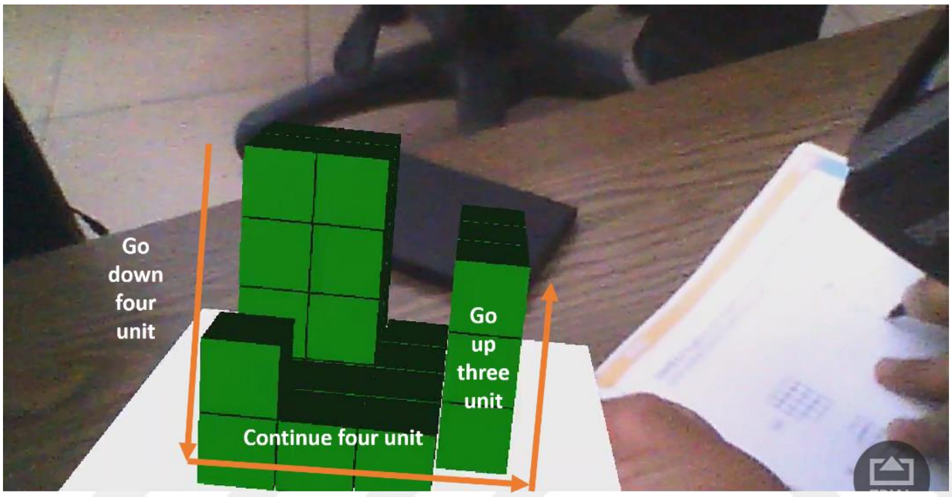


Figure 4.27. Ahmet was describing a virtual object to his partner Ömer like an address description, during implementation.

Besides this strategy, another strategy was also revealed. This strategy was about "drawing overviews or frames" for views like a square or any other figure just a draft to identify size of virtual objects. In retrospective interview, Erhan and Nurgül described their strategy (Figure 4.28) as;

> "*… with squares … I mean I drew squares. For example, I made a frame with square (as an overview for side view) and remove overflowing places*".

> "*… if we managed identifying bases (an overview for side view), others (inner details) are easy (Nurgül, retrospective interview)*"

In general, all students could sketch both missing side views and side views from three directions for virtual objects correctly by using previous spatial strategies, modifying them for current situation or finding new strategies. Therefore, it can be said that students have shown some clues for fostering spatial ability throughout this implementation of the SPATIAL-AR toolkit.

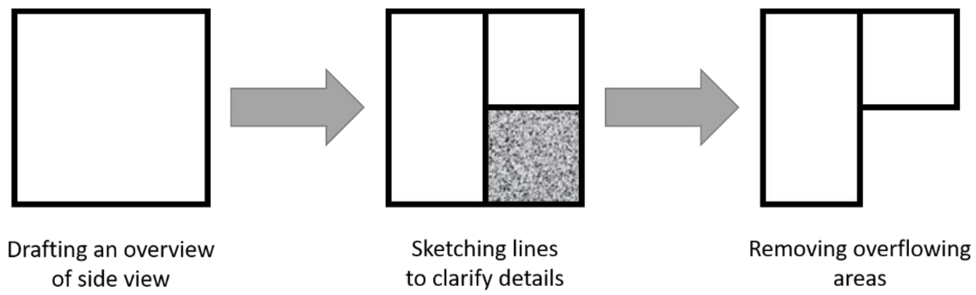


Figure 4.28. A demonstration of “drawing overviews or frames” strategy

Additionally, a remarkable finding was occurred on transcripts of the retrospective interview. In order to understand the possible effect of the intervention, a question about what students envision in their mind while solving questions in the SAT administrations was asked to the students. Generally, students stated similar answers that they envisioned the following things by remembering their experiences with the SPATIAL-AR toolkit in the ARLE;

- To remember what is the meaning of looking a three dimensional object from sides.
- To remember how does a three dimensional object seem from sides?
- To remember how do two dimensional orthographic and perspective views of objects represent the actual object?

Therefore, it can be said that they could spatially think three dimensional objects and relation with representations modes of them while answering questions of the posttest administration of SAT.

To sum up, some emerged strategies, reusing of these strategies and modifying these strategies to situation of tasks were observed throughout implementation of spatial tasks in this micro-evaluation study. Students were able to use and adjust strategies in spatial tasks. Moreover, some evidence about improvement in spatial ability of students were found in the logs and students' booklets. Because, the four-parted MISAR could be considered as including spatial contents for improving spatial ability as well as giving some clues about learners' current state of spatial ability. In other words, these characteristics could work as a learning way as well as an assessment way by analyzing their solutions and works on spatial tasks booklets. In general, students' works on booklets indicated that all of them accomplished all sketching tasks correctly. Therefore, this SPATIAL-AR toolkit provided some spatial ability gains to all students from various spatial ability level. These gains can also be seen on students' scores in the SAT.

Students' scores in pre and post administrations of the SAT were presented in table 4.15 at the beginning of this section. As seen on this table, their scores were on the rise. Since the sample size was small, a Wilcoxon signed-rank test was conducted to evaluate whether this intervention was helpful to foster spatial ability of students (Table 4.16). The rationale for using this nonparametric test was small sample size of students in the comparison of scores in pretest and posttest administration of the SAT since the Wilcoxon signed-rank test is stated as more powerful than paired sample t-test for small sample size (Arnold, 1965; Klotz, 1963).

Table 4.16. The results of Wilcoxon signed test for pretest and posttest score of the Spatial Ability Test

Pretest – Posttest	n	Mean Rank	Sum of Ranks	z	Sig.
Negative Ranks	0	0,00	0,00	-2,539	0,011
Positive Ranks	8	4,50	36,00		

The results in this table indicated a significant difference. In other words, the Wilcoxon signed-rank test showed that an intervention for fostering spatial ability with the SPATIAL-AR toolkit elicited a statistically significant change in spatial ability levels of students' pretest scores (Mdn = 7.50) and posttest scores (Mdn = 9.00) in the SAT, median estimate = 2.50, 95% CI = [1.5, 3.5] (W=36, Z = -2.539, p = 0.011, r=0.63). These results suggested that the SPATIAL-AR toolkit indeed have some degree of contribution to on seventh graders' spatial ability since students' posttest scores are significantly higher than pretest scores, in accordance with these results, without regarding their initial spatial ability level and their used devices. Hence, spatial abilities of students, who were initially have either low, average or high spatial ability, were fostered. Of course, these scores might not be compatible to generalize since there was no comparison group in this study and sample size was small so that this result could be quite 'fragile' and not very generalizable. Nevertheless, this result could give some useful information about students' spatial ability before and after the study at a glance.

As a final remark, while students were working on tasks, it was seen that the first and second levels of the MISAR and the virtual objects were appropriate to seventh graders' understanding level and these levels made students adaptation to the mobile AR interface and their usage with booklets successfully easily, as planned.

4.2.2.2. Learning Opportunities in Environment

In this section, findings reflecting how students acted and expressed their way of thinking while they were working on spatial tasks in an ARLE with tablets or smart glasses were explained. Therefore, data obtained through various sources were presented to understand expected effectiveness of the SPATIAL-AR toolkit in terms of opportunities in learning environment. Findings of this subsection were explained in terms of design principles of ARLE which were (i) Interactions, (ii) Active process of learning and (iii) Teacher as mediator.

i. Interactions in ARLE

ARLE was conjectured to provide some opportunities for interactions to groups of students while they were working on spatial tasks. In order to design SPATIAL-AR toolkit to support this feature, one characteristic was derived from literature and one was emerged from findings of the prototyping phase. They were natural way of interaction, and sharing and comparing features. Findings from observation notes, video logs and transcripts of the retrospective interview were analyzed in terms of students' interactions through speech, gesture, non-verbal communications and using own terminology to accomplish tasks.

Firstly, natural way of interaction characteristic was derived from the literature since researchers stated that AR interface can provide a natural way of physical interaction for virtual objects like walking through or around virtual objects (Kaufmann, 2003; Kaufmann, 2011; Kaufmann & Schmalstieg, 2003). Therefore, this characteristic was formed to provide students some opportunities for interactions like exploring an object by seeing each other, move or tilt object as in a natural way, and others. By this way, it was aimed to provide students an ARLE in which they can work on objects by interacting with these objects and their partners via gestures, gazes, talks, hand and body movements or non-verbal cues. Hence, the components of SPATIAL-AR toolkit which were the mobile AR interface and the booklets were designed to provide these interactions with physical and natural ways.

According to observation notes, there were two kinds of physical interaction ways which were standing up or move body sides to see every aspects of the inspected virtual objects and moving or tilting booklets to examine objects. These differences were caused from used devices which were tablets and smart glasses. In the retrospective interview, these differences in interactions were asked to students and their feedbacks enlightened these differences. Students, who used tablets, stated their interactions as

> "*I did not do this (standing up) consciously, I was only trying to see objects from every directions (Ümit, retrospective interview)*"

> "*Sometimes, to see top or backward of objects, I had to stand up (Şebnem, retrospective interview)*".

On the other hand, one of the students, who used smart glasses, stated this argument about his way of interaction as

> "*I feel more comfortable to relocate this booklet (qr-codes booklet) … my hands were free (Erhan, retrospective interview)*".

Therefore, it was discovered that students with tablets spent more time remaining standing and walking around virtual objects (Figure 4.29). On the other side, students with smart glasses spent their time just sitting on chairs and moving, turning or tilting qr-codes booklet with their hands (Figure 4.30).

Figure 4.29. Interactions of students with tablets

Figure 4.30. Interactions of students with smart glasses

Moreover, since students were able to see each other with or without interface, they had the opportunity of talking and sharing their thoughts, directly. Secondly, sharing and comparing characteristic was added according to findings of the first iteration, in order to provide students opportunity of changing visuals on screens from multiple virtual objects to a single virtual object and to make them explore virtual objects in detail in which spatial tasks was about matching side views. In this micro-evaluation study, some students were observed as exploring virtual objects via investigating both multiple view and single view during the study (Figure 4.31).

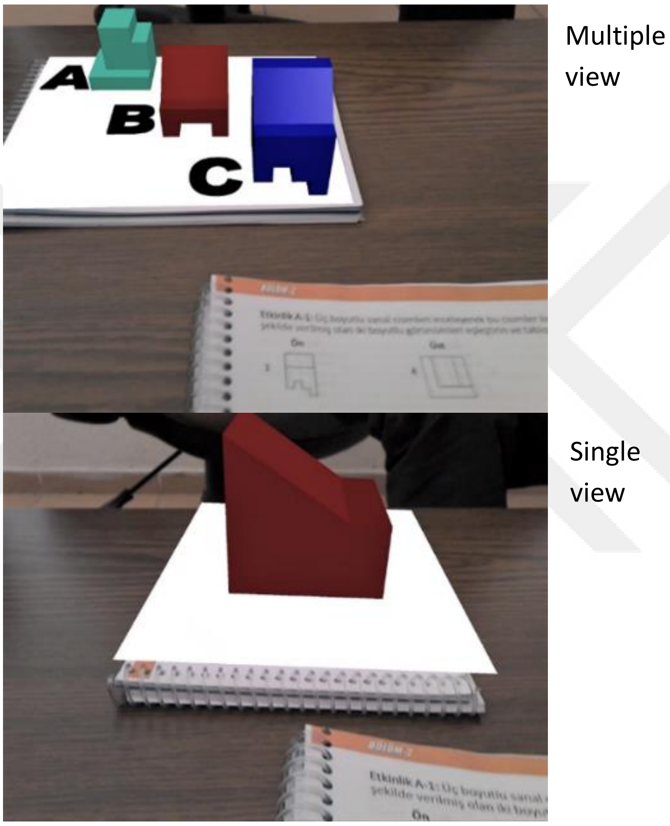


Figure 4.31. Comparing multiple virtual objects

In the retrospective interview, this situation was asked to students and one of them stated

> "*I made this to compare so I explore virtual objects in detail firstly by magnifying them. They seem so similar to me. So, I examine them again together (in multiple view) to compare their views (Nurgül, retrospective interview)*".

According to her statement, she compared virtual objects one by another in order to understand spatial relationship between objects and expressed own point of views to her partner during this type of tasks. Therefore, it was seen that this characteristic provided students opportunities for comparing different objects on the same target.

ii. Active process of learning in ARLE

Spatial tasks should be carried out by students in an active process of learning to let them link their previous knowledge with these tasks and interact each other. This was another feature of the design principles for ARLE because students could better build spatial information about objects via active participation in tasks (Sundberg, 1994). Hence, In order to provide active process of learning for students in ARLE, two characteristics were derived from the literature such as challenging tasks and independence of viewpoint.

Firstly, spatial tasks were designed to challenge students while carrying out these tasks. In order to accomplish this, spatial tasks were designed based upon the MISAR which was derived from literature and revised until to be relevant to curriculum, and consisted and practical in design throughout the prototyping phase. In other words, this model was revised in order to be more suitable for middle school level and ARLE. Moreover, a pool for spatial tasks were formed and evaluated by the mathematics education experts in the focus group study in order to identify and select challenging tasks. According to observation notes and other findings, students challenged through these tasks since according to findings at the previous section, which was about spatial ability, it was revealed that students could use some spatial strategies during tasks and they successfully completed nearly all spatial tasks correctly and without boring or distracting from tasks. Therefore, it can be said that students could understand, apply and synthesize needed spatial information to accomplished spatial tasks within this ARLE. Moreover, according to observation notes and interview transcripts, students described the tasks of surfaces & vertices level and counting level, which were the first and second levels of tasks, as less challengeable and easy to work, by stating *"(objects) having with numbers on (surfaces) were easy to me"*, *"they were easy since objects* *were simpler"*, *"easy because we can see numbers on them"*, and others. On the other hand, they stated that the tasks of matching level and sketching level, which were the third and fourth levels of tasks, were more challenging, especially tasks with unit-cubes for matching and tasks for complex shapes for sketching.

Other characteristic was independence of viewpoint for active participation. This characteristic was about providing students opportunity of moving freely by controlling and choosing their own independent points of view for virtual objects in order to eliminate passive observation. Therefore, control of the ARLE would not belong to any specific student, anyone could control the ARLE at the same time, same place and with same booklets. Similar to differences in interactions across devices, observation notes and video logs indicated that this independence of view point characteristic showed a difference in terms of device. It was observed that, students shared their points of view in order to correct mistakes of their partners or to describe an object. For instance, Ahmet in SG group shared his point of view in order to correct his partner mistake in the tasks of the first level by stating "*it is not top of this* object" and pointing the numbered surfaces on orthographic views on the booklet (Figure 4.32) and describing these numbered surfaces as following a route around object. He stated this sharing as "*sometimes, we described objects among us like address descriptions*" in the retrospective interview. On the other hand, students in TB group shared their points of view or thoughts by just pointing their screen to show their points of view and describe object on their tablet's screen in order to correct peer's mistakes (Figure 4.33).

Figure 4.32. Sharing among smart glasses based groups

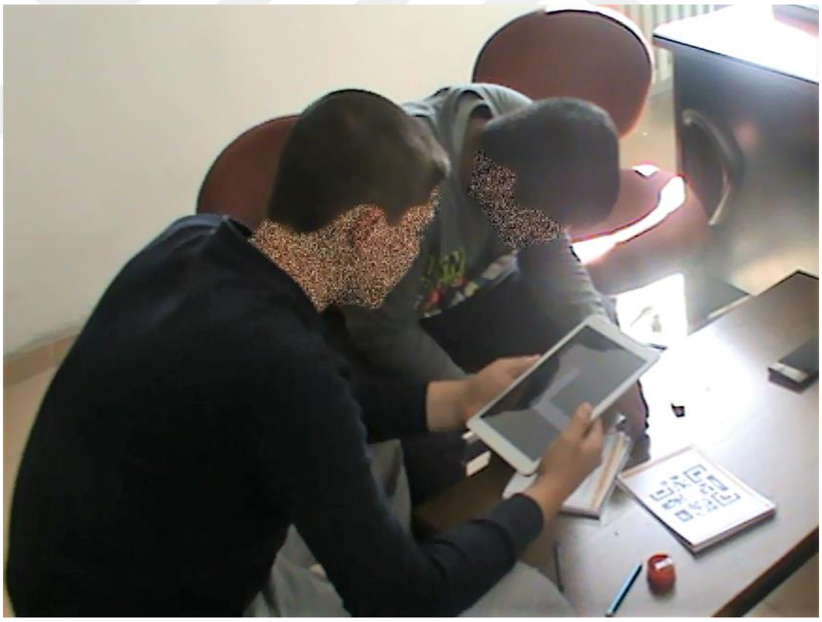


Figure 4.33. Sharing among tablet based groups

In general, it was observed that students in TB groups could explain their unique viewpoints with partners by pointing out and showing screen of their tablets by some gestures. On the other hand, students in SG groups did not have such opportunity since they could not share their point of views by showing screens. Therefore, they generally used phrases about directions like "*above that*", "*below that*", "*on right or left*" and others while describing their point of views to partners similar to following a route or describing an address. Moreover, some students were progressed from one task to another after verifying their works via looking objects from different directions. Therefore, it was revealed that this characteristic provides opportunities to students for an active process of learning so that it contributes with unique opportunities to ARLE (Figure 4.34).

Figure 4.34. Students investigate virtual objects from own unique viewpoints.

In short, observation notes and video logs of screen captures verified that this characteristic exceled at its purpose. In other words, students in both TB and SG were always active while dealing with spatial tasks in order to examine objects from their own points of view. Therefore, since they could control the point of view, they examined virtual objects freely.

iii. Teachers in ARLE

In the ARLE, the roles of teachers were conjectured as mediator and facilitator in design principles. In other words, for this ARLE, teachers were thought as mediating learning through dialogues and collaborating with students as facilitator or coach. In order to support these roles of teachers, two characteristics were revised during the first and second iterations. These characteristics were providing tasks and just-in-time information.

Firstly, in order to support teacher's role, the mobile AR interface was designed to provide tasks in various levels so teacher can choose and administer spatial tasks for linking new information to prior one for providing learning opportunities for students. Therefore, the spatial tasks were designed in some kind of levels and teachers could choose an appropriate beginning level of spatial tasks for students. In addition to this, a need for extension tasks had been arisen during the walkthrough study since the participants in the second iteration completed tasks little earlier than planned duration. Therefore, some extension tasks were chosen from using excluded spatial tasks and virtual objects in the focus group study. However, these extension tasks were not needed in the micro-evaluation study. Nonetheless, it would be better to prepare some more challenging tasks as extension just a precaution for students in order to determine and provide suitable tasks for students from a variety levels of spatial ability.

Secondly, teacher as a coach could provide feedbacks about students' works, necessary information and hints or extra information as so these should be neither too much nor too little, if students need them. Some need for sample demonstrations for "how tasks could be carried out" showed up from findings of the walkthrough study. Therefore, some sample tasks were designed for this micro-evaluation study. These sample tasks were demonstrated by researcher to students in order to make them understand what are expected from them. Observation notes showed that sample tasks, which were added after the walkthrough study, accomplished their design purpose since students did not need any extra guidance about tasks while they were working with SPATIAL-AR toolkit on spatial tasks after demonstrating sample tasks. Moreover, it was also seen that teacher could collaborate learning through AR interface with his device if students need guidance. For instance, while Ahmet and Ömer were working on tasks in the counting level, Ömer confused about whether some bricks touch each other or not. In order to see this virtual object and provide Ömer needed information about this object, the researcher looked target image related to this object with his tablet (Figure

4.35). Hence, it was revealed that since students and the researcher shared a common virtual space and objects, the researcher could provide any necessary information through his tablet to students in line with just-in-time characteristic of the ARLE.

Figure 4.35. Opportunity of collaborating with students during learning.

To sum up, findings showed that the ARLE and the AR interface provided some opportunities to teachers as well. According to findings, since the SPATIAL-AR toolkit consisted of various levels of tasks and different virtual objects, teachers have the opportunity of choosing and providing suitable tasks to students' ability levels and sample tasks in order to give a quick information about learning tasks. Moreover, the researcher was able to see virtual objects that students were working, just using his tablet and so he had the opportunity of collaborating learning through his device in order to provide clues or extra information for learners.

4.2.3. Summary of Findings from Micro-Evaluation Study

The overall prototyping phase was carried out over three iterations. All of these iterations included different participants from mathematics educators to seventh graders. Throughout this prototyping phase, the design principles and descriptions of them had been reshaped formatively. This section presented evidences about practicality of these revision as well as contributions of the SPATIAL-AR toolkit. In general, the SPATIAL-AR toolkit were found relevant to seventh grade curriculum, consistent and practical in this design as well as having some possible contributions for fostering spatial ability and providing learning opportunities in an ARLE. According to findings described above, there was no critical issues about the design principles for this micro-evaluation study so that the final shape of the design principles and the MISAR were verified. These final design principles and the MISAR were described in the following section.

In the micro-evaluation study, the students used the third and final prototype of SPATIAL-AR toolkit in groups based on spatial ability levels and devices. According to findings, students carried out spatial tasks with some strategies. These students' strategies for spatial tasks were listed in table 4.17.

Table 4.17. Students' strategies for tasks with the SPATIAL-AR toolkit

Parts of Tasks	Strategies
Surfaces & Vertices	specifying a reference following a path
Counting	specifying a reference counting components
Matching Correct Views	specifying a reference counting components
The Second Dimension – Sketches	counting components estimating components following a path drawing overviews or frames

Moreover, analysis of students' works and answers on spatial tasks booklets showed that all students completed all tasks correctly. Furthermore, a Wilcoxon signed-rank test was also conducted in order to see whether the difference in scores of pretest and posttest administration of the SAT was significant. This analysis revealed that students' posttest scores were significantly higher than pretest scores so an improvement in spatial ability occurred within this intervention. Throughout this micro-evaluation study, the AR interface was used by students from a variety of different spatial ability levels properly. Therefore, according to findings explained above revealed that the SPATIAL-AR toolkit could be helpful for students, from any levels of spatial ability, to use strategies of spatial tasks and improve their spatial ability. Findings revealed also possible contributions of this design to an ARLE for seventh grade students with spatial tasks.

4.3. Final Design Principles

In the preliminary research phase, some design principles for key features of a mobile AR interface and an ARLE were determined as well as spatial contents for the MISAR. Due to the nature of educational design research, these initial design principles and model for spatial contents were revised and refined throughout the phases of the study. In the previous sections of this chapter, reasons of these revisions, and practical outputs of these design principles and the MISAR were explained in detail, and in accordance with these all revisions, reshaping stages of the SPATIAL-AR toolkit throughout prototypes were also mentioned. Finally, the final design principles were formed, and the SPATIAL-AR toolkit was revised and redesigned with regard to these final design principles. This part gave information about the products of this study as final design principles and the MISAR.

4.3.1. Final Design Principles for Augmented Reality Learning Environment

In the preliminary research phase characteristics suitable for an ARLE were reviewed form literature. Therefore, related characteristics for fostering spatial ability with a mobile AR interface in learning environment were chosen as initial draft design principles. Throughout the prototyping phase, these characteristics as design principles for ARLE were revised together with all other design principles and the MISAR with different participants. Moreover, some characteristics showed up in cycles of iterations. The design principles for ARLE cover all aspects of the design and development processes of the SPATIAL-AR toolkit in order to provide a suitable learning environment for fostering spatial ability of middle school students with mobile AR interface. There were three main characteristics in these principles which were interactions, active process of learning and teacher as mediator (Figure 4.36).

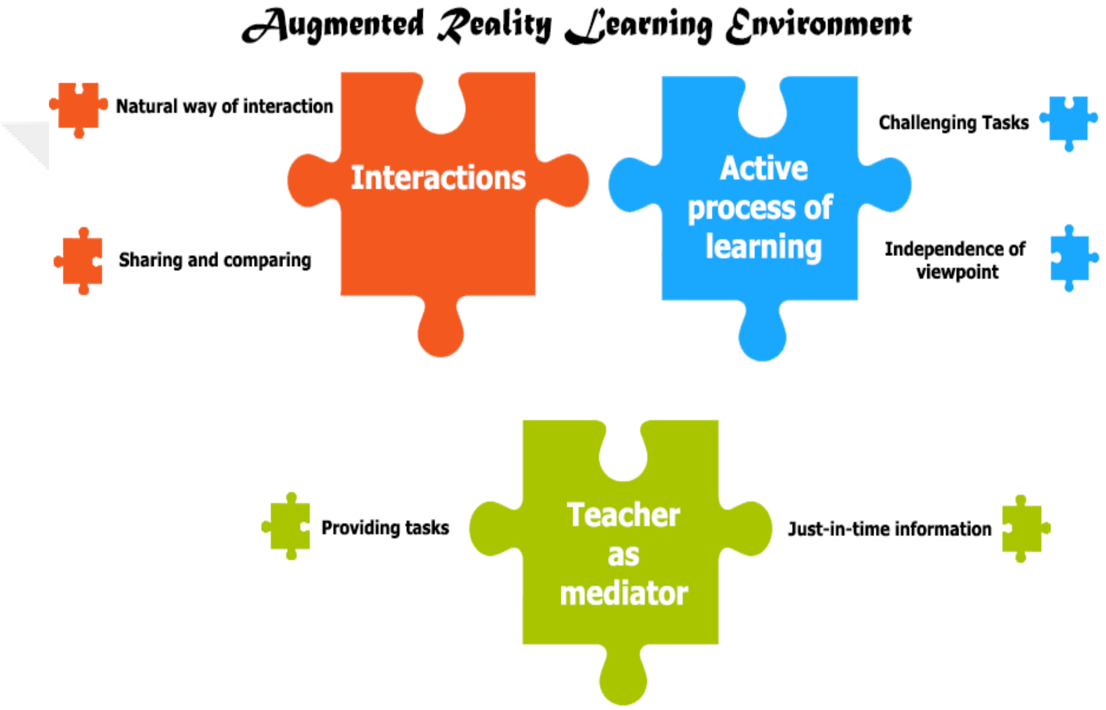


Figure 4.36. The final design principles for ARLE

The main characteristics of designing an ARLE were summarized in figure 4.36. These final characteristics were formed as in the following manner.

Interactions: ARLE should provide some opportunities for interactions of students during implementation. Hence, learners could help each other in order to overcome problems in such interactions. They can use speech, gesture, gaze, non-verbal cues and own terminology in communication in order to achieve tasks. These interactions could be provided via:

- **Natural way of interaction:** Findings of the study have showed that providing students such opportunities for natural and physical ways of interactions enhanced learning in groups of students. Therefore, ARLE should support multi-user interactions and physical or natural interactions as in real world with real objects in order to provide more opportunities for interactions with virtual objects and each other. Thus, groups of students should explore an object by seeing each other and moving virtual objects in a natural way (Szalavari et al., 1998).
- **Sharing and Comparing:** This characteristic showed up itself on prototyping phase. In the focus group study, the mathematics education experts commented that providing such features for interactivity with interface might support interactions in an ARLE. Moreover, result of other following iterations have verified practicality of this characteristics in an ARLE. Therefore, ARLE should provide students a way to observe and compare multiple virtual objects or explore one of them in detail within a same scene in order to provide more opportunities for interactions with objects and each other if multiple virtual objects are in use

Active process of learning: Students should be engaged in an active process for learning with tasks since they could build ideas and spatial information about shapes better through active participation in tasks rather than passive observation. Active participation in tasks could be provided through:

- **Challenging tasks:** In the preliminary research phase, it was seen that challenging tasks could make students participate learning phase actively. Therefore, challenging tasks were designed and chosen throughout the preliminary research phase and the focus group study. In the following studies, it was observed that the spatial tasks which challenge students, support students' active participation of learning as well as their understanding. Therefore, in ARLE, students should be provided with challenging tasks in order to engage in an active process for learning. With challenging tasks, students could understand and synthesize needed spatial information for spatial contents.

- **Independence of viewpoint:** Students could explore virtual objects with their own point of view via AR interface. According to Szalavari and others (1998), this feature eliminated some users being passive observers since control of environment does not belong to a specific person and they could engage in situations in which they explain their own viewpoints to each other. Moreover, it was also found practical in the last two iterations and provided students some opportunities for active participation by forcing them to view and explore virtual objects with their provided devices. Additionally, it was also observed that, such ARLE provided students to see same virtual objects on the same target images with different angles of view point, thus they forced to talk and explain each other their own view point. Therefore, in ARLE, students should be provided with an opportunity of moving freely by controlling and choosing own independent viewpoint for inspected virtual objects in order to engage in an active process for learning.

Teacher as mediator: ARLE should provide teachers opportunities of mediating learning through dialogues and collaboration with students in terms of facilitating and coaching through:

- **Providing tasks:** This study was aimed to provide spatial tasks and a model for these spatial tasks for students having variety levels of spatial ability, therefore, if it needed, teachers could provide spatial tasks in accordance with students' current level of spatial ability within this environment. Findings showed that designing an ARLE in accordance with this characteristic supported researcher some opportunities for providing suitable tasks for students' spatial ability level and extension tasks if it needed. Therefore, in ARLE, teachers should have the opportunity of choosing and administrating suitable tasks as well as easily accessing extension tasks for students' current situations within AR tools. Therefore, teachers could administer and determine spatial tasks for linking new information to prior one for providing opportunities for interactions and they could choose an appropriate beginning level for students in classrooms (Davidson, 1994; Lejeune; 2003).

- **Just-in-time information:** The preliminary research phase revealed that teachers could support students with feedback for their works and progresses. Moreover, according to findings from prototyping phase, some other elements showed up so as to provide some other opportunities for collaboration of teachers with students such as demonstrating sample tasks, providing clues and extra information for tasks. By the way, it was observed that these added features were practical for researcher to help students in terms of providing needed information and clues. Therefore, in ARLE, teachers should have the opportunity of supporting students with feedbacks about their works and progresses as well as demonstrations and extra information just in time if a need occurs so that teachers should see and collaborate students' works with his/her AR interface, and provide sample demonstrations of tasks. However, these information should be neither too much nor too little for students. Thus, students could retain as much responsibility as possible for their own learning (Davidson, 1994; Lejeune; 2003).

These characteristics of the final design principles for ARLE were regarded as base for planning implementation of the SPATIAL-AR toolkit as far as possible to support various learning opportunities with AR interface. Therefore, the mobile AR interface, spatial tasks and booklets were designed considering these design principles along with the other design principles belong to them.

4.3.2. Final Design Principles for Key Elements of a Mobile Augmented Reality Interface

The related literature revealed some needed principles to design a mobile AR interface. The initial key elements had been derived from the literature and given at the second chapter of this dissertation. After that, some revisions and additions of characteristics have been done throughout the cycles of iterations.

Figure 4.37. The design principles for key elements of a mobile AR interface

The final lists of these design principles for key elements of a mobile AR interface were summarized in Figure 4.37. In detail, these final key elements of AR interface were formed as in the following manner.

Virtuality for objects: In the preliminary research phase, it was defined that an AR interface superimposes virtual objects on real world and mimics reality for these virtual objects in terms of properties of height, depth, location and others. In addition, findings of the prototyping phase have shown that a mobile AR interface actually allowed students to experience objects which are not really in real environment. By this way, according to Szalavari and others (1998) objects can be seen and examined in the real environment even if they do not actually exist in this environment. Moreover, according to results, if a virtual scene includes more than one virtual objects together, these multiple objects could be given in different colors such that students' verbal interactions could enhance via describing these objects with their own terminology. Therefore, a mobile AR interface should superimpose virtual objects in the real world by mimicking some properties of real objects like length, depth, height, multiple colors and others. Thus, objects do not have to be physically in this environment by designing virtual objects which are almost real with their physical properties such as size, position and complexity (Azuma, 1997).

Augmentation of environment: In the preliminary research phase, it was determined that AR interface augments real objects in real environment with virtual elements. In this study, a prototype booklet was augmented with virtual elements by a mobile AR interface. Therefore, findings showed that the mobile AR interface could be also used to augment pages of booklet practically along with learning goals. Thus, every objects physically existed in the real environment can be augmented by superimposing dynamic information and variation of virtual new components for an existing object via virtual annotations (Szalavari et al., 1998). So, AR interface should enhance reality by augmenting real objects with virtual annotations and elements.

These two characteristics for key elements are musts for AR interface and define an interface as consisted AR features since the main goal of AR technology is providing a bridge on the gap between real world and virtual world.

Unity in design: This characteristic was modified through findings of the iterations. It was seen that students could easily manage switching between separated parts of AR interface with an opening menu without distracting from learning goals. Therefore, AR interface should be programmed and compiled as a single interface in order to use easily. On the other hand, if it requires to include numerous target images and virtual objects, in order to prevent delay issues for searching related visuals in database, it should be divided into parts by providing some kind of menu to make transition between parts as easy as possible. Thus, the tasks and interface should be in association with each other so that students could not make extra effort other than working on tasks while using interface.

Recognition and projection: AR interface could be programmed in different ways as target based, without target and location based systems. In order to provide a way for augmentation of regular textbooks, the AR interface was programmed as target-based system to augment pages of booklets in this study. Findings revealed that while using two dimensional target images like pictures, at least one third part of these target images could be different from each other in order to prevent recognizing or projecting failures. Thus, target images should be assigned or chosen as recognizable as possible for AR interface if AR interface is programmed as requiring target images to superimpose virtual objects.

Moreover, target based AR interface need some reference locations from real world to project virtual objects. In this study, as mentioned above, these targets were given on pages of booklets and the AR interface had been programmed to project virtual objects at very top of these targets. However, projection virtual objects on very top of targets caused some projection issues. Therefore, projection locations were realigned to overcome these issues. Thus, in order not to face with these issues, if target images are in use, AR interface should be programmed as projecting virtual objects at relatively higher positions from base layer in order to visualize virtual objects in more accurate way. In addition, the gap between projection location and target images should not be noticed by users. In order to provide this, some kind of virtual plane should be located between target images and virtual objects to hide this gap.

Interactivity via touch or pointer: The findings from the focus group study revealed a need for onscreen interactivity. This feature for interactivity with interface gave opportunities to students to compare objects independently among many objects and share their points of view to each other. Therefore, AR interface should be designed to provide students a way to interact interface in order to observe and compare multiple virtual objects or explore one of them in detail within a same scene. These interactivity could be provided with onscreen buttons via touch for tablets and pointer for smart glasses, or with virtual buttons for both devices which can be interacted via hand gestures (Szalavari et al, 1998).

Reference Information: The findings signified a need for some reference information for students in order make easy their adaption process to logic of AR technology such as orientational clues for virtual objects and support teachers' role as mediator by providing needed clues. Thus, AR interface should provide reference information in order to help students' adaptation process for logic of AR technology.

The design principles for key elements of a mobile AR interface were considered while designing and developing the mobile AR interface throughout the research. This AR interface, in this research, was a component of the SPATIAL-AR toolkit. Qr-codes and links to download a demo for this AR interface for Android OS based smart phones, tablets and smart glasses can be found in the Appendices with needed target images.

4.3.3. Final Design Principles for Booklets

At the preliminary research phase, the first prototype of spatial tasks booklet was designed as draft. However, some needs have arisen during the focus group study in order to make booklet more portable and so to separate it into two parts as booklet for spatial tasks and qr-codes as explained in findings of the focus group study. The following list of characteristics were conjectured with an expert from the field of instructional technologies. These draft design principles for booklets were also revised during the following iterations. For example, during the walkthrough study, a need had arisen for sample tasks and introductory pages, so a new characteristic was added to the design principles (Figure 4.38).

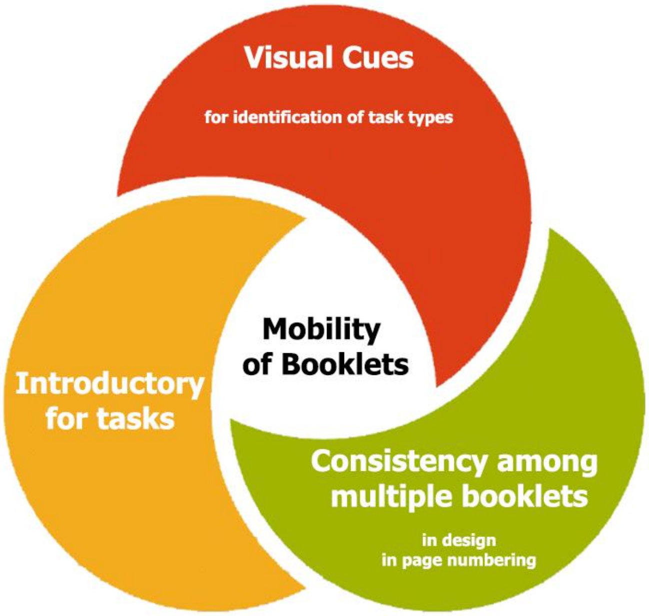


Figure 4.38. Final design principles for booklets

The final lists of the characteristics of the design principles for booklets were summarized in above figure. Now, these final design principles for booklets were explained as in detail in the following manner.

Mobility: In the first iteration, it was seen that if a task was presented on a worksheet, a need for presenting related target image on a separated page has occur. Therefore, in order to provide mobility feature to enhance interactions in the ARLE, spatial tasks and target images were presented on different booklets. Moreover, it was seen that the students' booklet provided mobility for students in ARLE both in the second iteration and the third iteration. Therefore, target images and tasks should be given on separated A5 size pages in order to provide mobility if an AR task is presented on worksheet and this task requires exploration of virtual objects at multiple points of view.

Visual cues: If ARLE requires usage of multiple worksheets for target images and tasks, these worksheets could give students some visual cues to identify task types and related target images visually so that they could use these multiple worksheets in an easy way cohesively. Therefore, if separated pages for an AR task and target image are needed to be used, these pages should be designed to be discriminated by some visual cues for identification of different types of tasks in order to make students' progresses concurrent among these multiple worksheets and target images without causing distraction for learning tasks. In this study, these cues for identification levels were using colors on top of the pages in this study. So different colors were attained for each level. In implementation through the last two iterations, seventh graders did not have any trouble to identify parts for spatial tasks. Therefore, this characteristic was practical by using same coloring on top of pages to identify each part of tasks. Hence, multiple booklets could be design to give visual cues for identification levels of tasks at same place of each page in order to make process concurrent for multiple booklets and their target images without distraction. Moreover, the cues for identification task types were provided using colors on outer sides of the pages in this study. So different colors were attained for each task type. In implementation through the last two iterations, seventh graders did not have any trouble to identify task types in spatial tasks. Therefore, this characteristic was practical by using same coloring on outer sides of pages, since students progressed through task types without confusing. Thus, multiple booklets could be design to give visual cues for identification task types of tasks at same place of the each page in order to make process concurrent for multiple booklets and their target images without distraction. These cues could be using same color on outer sides or bottom of pages to make easy to identify each task type for students.

Consistency among multiple booklets: If AR environment requires usage of multiple booklets for target images and tasks, these booklets could also provide some other elements in order to make easy to discriminate task and related target image. In this study, two booklets were designed after the focus group study which were booklets of spatial tasks and booklets of qr-codes, as mentioned before. In order to provide coherent design and process among these booklets, same design styles were applied tasks and related qr-codes on the other booklet. Any issue about this type of design was not observed in both the walkthrough and micro-evaluation studies. Moreover, besides using same design styles, same page numbers were applied tasks and related qr-codes on the other booklet in order to enhance discernibility, in this study. Any issue about this type of design was not also observed in both the walkthrough and micro-evaluation studies. Therefore, if separated pages for AR tasks and target images are needed to be used, these pages should be designed in the same manner by using the same design styles to make students' progress in a synchronous way and by presenting related target image and task at the same page number among different booklets in order to find the target image of a specific tasks from their page numbers easily while working with multiple books.

Introductory for tasks: In the walkthrough study, needs for describing and demonstrating students about spatial tasks and type of tasks were shown up. Therefore, some sample tasks and introductory for levels were designed and implemented in the micro-evaluation study. It was observed that these sample tasks and introductory for levels helped researcher to demonstrate spatial tasks as well as describe type of tasks. Therefore, booklets should include introductory and sample tasks pages for each type of tasks to provide students helpful information about instructions about tasks and type of tasks. Thus, students could be informed about what are asked in this tasks, since some students may not pay attention to written statements about tasks.

The final prototypes of booklets of spatial tasks and qr-codes were designed considering these final design principles for booklets. Demos for the booklet of spatial tasks and the booklet of qr-codes can be found in the Appendices.

4.3.4. The Model of Improving Spatial Ability in Augmented Reality Environment and Its Connection with Design Principles

In the preliminary research phase, some models for training spatial ability (TSA) and characteristics about contents of tasks for improving spatial ability of students which are suitable to ARLE were determined. The model of spatial operational capacity (SOC) (Sack, 2013; Sack & van Niekerk, 2009; Sack & Vazquez, 2013), TSA (Martin-Gutierrez et al., 2010; Perez-Carrion & Serrano-Cardona, 1998) and spatial contents proposed by Wiesen (2004, 2015) consisted of a base for characteristics of spatial tasks. These models and spatial contents were explained at the Chapter 2, in detail. In this research, the characteristics of spatial contents were considered while designing spatial tasks, and revisited to be suitable for middle school students, seventh grade mathematics curriculum of Turkey and mobile AR systems. The revisions and additions of characteristics were explained in the previous sections of findings, in detail.

First of all, the final MISAR included four sequential levels (Table 4.18). The MISAR was shaped to inform readers about sequential process of spatial tasks and their ingredient in terms of spatial contents as implemented in the whole study.

Table 4.18. The four-parted model for improving spatial ability in an augmented reality environment

Parts	Spatial Contents
Part 1: Surfaces & Vertices	Identification of surfaces on orthographic views
	Identification of surfaces on perspective views
	Identification of vertices on both orthographic and perspective views
Part 2: Counting	Counting the number of components in touch with given component of a virtual object
Part 3: Matching Correct Views	Determining side views from organized orthographic views
	Determining side views from disorganized orthographic views
Part 4: The Second Dimension - Sketches	Sketching missing orthographic view
	Sketching all orthographic views from three directions

This table also summarizes the spatial contents in different task types. Within perspective of the MISAR, the MISAR only informs about spatial contents of tasks, but while implementing these series of spatial tasks in an ARLE, one could consider the characteristics of the final design principles for ARLE. In this section, these four sequential levels were explained to identify spatial tasks in the final version of SPATIAL-AR toolkit. These tasks were formed as in the following manner.

i. Surfaces & vertices

This level was introduced as an entrance level for the MISAR. In the focus group study, these types of tasks were presented at the beginning since it was conjectured that these tasks could help to understand working principles of the AR interface. This conjecture was verified during the walkthrough and micro-evaluation studies since seventh graders easily adapted usage and logic of the mobile AR interface. Because of this practicality about this spatial content, spatial tasks should start with identifying components of virtual objects in order to make students adapt an ARLE. According to suggestions of Martin-Gutierrez and other (2010), Perez-Carrion and Serrano-Cardona (1998), and findings of this study, tasks for this spatial content could include tasks about

- Identification of surfaces on orthographic views
- Identification of surfaces on perspective views
- Identification of vertices on both orthographic and perspective views

In this study, spatial tasks for this level were designed into three task types. The first task type includes tasks about identifying surfaces of virtual objects and transferring information about these surfaces from virtual three dimensional objects to orthographic views from top, front and left sides. Therefore, students were asked to identify numbered surfaces of virtual three dimensional object on its orthographic views from top, front and left sides. In accordance with these tasks, virtual three dimensional objects were developed as having numbers on specific surfaces. In addition, the booklet of spatial tasks was designed to involve orthographic views of the virtual objects with blank areas to mark the numbers of the specific surfaces and perspective views without numbers on them in order to give a glance of these virtual objects to students. The virtual three dimensional objects could be organized from easy to hard as shapes having surfaces vertical or horizontal planes to inclined plane (Figure 4.39).

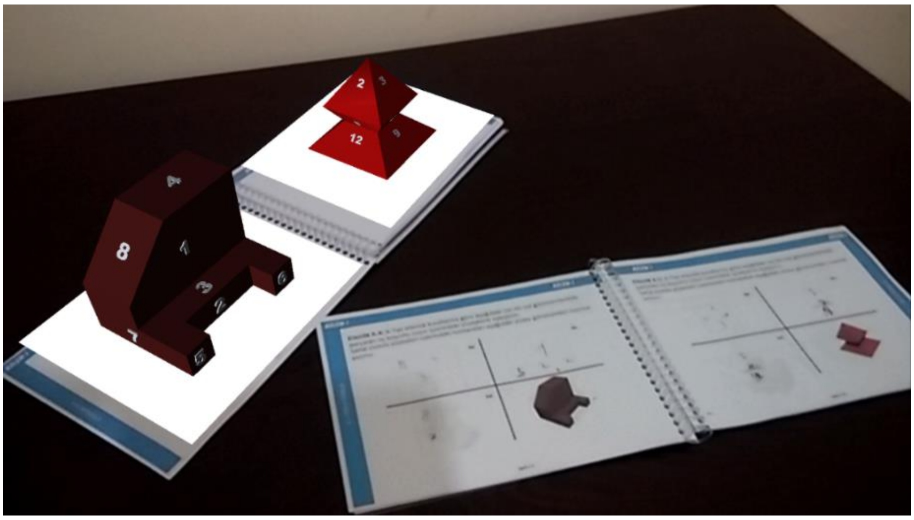


Figure 4.39. Identifying numbered surfaces on virtual three dimensional objects

The second task type was inverse of the former tasks. This time, the surfaces were numbered on orthographic views of virtual objects. In other words, these tasks included tasks about identifying surfaces of virtual objects and transferring information about these surfaces from orthographic views of top, front and left sides to perspective view. In accordance with this task type, virtual three dimensional objects were developed to be used only a reference in order to recognize which surface on orthographic views could be where on the perspective view. In addition, the booklet of spatial tasks involves orthographic views of the virtual objects with the numbers on the specific surfaces and perspective views of the virtual objects to mark these numbers of specific surfaces on side views. In this subpart, students were asked to identify numbered surfaces on orthographic views of a three dimensional object on its perspective views via exploring virtual demonstration of this object. Similar to the former tasks, these tasks involved shapes which have vertical or horizontal surfaces and inclined surfaces or cylindrical surfaces (Figure 4.40).

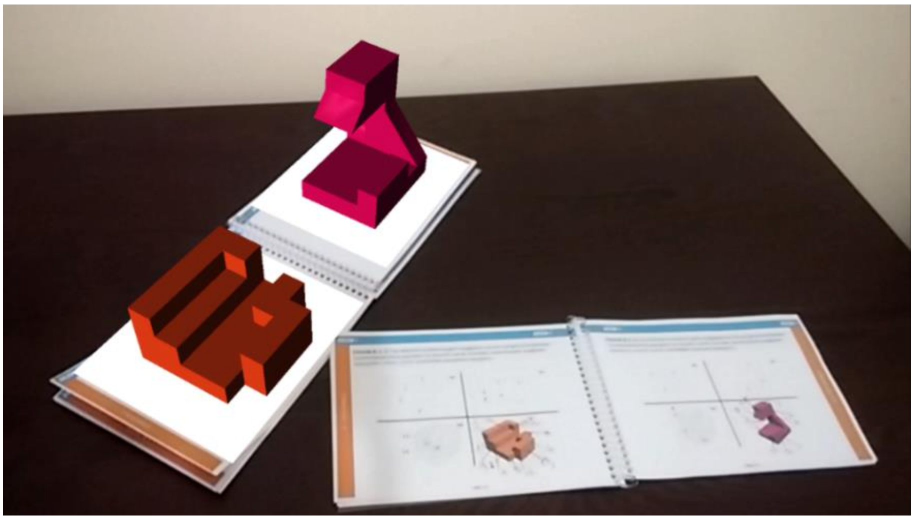


Figure 4.40. Numbered surfaces on orthographic views

The last task type included tasks about identifying vertices of virtual objects and transferring information about these vertices from virtual three dimensional objects to both perspective view and orthographic views from top, front and left sides. In order to make students clearly identify these vertices, they were numbered. That is, virtual three dimensional objects were developed to have numbers on some of their vertices. In addition, the booklet of spatial tasks involves orthographic views and perspective views of the virtual objects to mark these numbers of specific vertices. Therefore, students were asked to identify numbered vertices of a virtual three dimensional object on both orthographic and perspective views of it (Figure 4.41).

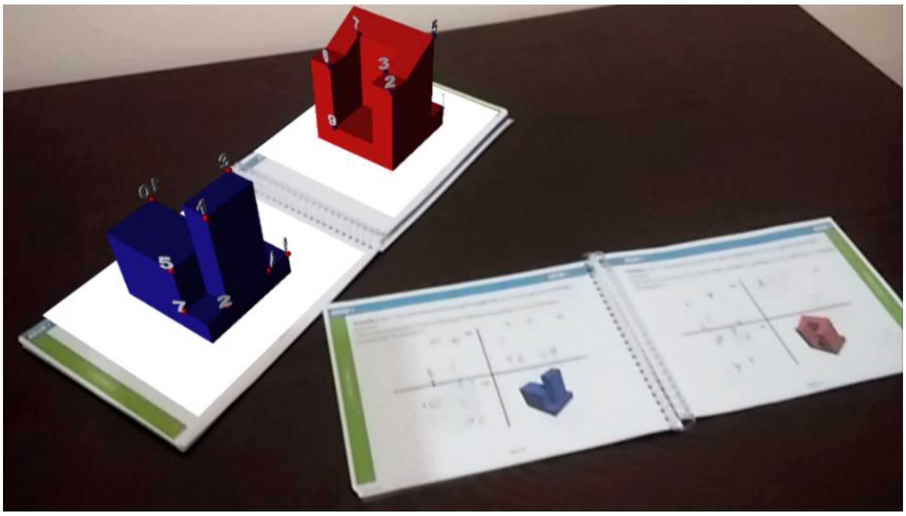


Figure 4.41. Numbered vertices on virtual three dimensional objects

The virtual three dimensional objects in this level were consisted of objects that have flat, inclined or cylindrical surfaces and hidden numbered surfaces or vertices from one point of view to make tasks more challenging for students. Moreover, some hints about tasks were presented on an introductory page with three sample tasks. As stated before, this level was thought as an entrance level for the final MISAR since the findings showed that these tasks were helpful to adapt usage of the mobile AR interface. Because the spatial tasks in this level required students to look and examine virtual objects from different directions in order to identify surfaces & vertices, they understood logic of AR technology unconsciously.

ii. Counting

This level was reordered as second level of the MISAR. One type of task was regarded while designing spatial tasks which was about counting components in touch (Perez-Carrion & Serrano-Cardona, 1998; Wiesen, 2015). According to the findings of the first iteration, it was revealed that spatial contents about these tasks required similar spatial works to accomplish tasks such as exploring objects from every possible angle of view. Therefore, it was conjectured that these tasks could also help students to adapt the AR interface similar to the previous level. Therefore, spatial tasks should be followed by tasks about counting components of virtual objects in order to eliminate novelty effects of an ARLE. These counting tasks are recommended to include spatial content about counting specific components with their relation to others, i.e. in touch with others.

These components were thought as rectangular prism bricks and virtual objects were designed as composing of these bricks in the mobile AR interface. Some of these bricks were titled in order to distinguish and specify them. In addition, the booklet of spatial tasks was designed to involve perspective projections of these virtual objects without any letter on bricks and a table to write the number of bricks which are in touch with titled bricks. Students' were asked to specify location of count and write on table how many bricks touch specified parts of an object which are named bricks (Figure 4.42).

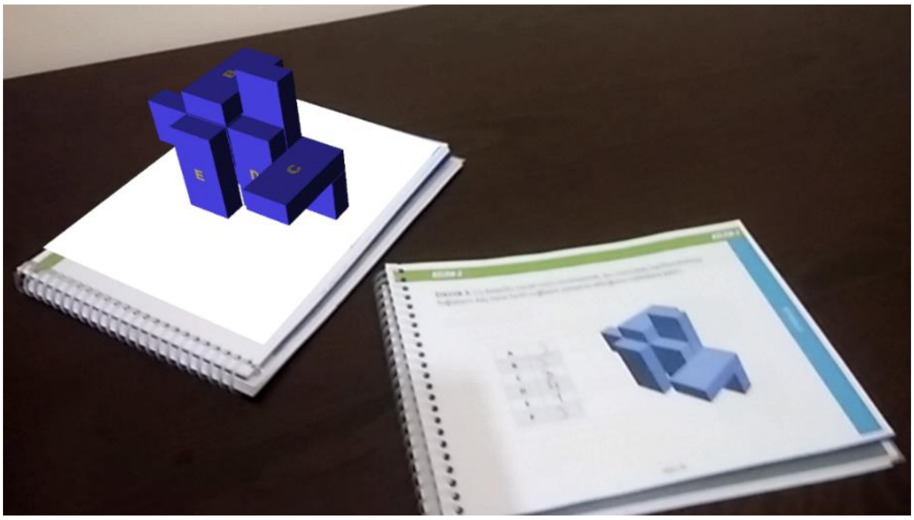


Figure 4.42. Counting components of a virtual objects in touch with others

In this level, virtual three dimensional objects had titled bricks for every directions including back and right ones. Moreover, some of these bricks or components touched them hidden and were discoverable only in some point of views in order make these tasks more challenging for students. By the way, some hints about students' works in tasks were presented on an introductory page for this level with one sample task.

As mentioned before, this level required student to explore virtual objects in every angle of views. Therefore, similar to the former level, this level was also helpful to make students get used to the AR interface. In fact, findings showed that students worked without any difficulty as that working with a common learning tool like with a kind of concrete material. According to Perez-Carrion and Serrano-Cardona (1998) and findings of this study, this type of spatial content could make students recognize spatial relationships within virtual objects.

iii. Matching Correct Views

This level included spatial tasks about matching side views of virtual objects and it was decided as third level of the MISAR. Spatial contents for this characteristic were revised in accordance with seventh grade curriculum and providing more challenging tasks, in the preliminary research phase such as including unit-cubes in tasks. Two types of tasks were considered as designing spatial tasks. According to findings of the study, these spatial task types could be

- matching side views from organized lists of views with categories of top, front and left
- matching side views from disorganized list of mixed views.

Therefore, each task was designed to involve multiple virtual three dimensional objects. Moreover, in every scene of the mobile AR interface, touch or pointer interactivity was programmed by C# scripts. The reason of this interactivity was to provide students not only to view multiple objects together but also to focus each one separately (Figure 4.43).

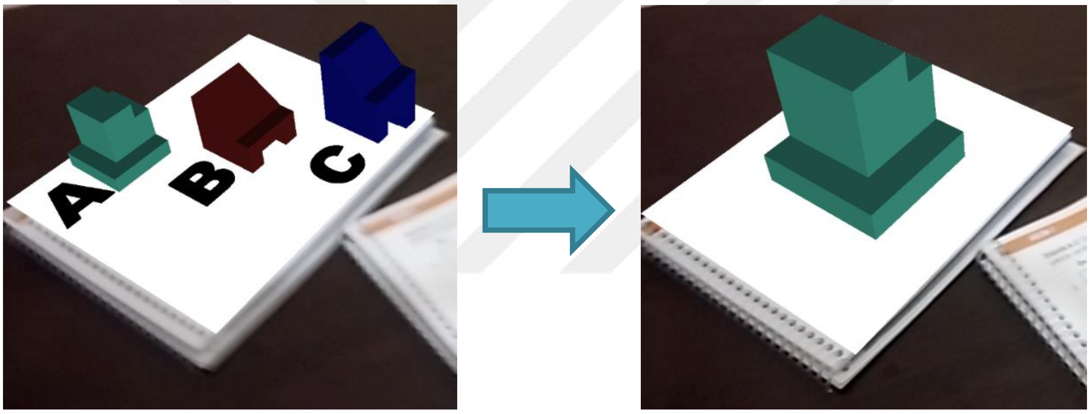


Figure 4.43. Touch or pointer interactivity to enlarge and focus objects

The first task type included spatial tasks about matching side views from organized lists which consist of side views of multiple virtual three dimensional objects within categories of three directions such as top, front and left sides. Therefore, the booklet of spatial tasks was designed to involve these orthographic views from three sides of these virtual objects in categories as top, front and left, and a table to match these side views with virtual objects. Within these tasks, students discriminated and matched correct side views from an organized list of top, front and left views of a virtual object among many.

The second task type included spatial tasks about matching side views from mixed and disorganized lists of views. These side views were again view from three directions as top, front and left sides. Students’ tasks were similar for these two task types. The only difference was that first one presented side views in categories of top, front and left views but the second one did not.

The multiple virtual three dimensional objects were developed as formed from both with unit-cubes (Figure 4.44) and complex shapes (Figure 4.45). Moreover, these virtual objects were presented at the tasks in order of complexity in order make spatial tasks more challenging to students.

Figure 4.44. Virtual objects composed of unit-cubes

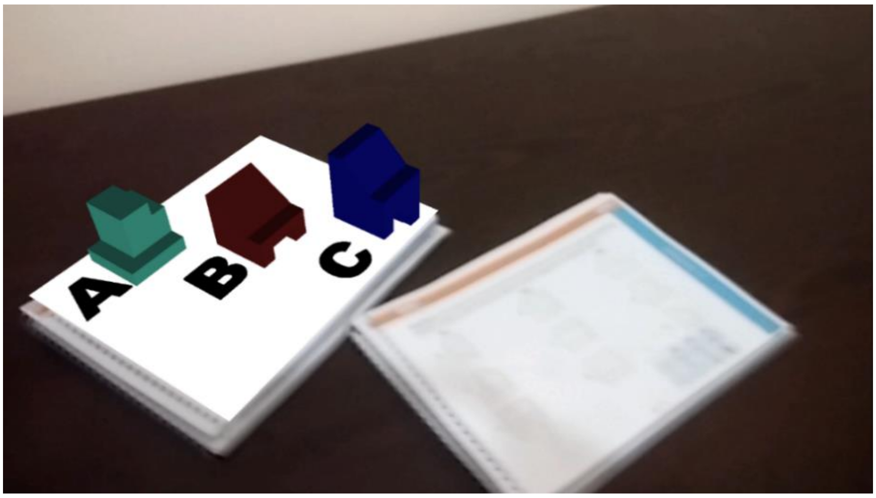


Figure 4.45. Virtual objects composed of complex shapes

Some hints about their works in tasks were presented on an introductory page for level with two sample tasks. This third level of the MISAR gave students opportunities to understand two dimensional representations of three dimensional objects so as to value of spatial relationship between objects and relationship between two dimensional spatial information and three dimensional one. In fact, this was a kind of needed spatial ability in order to understand and sketch representations of objects at the following tasks.

According to findings, these spatial tasks were found relevant, consistent and practical to be carry out by seventh graders in an ARLE. Moreover, in the micro-evaluation study, it was observed that students could relate two dimensional spatial information with three dimensional one throughout the tasks. Therefore, spatial tasks should include matching correct and incorrect side views in order to make spatial relations recognizable by students. These tasks are recommended to include spatial contents about matching side views from organized lists and disorganized lists.

iv. The Second Dimension – Sketches

This level was the last level of the MISAR and included spatial contents about sketching different side views of virtual objects. Similar to the former level, spatial contents of this level were also modified in the preliminary research phase as including unit-cubes. According to Perez-Carrion and Serrano-Cardona (1998), and findings of this study, task types for this level could include tasks about

- sketching missing side view,
- sketching side views from three directions.

Therefore, this last part includes two different task types. The first task type included students' works about sketching missing orthographic view of a virtual three dimensional object. Two of three side views of an object were given in task and other remaining one was asked to students. Therefore, the booklet of spatial tasks was designed to involve side views from two sides and plotting paper area to sketch missing one. The second task type was about sketching side views from all three directions as top, front and left sides. In this time, students were asked to sketch all side views from three direction as top, front and left side of a virtual three dimensional objects. Therefore, the booklet of spatial tasks included only a plotting area for this subpart.

Similar to the previous level of spatial tasks, virtual three dimensional objects were developed as formed from both with unit-cubes (Figure 4.46) and complex shapes (Figure 4.47). Moreover, these virtual objects were presented at the tasks in order of complexity to make spatial tasks more challenging for students.

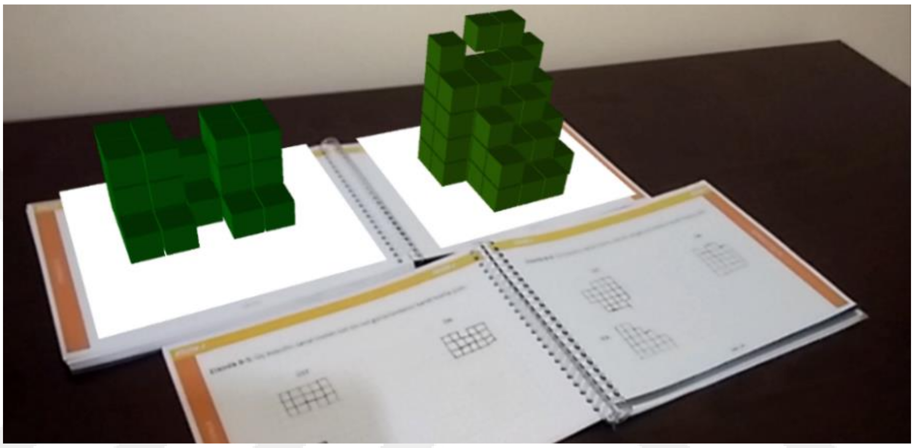


Figure 4.46. Sketching orthographic views of virtual three dimensional objects constituted of unit-cubes

Figure 4.47. Sketching orthographic views of virtual three dimensional objects constituted of complex shapes

Some hints about students' works in tasks were presented on an introductory page. However, sample spatial task was not designed for this level since this level was higher level of the MISAR and one aim of this level was providing a way to evaluate students' spatial ability at the end of the series of tasks as well as a way to improve it. In addition, spatial tasks about the first task type included demonstrations of sketches in such ways by providing sketches of side views from two directions and ask to sketch only missing one. Thus, this first task type could serve as a sample task for the following sketching tasks.

According to the findings, seventh graders could transfer spatial information between three dimensional and two dimensional objects while challenging with spatial tasks about these spatial contents since they completed all tasks. Therefore, spatial tasks should include sketching activities for students in order to provide them opportunities to make use of their spatial ability as well as spatial relations within virtual objects. These tasks are recommended to include spatial contents about sketching missing side view and all side views from different directions, i.e. from front, side and top.

To sum up, these spatial contents and revisions regarded to findings had been used to shape the final MISAR, and the spatial tasks in this study were designed according to the MISAR.

4.4. Summary of Findings

This study had two aims. These were to guide and improve the design of SPATIAL-AR toolkit which supports improvement in spatial ability of learners, and to find out possible contributions of intervention to seventh grade students with this SPATIAL-AR toolkit in terms of spatial ability and to learning environment. Moreover, the design principles and design artefact of this study were explained in terms of a MISAR to provide a way to put theory into practice.

First of all, the design and development processes were covered in both the preliminary research phase and the prototyping phase. In the preliminary research phase, some initial draft design principles for ARLE, key elements of a mobile AR interface and some spatial contents for draft MISAR were gathered from related literature. The collection of characteristics for these draft principles served as a framework to design and develop an AR toolkit to foster spatial ability of middle school students in an ARLE, especially seventh graders. According to this framework, spatial tasks, which can be applied in a learning environment based on AR technology, proceed with identifying components, counting components, understanding views from different sides and sketching different views of a virtual three dimensional object. These spatial contents helped to improve spatial ability of seventh graders.

The findings of the focus group study have pointed out needed revisions about design of booklets which were not be thought at the beginning of the study. Because, it was seen that multiple booklets could be designed to provide optimal portability since students might require to explore virtual objects from all available viewpoints effectively. Therefore, a need for some design principles for booklets was arisen. While designing and printing other following prototypes of the booklets, these design principles for booklets were considered. In accordance with the findings throughout the prototyping phase these characteristics and descriptions of them had been reshaped formatively until the prototype of SPATIAL-AR toolkit became a completed product for effective learning.

At the last iteration of prototyping phase, this completed product of SPATIAL-AR toolkit was implemented within the micro-evaluation study in order to reveal its possible contribution for fostering spatial ability and learning environment. The usage of the SPATIAL-AR toolkit in an ARLE provided gains in spatial ability for seventh graders since they could find and use suitable strategies in order to accomplish duties in the spatial tasks. Moreover, findings about students' works and answers on spatial tasks booklets indicated that all students completed the tasks correctly. Furthermore, it was seen that, in general, the SPATIAL-AR toolkit helped students with some opportunities for working with spatial tasks in an ARLE. Findings about collaboration to learning environment have been also verified that this design of SPATIAL-AR toolkit could enhance learning environment with interactions with virtual objects and each other as well as finding a common implementation way for different types of devices such as tablet and smart glasses since students used similar strategies and accomplished tasks without noticing which device based group they were from.

Lastly, the findings of the iterations have led to form the final MISAR. First of all, the initial version of the spatial contents were given in literature as in a consecutive order and also considered in a consecutive order with some modifications like reordering them for the four-parted MISAR in this study. Therefore, the final MISAR consists of four sequential levels. The first two levels aimed to make students adapt and understand the AR technology by performing spatial tasks. Moreover, these two levels also aimed to make students think about some spatial strategies and perform them into tasks. The last two levels of the MISAR could be also named as analysis and synthesis levels since the spatial tasks of these levels required to understand spatial relationships between multiple objects, analyze relationships between two dimensional spatial information with three dimensional one, and synthesis spatial information for two dimensional and three dimensional relations. Thus, these two levels could also provide opportunity for understanding students' spatial ability. Furthermore, students used some strategies to accomplish spatial tasks throughout the intervention. Therefore, the spatial tasks, in the same line with the MISAR, could also provide some opportunities for students to find and use relevant spatial strategies for spatial tasks.

To conclude, the characteristics of design principles and spatial contents were correlated with each other within the SPATIAL-AR toolkit. Hence, this toolkit was designed and developed from syntheses of them. Students perceived the SPATIAL-AR toolkit as practical and easy to carry out because background of the MISAR so on the SPATIAL-AR toolkit came from both theory with literature and practice with different participants of mathematics educators and seventh graders.

CHAPTER FIVE

DISCUSSION, IMPLICATIONS AND SUGGESTIONS

This study generally aimed to find out factors to be considered in order to design and develop a spatial augmented reality (SPATIAL-AR) toolkit, which includes set of spatial tasks and a mobile augmented reality (AR) interface, in order to foster spatial understanding of seventh grade students in an augmented reality learning environment (ARLE). In the previous chapter, findings were summarized with textual and pictorial examples from different data sources and these lead to form the final shape of design principles, a model for improving spatial ability in AR environment (MISAR) and the SPATIAL-AR toolkit and to reveal possible contributions of SPATIAL-AR toolkit in an ARLE. Hence, this chapter provides an insight for implementation of spatial tasks in the ARLE and suggests implications for educational practices and future research.

5.1. Discussion of Findings

In this section, findings of the whole study were discussed under three main parts in accordance with characteristics of designed environment to improve spatial ability with AR learning tools, possible contributions of this environment for spatial ability and possible contributions for learning environment.

5.1.1. Characteristics of Augmented Reality Learning Environment for Fostering Spatial Ability

The findings of the whole study provided substantive knowledge as well as procedural knowledge for designing an intervention for fostering spatial ability in an ARLE. The preliminary research phase guided design and development of essential learning material prototypes with related characteristics in the draft design principles. These characteristics formed a framework to design and develop a mobile AR interface and set of spatial tasks in a student's booklet, which constituted a SPATIAL-AR toolkit, in order to provide an ARLE for fostering spatial ability. In the preliminary research phase, it was revealed that AR based spatial tasks can be more efficient for students with opportunities for interactions with virtual objects and each other in learning environment (Kaufmann, 2003; Matcha & Rambli, 2011; Szalavari, et al., 1998). Therefore, this framework guided some needed characteristics for ARLE.

In the preliminary research phase, the derived characteristics could be explained as follows. First of all, in order to accomplish an ARLE students should be active learners and they should engage in challenging and gamified tasks, which require no special training of students, include suitable three dimensional object for current situation of students, give real time feedbacks about progresses of students, support interactions with virtual objects and talking about these objects (Billinghurst & Dünser, 2012; Billinghurst & Kato, 2002; Dunleavy, 2014; Lahlou, 2009; Smith & MacGregor, 1992; Vygotsky, 1978; Wu et al., 2013). Moreover, this framework shed light to key features for a mobile AR interface in order to provide these opportunities in an ARLE. According to Szalavari and others (1998), an AR interface should provide virtuality on real environment by augmenting this environment. In addition, users should interact independently with the same environment at the same time via sharing visual output of the same object but from their own view points with an interactive user interface. Furthermore, a draft MISAR was shaped as consisting five levels in order to provide spatial contents for tasks in the ARLE. Detailed descriptions of these characteristics were provided in Chapter 2 and Chapter 4. These characteristics were provided from related literature, and these characteristics were regarded as starting point in order to design and develop an AR based learning tool. Thus, these suggestions were collected from the literature to guide this study and to form initial draft design principles and draft MISAR. The design of first prototype was based on these characteristics, and the predetermined draft design principles as well as this first prototype were revised formatively throughout this educational design research.

After cycles of iterations to design, formatively evaluation and revision for prototypes of the SPATIAL-AR toolkit throughout the study were handled based on their relevancy for intended mathematics curriculum, consistency within design, practicality for usage of students and effectiveness in learning gain. This study leads final set of design principles and the MISAR. The spatial tasks so that the final MISAR were found as possible as relevant to seventh grade mathematics curriculum. Moreover, prototypes for intervention have reached consistency in terms of design at the final iteration. The final prototype of SPATIAL-AR toolkit for intervention, which was designed and developed to improve spatial ability, has been verified its practicality and usability with seventh graders in an ARLE through the following characteristics of design.

First of all, in the light of the results, the ARLE provides students opportunities for multi-user interactions through natural way of interactions with virtual objects, observing multiple and single virtual objects by comparing them or separately examining one of them, and explaining their findings by talking each other or describing a virtual object by pointing and using their own terminology. These provided opportunities are in the same line with features of learning environment supported face-to-face interactions (Lai, 2011) as well as contributions of AR technology to learning environments (Matcha & Rambli, 2011). Moreover, students engage in an active process of learning with challenging tasks and choosing their own point of view to examine virtual objects in the ARLE with the SPATIAL-AR toolkit as stated by Szalavari and others (1998), and Smith and MacGregor (1992). In the meantime, the mobile AR interface provides some important elements to help teachers to enhance collaborative works with students in learning environment. For example, teacher can choose and administer extra tasks for students if they need or can help students to understand their duties on tasks by demonstrating sample tasks or giving extra information by collaborating their tasks with his/her own device. Thus, according to Smith and MacGregor (1992), teachers become designers of intellectual learning experiences for students and gain a role of mediating the learning environment.

The SPATIAL-AR toolkit was designed and developed to meet these discussed features by providing needed elements of spatial tasks via an AR interface. Therefore, the SPATIAL-AR toolkit was formed with a mobile AR interface which holds required virtual elements and codebase of AR, booklets which hold necessary target images and worksheets, and spatial tasks which connect virtual elements of AR interface and worksheets of booklets. Hence, we need to understand characteristics of this designed mobile AR interface and spatial tasks in order to comprehend the SPATIAL-AR toolkit and so characteristics of the ARLE.

The key characteristics for a mobile AR interface were defined as virtuality for objects and augmentation of environment. These are musts or in a different term "*sine qua non*" for all AR interfaces, since these characteristics differentiate the AR environments from VR environments. Moreover, according to findings of the iterations, four new characteristics were added and validated for the list of design principles for key elements of a mobile AR interface exclusively for improving spatial ability of middle school students. One of these characteristics is "recognition and projection" which refers high discrimination in target images as recognizable target images and objects locations about relocating all virtual objects on little higher position above base layer to use AR interface without recognition issues. Others are about providing "reference information" to support teachers with AR based just-in-time information feedbacks or students with clues for tasks, "interactivity" feature to support sharing and comparing characteristic of the ARLE, and "unity in design" to hold AR interface in line with multiple parts of spatial tasks. As is seen, while some of these characteristics could directly support the ARLE, others could support indirectly just providing a bug-free and stable AR interface for implementing intervention and provide an ARLE. These characteristics are in line with statements of Azuma (1997), Kaufmann (2004), Hedley (2003), Shelton (2003), and Szalavari and others (1998). In their statements, the main purpose of AR is stated as to enhance reality with virtuality and to provide users to experience virtual elements as if they exist in this real environment.

In this study, a target-based AR system was employed in order to provide more natural learning environment for students and to enhance natural way of interaction by supplementing student's books not completely replaced them with technology. Since students can interact with AR interface just the way that they interact with a standard textbook by flipping pages, moving book, and others. This construct was also stated in studies of Hedley (2003) and Shelton (2003) as "fly into" three dimensional spaces with virtual elements, and "walking through" around virtual elements in study of Kaufmann (2003). This target-based AR interface requires some kind of booklet or pages to provide target images and if necessary worksheets of tasks to students since the AR interface requires some kinds of images as target in order project correct virtual object on a correct location. In this study, it was seen that, multiple booklets designed with A5 size pages could provide more comfortable learning environment to students for both for tablets and smart glasses. Because, design multiple booklets separately in terms of target images and tasks could enhance portability of them so on it provides opportunities of active learning for students (Sugimoto et al., 2003) because students made physical interactions moving, holding or turning around the booklets. Findings of this study guide this design of the booklets with some characteristics. According to these findings, these characteristics could provide visual cues for identification of task types, present some introductory pages as well as samples for tasks, and support consistency of design and page numbering among booklets. Therefore, students could discriminate and determine related task and its target image by only visual information without any distraction.

Lastly, another important aspect for characteristics of the ARLE is providing suitable and challenging tasks for spatial ability. Spatial contents suitable for implementing AR were dug from related research in the preliminary research phase (Martin-Gutierrez et al., 2010; Perez-Carrion & Serrano-Cardona, 1998; Sack, 2013; Sack & van Niekerk, 2009; Sack & Vazquez, 2013; Wiesen, 2015). These spatial contents constitute a base for the MISAR. The MISAR for seventh graders was formed within four levels. In fact, this model had been formed as five levels at the preliminary research phase, but third level of the draft MISAR, nets, was not found related with seventh grade mathematics curriculum of Turkey. The first two levels of the MISAR might be summarized as spatial tasks about investigating virtual objects from every possible angles of view. These tasks help adaptation process of students if they meet the AR technology at the first time as well as provide students an intuition about how orthographic and perspective representations could be related to a three dimensional object since they have to relate two dimensional representations with three dimensional objects in order to complete tasks in these parts. As stated before, these tasks could also be helpful to adapt logic of the AR because these tasks force students to examine a virtual object from different directions. Therefore, students have some experiences with these works within an ARLE. The remaining two levels of the MISAR, which are about matching and sketching activities, support students spatial understanding by providing opportunities to analyze spatial relationships between two dimensional representations with three dimensional objects and to relate the two dimensional spatial information with three dimensional one as well as to synthesize two dimensional information from three dimensional one. Therefore, students' works in these spatial tasks for the sketches part as well as the others constitute a way to evaluate current spatial ability level of students since the MISAR provides a way to improve spatial ability as well as gives information about current spatial ability of learners. In fact, as Dünser and others (2006) stated, traditional paper-pencil based spatial ability tests could not measure all aspects of spatial ability that are used while working in AR environment. Thus, AR tools could provide opportunities to assert and measure spatial ability of learners, directly in AR space as well as to train their spatial ability. Therefore, spatial tasks regarding MISAR could also provide a way to understand students' spatial understanding within tasks.

To sum up, the literature guided this study by showing possible ways to design and develop an AR learning toolkit to foster spatial ability by providing multi-user interactions in learning environment. These ways shed light to initial draft design of prototype of SPATIAL-AR. This design has been strengthened through educational design research methodologies in cycles of iterations to assert relevancy of prototype with curriculum and purpose, consistency within design, practicality for implementing prototype with target group and effectiveness of final completed product on target group. These processes of iterations have been employed with various participants as mathematics education experts and representativeness of target group. Throughout the preliminary research phase, the design principles derived from the literature were determined in accordance with their relation and harmony with each other.

Additionally, since this study was conducted to foster students' spatial ability, it was needed to design spatial tasks as well. The relation and interconnection between them have gained strength throughout the educational design research with findings from both experts and target students. The final and completed prototype of SPATIAL-AR arose from the interrelation between the characteristics of the design principles and the MISAR, as relevant, consistent and practical as possible through theory and practice with different groups. These characteristics were not meant to specify precise descriptions for designing and developing a mobile AR interface for fostering spatial ability in an ARLE. Instead of this, they are meant to show a way to use of a mobile AR interface to provide learning opportunities for improving spatial ability to help teachers for implementing this type of learning opportunities in their classroom. However, none of these iterations was conducted in a target settings for the target students as a regular classroom. Therefore, possible contributions of this design was explained according to findings for current design for this study, rather than actual effectiveness. The following sections discuss findings related to expected effectiveness of this design to spatial ability and possible contributions learning environment.

5.1.2. The Possible Contribution of the Intervention on Spatial Ability

The possible contributions of the final SPATIAL-AR toolkit in an ARLE on spatial ability of seventh graders was asserted by focusing on the use of it with representative sample of the target group. Since these results were not obtained through a field study with target group in target settings, some expectations for effectiveness of SPATIAL-AR toolkit in the ARLE were discussed from findings from students' works, observations, interviews and spatial ability test (SAT) in the final iteration of the study. Therefore, the possible contributions of the SPATIAL-AR toolkit has been demonstrated in various ways related to adaptation on AR and tasks, emerged spatial strategies, spatial gains measured via the post administration of SAT or interpreted via their envisions in this administration of the SAT.

Overall, this research was conducted with two different devices which were tablets and smart glasses in order to understand device specific effects of the SPATIAL-AR toolkit. However, in terms of spatial ability, any different or specific feature based on device was not encountered or observed. The SPATIAL-AR toolkit worked well on these devices and students did not assert any negative or positive feedback in terms of used device. In case of learning opportunities, however, devices made some differences for learning opportunities of environment. Discussion for these differences were presented in the following section. At last, it could be stated that using SPATIAL-AR toolkit with mobile AR systems either tablets or smart glasses do not make specific differences for spatial gains in accordance with the results of this study.

The results of the prototyping phase showed that the mathematics education experts and students had not encountered any difficulty to use the SPATIAL-AR toolkit as a learning tool. They could manage to comprehend its usage even if this was the first time that they met AR technology. The results showed that the first and second levels of the MISAR helped this adaptation process of students to this new type of technology. As stated above section, these levels include spatial contents which require to examine inspected virtual objects from all possible angle of views. Since students were forced to use actively the mobile AR interface to examine virtual objects they started to be familiar with usage of this AR technology. This is a remarkable result because the AR is relatively a new technology yet, especially for learning environments. This study showed that students get easily adapt to use the mobile AR interface like using a common tool for them, even if they are using the AR at the first time. This result is in line with arguments of Dunleavy, Dede and Mitchell (2009) about that the novelty of AR interface used as a supplement to learning environment could not remain after the participants became accustomed to this learning environment.

Another aspect of grouping students was performed in accordance with their spatial ability levels. In literature, there are two opposite hypotheses about improving spatial ability via technological tools. These hypotheses are ability-as-compensator (Hays, 1996; Mayer & Sims, 1994) and ability-as-enhancer (Mayer & Sims, 1994). The ability-as-compensator hypothesis states that learners with low spatial ability levels would have more profit virtual representation via technological tools (Hays, 1996; Mayer & Sims, 1994). On the other hand, the ability-as-enhancer hypothesis suggests that in fact, learners with high spatial ability levels would have more benefit from virtual representations via technological tools (Mayer & Sims, 1994). Due to these different and opposite views about using technology as a tool for spatial ability, the results were also discussed in terms of expected situations for these hypotheses. First of all, the students were grouped into tablet or smart glasses based ARLE regarding their preliminary spatial ability levels which were assessed by the SAT in order to form groups which included students with high, average or low spatial ability. According to results, in general, students accomplished all spatial tasks and any issue was not found in terms of their interpreted spatial ability for tasks. The SPATIAL-AR toolkit seemed equally treated students without resulting different outcomes in terms of their spatial ability levels. While students were working with spatial tasks, if they confused, a previously used strategy could be reminded and proposed them. Hence, they could proceed tasks with collaboration between teacher and students within this current design.

Furthermore, according to findings of this research, students used some spatial strategies during spatial tasks with the SPATIAL-AR toolkit. Firstly, two spatial strategies while working spatial tasks of the surface and vertices level were used by students as “specifying a reference” and “following a path” strategies. Similarly, within the tasks of counting level, students used again “specifying a reference” strategy with addition of “counting components” strategy according to findings of this research. During spatial tasks about matching side views, students used two strategies as the “counting components” strategy and the “specifying a reference” strategy, according results of this research, similar to the previous levels. However, types of virtual objects affected their choices for strategies. For example, students used the “counting components” strategy with virtual objects composed of unit-cubes and the “specifying a reference” strategy with virtual objects composed of complex shapes. Lastly, students used similar strategies again for the last, sketches, level with addition of modified version of them in terms of the virtual objects' types. For example, students used "counting components" strategy for sketching virtual objects composed of unit-cubes, "estimating components" strategy for virtual objects composed of complex shapes, "following a path" strategy for both type of virtual objects, and "drawing overviews or frames" strategy for again both type of virtual objects.

These strategies could be classified in holistic and analytic strategies continuum since the spatial strategies were used with and without spatial relations in these tasks (Glück & Fitting, 2003). First of all, "specifying a reference" strategy refers to finding some notable surface or vertices with regard to spatial contents. This strategy resembles "key feature comparing strategy" in the literature since students tried to find out spatial relations of surface, vertices and components of virtual objects by comparing them with some specified reference objects (Burin et al., 2000; Kayhan, 2012). For example, in this research, students had chosen a reference surface or vertex in the first level of the MISAR, and a reference component for the second level of the MISAR as a beginning point and describes other components based on this reference by using phrases of directions. Moreover, in the matching tasks, they used some inclined or ladder type objects to determine their side views. Approaches for this strategy changed over holistic – analytic continuum. For example, although they approached identifying surfaces tasks analytically without spatial relations, they approached identifying vertices, counting components and matching tasks either intermediate or holistically. They formed spatial relations between parts or components of virtual objects from these comparisons for key features in order to complete tasks. In other words, their approaches for tasks changed in accordance with the characteristics of tasks (Glück & Fitting, 2003; Hsi et al., 1997).

Secondly, "following a path" strategy refers to again finding some notable components and this time following a path from these components to others. This strategy is similar to "following a route without spatial relations strategy" in the literature since students followed a route to locate other vertices of virtual objects in the first level of the MISAR and to sketch side views of virtual objects in the last level of the MISAR (Glück & Fitting, 2003). For example, in the first level, students had started a vertex which at corners or near to them, and followed a path of outer to inner or a spiral path beginning to end systemically and without mentioning any spatial relations. Another example is that students followed a path to sketch side views as moving along objects step-by-step. Therefore, they just followed some routes around objects without using spatial relations between or within objects, hence, this strategy was analytical (Glück & Fitting, 2003).

Another strategy was “counting components” or “estimating components” strategy. This strategy refers to simply counting parts or estimating size of or distance between components of virtual objects. This strategy covers its derivatives in holistic – analytic approaches continuum claimed by Glück and Fitting (2003) and Hsi and others (1997). In other words, this strategy consists of counting as whole, counting as partial and counting systematically (Glück & Fitting, 2003; Hsi et al., 1997; Kayhan, 2012; Workman & Lee, 2004). The counting or estimating strategy was used in last three levels of the MISAR for counting components, matching and sketching tasks. In the counting part, students generally used the counting strategy with “specifying a reference” strategy in a harmony, for example, they used another titled bricks as reference to count components in touch with a titled brick. Therefore, they could realize some spatial relations within objects and used these partial spatial relations to solve these tasks. Hence, the counting strategy was used for this level as “counting as partial strategy” (Hsi et al., 1997). In the matching side views level, students just counted unit-cubes in objects and selected correct views based on these counts. Hence, it can be stated that the counting strategy was used as analytic strategy so that it included step-by-step counting (Glück & Fitting, 2003; Hsi et al., 1997; Kayhan, 2012). In the sketches tasks, students counted unit-cubes in objects in order to sketch their views. Moreover, students used a modified strategy to the counting strategy in this part. They estimated dimensions of components in virtual objects composed of complex shapes. They sketched the side views by representing the unit-cubes as a whole or estimating components since they recognized dimensions of these cubes or components and transferred three dimensional spatial relations into two dimensional sketches correctly (Hsi et al., 1997). As is seen, the usage of counting or estimating strategy was affected by the characteristics of the tasks and flowed along the holistic – analytic approaches continuum. This deduction was also stated by other researchers that task characteristics affect choosing spatial strategies (Glück & Fitting, 2003; Hsi, et al., 1997; Kayhan, 2012).

The last strategy was "drawing overviews or frames". This strategy could be explained with the combination of the "counting as whole" and "following a route with or without spatial relations" (Glück & Fitting, 2003; Hsi et al., 1997; Workman & Lee, 2004). Because, students firstly followed a virtual route around objects to sketch a rough outline of a side and they determined exclusion areas to remove this rough outline then they elaborated components of virtual objects. Hence, they used more than one strategy to complete their sketches by considering spatial relations within object. Therefore, this strategy was placed on holistic approaches of the continuum.

From these results about using similar strategies for other levels as well as modified versions of them according to circumstances, this final level of the MISAR provides students an opportunity to synthesize three dimensional spatial information with two dimensional one. Therefore, according to these findings, it could be said that students could transfer their spatial knowledge for two dimensional objects to three dimensional objects so on they could realize spatial relationships within objects. These results could be considered as an indicator for using of spatial ability of seventh graders, since they found and used suitable strategies for tasks and they could also manage to alter their previously used strategies onto different situations. In other words, they could use their experiences and spatial ability for identifying parts, counting components, matching and sketching side views of three dimensional objects repeatedly. They could transform their previous learning or for this tasks, previous strategies to new situations (Khoza & Workman, 2009; Strong & Smith, 2002).

Lastly, their spatial ability gain could also be supported with the results about the SAT administration which was specially designed for this research in order to provide an assessment tool for intervention with the MISAR. Difference in students' scores on pre and post administration of the SAT were analyzed with a Wilcoxon signed-rank test. The result of this test has demonstrated that their scores were on a rise which signify their gain in spatial ability. This result was also in the same line with studies about trainability of spatial ability with AR technology and spatial tasks (Dünser et al., 2006; Kaufmann, 2004; Kaufmann & Schmalstieg, 2003; Martin-Gutierrez et al., 2010; Shelton, 2003). Moreover, in the retrospective interview, students were asked to talk about their way of thinking before and after using the SPATIAL-AR toolkit while they were solving questions of the SAT on pre and post administration. Generally, they expressed about what emerged in their mind that they envisioned about what it means looking from different directions to a three dimensional object, how an object seems from different sides, and how two dimensional representations stands for actual three dimensional objects. As seen on these findings, they could transfer their experiences with the SPATIAL-AR toolkit onto paper and pencil environment. They expressed and used their spatial ability and spatial experiences in this toolkit for answering a multiple choice test via using only two dimensional orthographic and perspective representational modes on paper test. This result is consistent with statements of Khoza and Workman (2009) that spatial ability is combination of spatial experiences of students in training, choices for strategies and using these strategies. Therefore, according to results of the Wilcoxon signed-rank test and the interview's logs for the SAT, the SPATIAL-AR toolkit gave students opportunities for improving their spatial ability and used their spatial ability in a learning environment with set of tasks as well as transfer their experiences and learning to a paper and pencil environment.

5.1.3. The Possible Contributions of the Intervention on Learning Opportunities

With the designed SPATIAL-AR toolkit, students were free to move in environment in order to inspect virtual objects from every point of views, and this feature of this ARLE requires students to be active participants not a passive observer. Therefore, they can walk around virtual objects or tilt and move qr-codes booklets like they exist in real environment (Kaufmann, 2003). These natural way of interactions and independence of point of view make students talk and explain their point of views to each other since in this ARLE everyone has an independent point of view for virtual objects (Matcha & Rambli, 2011). Therefore, students could be active participants in order to observe virtual objects from different directions. Moreover, all needed information about tasks were given in booklets and the mobile AR interface, so teachers could be supported with this information if any need occurred.

Overall, according to the results of the study, the tablet and smart glasses based ARLE made some differences for learning opportunities in terms of natural way of interaction and sharing. The results revealed that students in tablet based groups worked with the SPATIAL-AR toolkit by walking around virtual objects and physically standing when they examined others sides of the virtual objects like back, top and others. In case of smart glasses based ARLE, students generally sit on their chair and tilted, moved or turned the target images' booklets when they need to examine virtual objects from different directions. It was also asserted that these students in smart glasses based groups did not feel a need for standing and walking through virtual objects since their hands were empty. Moreover, results showed that although students in tablet based groups could share and describe their viewpoints just pointing screen of their tablets, students in smart glasses based group could not have such opportunity. Results revealed that these students defined their points of views to peers by describing verbally like describing an address with phrases of above, below, and others. This situation was consistent among low, average and high spatial ability levels. Therefore, it can be asserted that students using smart glasses for spatial tasks could use neither partner-centered attributions nor egocentric ones while describing an object as stated by Schober (2009), since students could use object-centered attributions to describe objects if this object is presented virtually and they examine it by smart glasses. Other than these stated differences, the two ARLE seem very alike each other in terms of other possible contributions to learning environment.

According to the results, the possible contributions of the SPATIAL-AR toolkit to learning environment can be summarized into five attributes as combination of the classifications of Davidson (1994), Lejeune (2003), and Szalavari and others (1998). These attributes are naturality, individuality, cooperation, supportiveness and portability.

Naturality refers to providing a learning environment full of with virtual elements as far as mimicking reality. First of all, AR interface supports environment with virtual objects by augmenting real objects as virtuality for objects and augmentation of environment characteristics described by Szalavari and others (1998). These augmented real objects constitute targets for AR interface and should be highly discriminable in order to prevent mingling. Moreover, projection locations of virtual elements could be located relatively higher from these real objects such that students can see both real objects and virtual ones precisely. Since, real objects are superimposed by AR interface and populated with virtual objects, a student can have an opportunity for natural way of interaction as holding, moving, tilting the real object or walking around it (Kaufmann, 2003). Besides, since the virtual elements are presented on real environment, students can see and interact each other as in natural ways (Matcha & Rambli, 2011).

Individuality refers to providing own independent angle of views for all students. Students have their own viewpoints for shared virtual objects in shared virtual space like independence characteristic of Szalavari and others (1998). So, they can control their viewpoint and choose own viewpoint with easiest viewing angle for them in environment, freely. Moreover, they could observe different virtual objects on the same real objects with some kind of interactivity for interface like touching to control and select observed virtual objects. So that, they can observe same virtual objects or different virtual objects in a shared virtual space (Szalavari et al., 1998).

Cooperation refers to providing shared virtuality to everyone. Each students can see other students in environment while working with virtual objects. Moreover, since they are in same real environment, they share same virtual objects. Therefore, they can observe same virtual objects only by looking same target images of other students. If they want to ask questions or want help from other students or teachers, other students or teachers can simply look related target images to observe virtual objects with their mobile devices. Similarly, Szalavari and others (1998) described this attribute in sharing vs. individuality characteristic. Moreover, this attribute refers cooperative behavior feature stated by Davidson (1994) and Lejeune (2003).

Supportiveness refers to providing tasks or contents in accordance with students' level of understandings or skills. Teachers can provide learning tasks and their related virtual objects by presenting to students target images and worksheets. Hence, students can carry out tasks with AR interface by looking these provided target images. Teachers can choose suitable tasks among many and provide students only ones which are suitable for students' understanding level and can challenge them. Moreover, teacher can perform some demonstrations to explain tasks. Therefore, a positive interdependence exists in this environment between both teachers and students, and within groups (Davidson, 1994; Lejeune; 2003).

Portability refers to providing free movement in environment to students. Students can be provided a mobile AR interface and booklets in order to move around target images or move target images in environment, freely. Thus, they can observe virtual objects at easiest ways as they wanted. Hence, portability overcomes some usability problems of AR interface and enhances multi-user interactions as well as offers students more opportunities for active participations (Sugimoto et al., 2004; Zurita et al., 2003). Therefore, a mobile AR interface and portable set of tasks enhance interactions in learning environment by allowing students actively participate in the whole learning process and providing unique opportunities of interactions.

5.2. Implications for Educational Practice

This research was conducted to design and develop a mobile AR toolkit to foster seventh graders spatial ability and enhance their understanding about two dimensional representations of three dimensional objects. The main aims lead to design and develop the SPATIAL-AR toolkit which consists of required AR interface and spatial tasks for fostering spatial ability. The results of this research showed a practical application of the SPATIAL-AR with seventh graders and possible contributions in terms of spatial ability and learning opportunities.

The practicality for this research refers to implementing the SPATIAL-AR toolkit with representative target group students in order to provide them opportunities for fostering spatial ability in an ARLE. Findings showed that the seventh grade students could use the mobile AR interface, fluently, in order to carry out spatial tasks without encountering any significant distraction. In other words, the seventh graders could use the designed mobile AR interface along with specified devices which were tablets and smart glasses, and student's booklets. As a matter of fact, they could study with the SPATIAL-AR toolkit after a while like that they were working with a common and standard learning material familiar to them such as concrete materials. Based on these findings, it could be stated that the SPATIAL-AR toolkit can be implemented to students in mathematics lesson to provide them opportunities for making easy to see and understand spatial relationships between two dimensional representations like orthographic views or perspective view with actual three dimensional object by visualizing it with a mobile AR interface even with common mobile devices like smart phones and tablets, not required a specific smart glasses.

This study was conducted with seventh graders from various spatial ability levels and it was seen that the SPATIAL-AR toolkit excels its designed purpose by providing practical and beneficial learning opportunities to environment for students with low, average and high spatial ability. Hence, the educators can use the SPATIAL-AR toolkit in mathematics lesson to compensate spatial ability differences among students as well as enhance their spatial ability. In fact, it was seen that seventh graders could transfer their experiences with the SPATIAL-AR toolkit onto paper and pencil ability tests. Since, they could visualize three dimensional objects in their mind only seeing their perspective views on papers via their spatial experiences with the toolkit, it could be deduced that students could transfer their previous spatial understanding with this toolkit and enhance their envisions for three dimensional objects by using spatial information form two dimensional representations. Therefore, they eliminate the negative effects of the cognitive filter which is caused from working on three dimensional objects from their two dimensional projections.

Furthermore, the set of spatial tasks of the SPATIAL-AR toolkit provides the essence for spatial contents in the study. These tasks were designed along with the MISAR which comes from methodologies about fostering spatial ability in the literature and constitute a model for spatial ability specifically in an ARLE. The MISAR was formed with four sequential levels. The first two levels help student understand and adapt logic of AR technology with its usage with tasks. Moreover, these levels provide students opportunities to comprehend spatial relationships within and between virtual objects. The other remaining levels which are matching and sketching side views requires students analyze and synthesize three dimensional spatial information to two dimensional one from these spatial relationships. Therefore, teachers could use this model as base for their activities both to provide opportunities for fostering spatial ability and to determine current level of spatial ability of their students. In other words, the MISAR provides opportunities for teachers designing spatial tasks to train spatial ability as well as measure it.

Previous researchers suggested that the AR could improve spatial ability of learners in learning environment via interactions with virtual objects and each other (Kaufmann, 2003; Matcha & Rambli, 2011; Shelton, 2003). This suggestion was considered while designing the SPATIAL-AR toolkit. However, in the second iteration as walkthrough study, this characteristic were not practically implemented since this iteration was thought as redesigning and revising prototype of SPATIAL-AR toolkit. These students worked individually in ARLE so they did not interact with each other. However, students did not encounter any specific technical or contextual issue within this iteration. They could fluently adapt usage of the SPATIAL-AR toolkit and successfully accomplish all spatial tasks. Based on these findings, it could be assumed that students could also work individually with SPATIAL-AR toolkit. In any case, teachers should select the proper implementation method to meet students' needs and shape its usage based on classroom environment.

To sum up, the results of this study provides some evidences to overcome "cognitive-filter" issue that the manipulative interaction with the objects in analytic space on computer screen is possible through using mouse and keyboard. With the set of spatial tasks used and supported by an AR interface could provide practical and effective solution for this issue. Thus, students from any level of spatial ability could benefit from the SPATIAL-AR toolkit in order to understand two dimensional representations and to envision three dimensional objects which are represented by these two dimensional views. Teachers are provided with a new tool to visualize mathematical concepts and students could be supported with this new tool as a new learning material with the SPATIAL-AR for tablets or smartphones. Moreover, curriculum developers can benefit from design principles for ARLE in order to make proper adjustments of learning environment to be suitable AR, design principles for booklets in order to make textbooks proper for AR tasks, and the MISAR in order to design spatial tasks for AR based learning. Furthermore, these design principles could provide basic developmental and implementation characteristics for making AR technology applicable and usable in Fatih project. At last, preservice teachers could be trained to learn and apply simple coding steps in order to develop their coding skills. Hence, they will have basic requirements to develop an AR interface with help of some SDKs for learning situations to use in their future classrooms.

5.3. Suggestions and Implications for Future Studies

AR interface can provide a novel way of interaction for technology but a common way for real life which was interacting virtual objects like that they exist in the real environment. The mobile AR interface, in this study, augments physical environment with virtual objects related with the MISAR by projecting them on top of target images on pages of booklets. The logic behind the AR interface can be explained simply as that target image is recognized via visual data from device's camera and related virtual object is found and added on the visual data, then this mixture of virtual object and the visual data of environment projected on device's screen. So that, students can interact with these virtual objects in a manner that they exist really on their booklets.

Motivation of this study was about design and development processes of an AR learning toolkit for fostering spatial ability of students by providing unique opportunities for learning. Therefore, a toolkit to improve spatial ability, which includes a mobile AR interface and set of spatial tasks on a booklet, was designed as a result of this motivation. Characteristics of providing an ARLE, programming AR interface, preparing student's booklets and a MISAR come from theory in the literature and were revolved into practice in cycles of iterations throughout this design based study. The collection of these characteristics formed a framework for designing the SPATIAL-AR toolkit to be implemented in an ARLE.

First of all, apart from designing and developing processes of an AR interface, implementation of such AR interface in a learning environment was seem very easy and practical. In fact, both seventh graders and mathematics education experts were accustomed the ARLE at a time. The novelty of this environment vanished on the first day of implementation and they were able to use the SPATIAL-AR toolkit without dealing with neither technical nor practical issues. On the contrary to other technology based systems, since inputs and control of AR interface can be done with natural and physical ways of interactions like moving body parts, gesturing, touching, tilting, moving and others, students and experts were not distracted with indirect way of controls like with mouse or keyboards. Therefore, they could use the mobile AR interface like they were using a concrete material, and so the mobile AR interface was not novel for them after a while. As stated at the beginning of this paragraph, apart from designing an AR interface, other things are practical. The AR interface of this study was developed nearly from scratch by writing and compiling some C# scripts as well as helps of some software development kits. However, teachers might not design AR interface for their lessons if they have not enough practice for coding a program. Therefore, studies for AR technology should provide clear directions or characteristics for anyone who want to design an ARLE for own lesson and students. Moreover, future studies should be also conducted to provide comprehensive frameworks and design procedures for implementation of AR environment for different educational practices in order to provide valuable and numerous design products which can serve valuable AR based learning materials for education. Hence, teachers can use such AR interfaces which are validated in terms of their practical and effective implementations, as a teaching tool along with tablets or even smart phones. Furthermore, researchers should provide more dynamic and interactive AR interfaces like GeoGebra and Cabri 3D as well as design principles such interfaces. Hence, dynamic geometry software would have augmented features so that students would have opportunities for direct interactions with virtual three dimensional objects in dynamic geometry environments without experiencing negative effects of cognitive filter issue which was also focus of this study.

The mobile AR interface of this study was designed for and used with both tablets and smart glasses. However, any specific difference regarding to devices about gains in spatial ability was not observed and just differences in opportunities for learning environment were observed. The tablets and smart glasses based ARLE resulted nearly similar outputs in accordance with the findings of this research. Expensiveness of smart glasses and extensity usage of tablets or smart phones considered, although researchers can make their choices freely, I recommend to focus on developing AR interface for tablets or smart phones since these two device are widely accessible for nearly every students, and also might be provided to students by governments like Fatih Project in Turkey. Furthermore, because the smart glasses have been still in development prototype process, they are not accessible for every one due to either their prices or stocks in markets. For example, I tried hard to obtain and buy the smart glasses for this study because they are not easily obtainable in markets in Turkey and their prices are higher. Maybe, the smart glasses will also have some device specific advantages in near future for both learning gains and implementation gains.

As stated before, due to restricted number of devices, a field study was not practical and so not conducted within this study. Therefore, this study lacks an actual validation of effectiveness of intervention on target settings with target students. Nevertheless, possible contributions of these characteristics and the SPATIAL-AR toolkit were asserted from the results of the study. Future research should be conducted in order to find out actual effectiveness of these resulted characteristics and the SPATIAL-AR toolkit with target group in target settings.

This study shed light to design and develop a mobile target-based AR interface which provides opportunities to foster spatial ability and learning environment like interactions with virtual objects directly. Moreover, a model for spatial ability training in AR environment which is the MISAR also comes to light from these design and development processes. Since the AR has been still relatively new technology for educational settings, there are no common and widely used comprehensive theoretical frameworks for development and implementation such educational AR interface, and packet software in order to make easy and accessible widely of the development processes for every teachers. Within this study, a framework to design and develop such mobile AR interface specifically for improvement of spatial ability was tried to be put into practice. Researchers could contribute development and evaluation of the AR technology for educational settings using this framework, which includes characteristics of an ARLE and key elements of a mobile AR interface, in order to validate or extend this framework into other settings. Moreover, researchers should also derive and revive characteristics of other AR based learning environments on different educational fields in order to find out and validate practicality and effectiveness of AR based systems for educational implementations. Moreover, the conjectured design principles for booklets according to findings regarding mobility issues, could be considered designing and developing target-based AR systems and multiple worksheets in AR based learning environments in future studies. Furthermore, in this study, learning opportunities for fostering seventh graders' spatial ability were studied with a mobile AR toolkit and small group of students. Further studies could be conducted to investigate actual effects of this toolkit in this grade level as well as effects to other grade levels in terms of spatial ability and learning opportunities, as well.

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APPENDICES

APPENDIX A: Demo AR interface and Booklets of SPATIAL-AR Toolkit

Download SPATIAL-AR demo application to your Android phone or tablet from here: https://goo.gl/FbDh0V

or scan this QR-code with a barcode scanner application with your phone.

SPATIAL-AR demo uygulamasını Android cihazınıza yüklemek için uygulamayı şu adresten indirebilir: **https://goo.gl/FbDh0V**

veya yandaki karekodu, cihazınızdaki herhangi bir karekod/barkod tarama uygulaması ile taratarak linke ulaşabilirsiniz.

Download and print SPATIAL-AR demo spatial task booklet from here: https://goo.gl/Gw4nur

Download and print SPATIAL-AR demo target images booklet from here: https://goo.gl/4MBXkP

SPATIAL-AR demo etkinlik kitapçığını şu adresten indirip yazıcınızdan çıkartın: **https://goo.gl/MCFJOw**

SPATIAL-AR demo karekod/hedef kitapçığını şu adresten indirip yazıcınızdan çıkartın: **https://goo.gl/KSXNME**

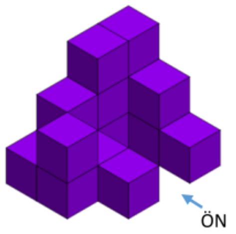
APPENDIX B: Sample Checklist for Spatial Tasks and Virtual Objects

Part	Tasks	Relevancy of tasks and objects in terms of*			Other thoughts for tasks	Order of tasks
		7th grade mathematics curriculum	Complexity of virtual objects	Discernibility of side views		
Surfaces & vertices	1					
	2					
	3					
	.					
	.					
	.					
	.					
	28					
	29					
	30					
Matching Side Views	31					
	32					
	.					
	.					
	36					
	37					
Nets	38					
	39					
	.					
	.					
	43					
Counting	44					
	45					
	.					
	.					
	.					
	53					
	54					
Sketches	55					
	56					
	.					
	.					
	.					
	72					
	73					

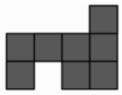
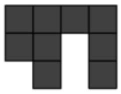
*Rate out of 10

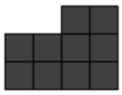
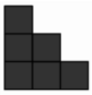
APPENDIX C: Spatial Ability Test for the MISAR

1.

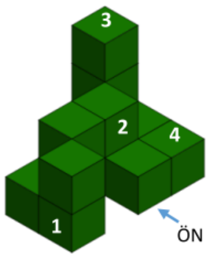


Aşağıdaki görünümlerden hangisi bu yapıya ait değildir?

A. 
B. 

C. 
D. 

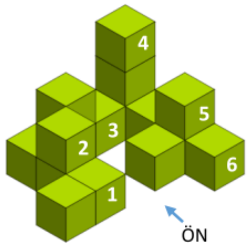
2.



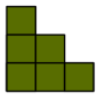
Yukarıdaki yapıya ilişkin olarak aşağıdakilerden hangisi kesinlikle doğru olamaz?

A. 1 numaralı küp çıkarılırsa yapının soldan görünümü değişmez.
B. 2 numaralı küp çıkarılırsa yapının üstten görünümü değişmez.
C. 3 numaralı küp çıkarılırsa yapının önden görünümü değişmez.
D. 4 numaralı küp çıkarılırsa yapının soldan görünümü değişmez.

3.

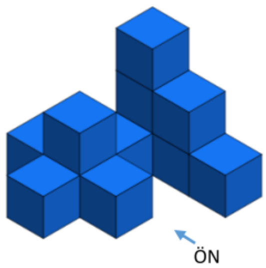


Yukarıdaki yapıdaki numaralandırılmış küplerden hangileri çıkarılırsa yapının soldan görünüşü aşağıdaki gibi olur?

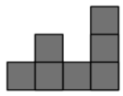


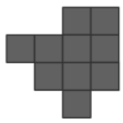
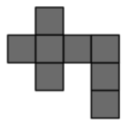
A. 1 ve 3 **B.** 2 ve 4
C. 3 ve 5 **D.** 5 ve 6

4.

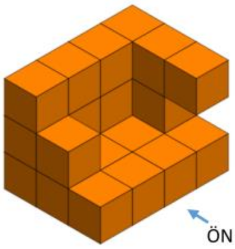


Aşağıdaki görünümlerden hangisi bu yapıya ait değildir?

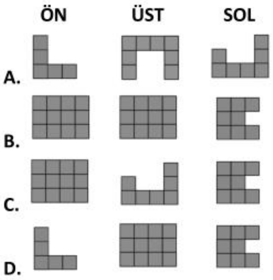
A. 
B. 

C. 
D. 

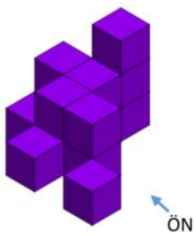
5.



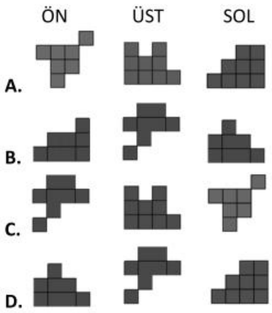
Yukarıda yapıya ait, sırasıyla önden, üstten ve soldan görünümleri aşağıdakilerden hangisinde doğru verilmiştir?



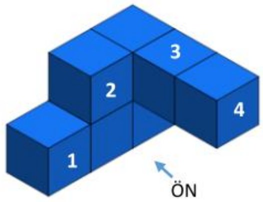
6.



Yukarıda yapıya ait, sırasıyla önden, üstten ve soldan görünümleri aşağıdakilerden hangisinde doğru verilmiştir?



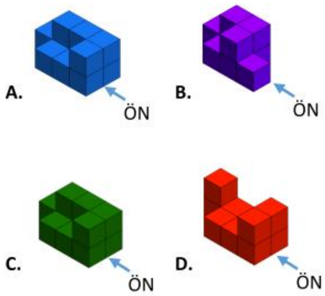
7.



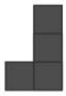
Yukarıdaki yapıya ilişkin olarak aşağıdakilerden hangisi <u>kesinlikle</u> doğru <u>olamaz</u>?

A. 1 numaralı yüzeyin önüne küp eklenirse yapının üstten görünümü değişir.
B. 2 numaralı yüzeyin önüne küp eklenirse yapının önden görünümü değişir.
C. 3 numaralı yüzeyin üstüne küp eklenirse yapının soldan görünümü değişir.
D. 4 numaralı yüzeyin önüne küp eklenirse yapının üstten görünümü değişir.

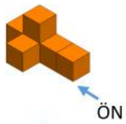
8. Aşağıdaki yapıların hangisinin üstten görünümü diğerlerinden farklıdır?



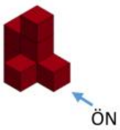
9.



Aşağıdaki yapıların hangisinin herhangi bir yönden görünümü yukarıdaki gibi olamaz?

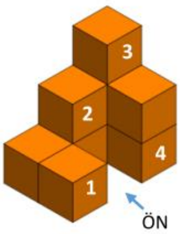
A. 

B. 

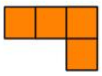
C. 

D. 

10.



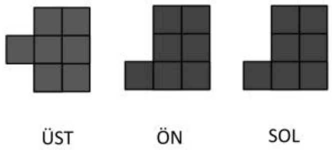
Yukarıdaki yapıdaki numaralandırılmış küplerden hangisi çıkarılırsa yapının üstten görünüşü aşağıdaki gibi olur?

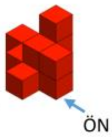


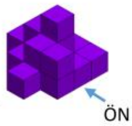
A. 1 **B.** 2 **C.** 3 **D.** 4

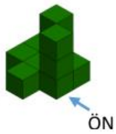
11.

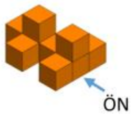
Üstten, ***Önden*** ve ***Soldan*** görünümleri aşağıdaki gibi olan yapı aşağıdakilerden hangisidir?



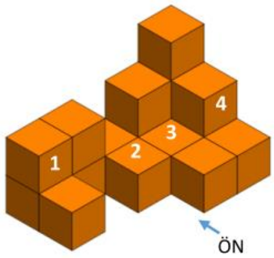
A. 

B. 

C. 

D. 

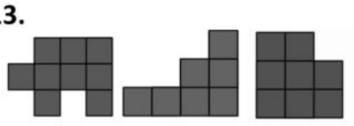
12.



Yukarıdaki yapıdaki numaralandırılmış yüzeylerden hangisine bir birim küp eklendiğinde yapının önden görünümü değişir?

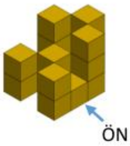
A. 1 **B.** 2 **C.** 3 **D.** 4

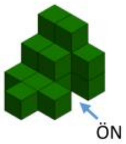
13.



ÜST ÖN SOL

Farklı yönlerden görünümleri yukarıdaki gibi olan yapı aşağıdakilerden hangisidir?

A. 

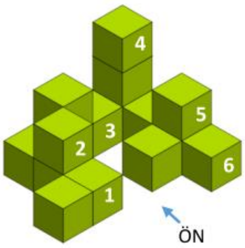
B. 

C. 

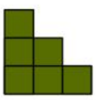
D. 

CEVAPLAR				
1	A	B	C	D
2	A	B	C	D
3	A	B	C	D
4	A	B	C	D
5	A	B	C	D
6	A	B	C	D
7	A	B	C	D
8	A	B	C	D
9	A	B	C	D
10	A	B	C	D
11	A	B	C	D
12	A	B	C	D
13	A	B	C	D
14	A	B	C	D

14.



Yukarıdaki yapıdaki numaralandırılmış küplerden hangileri çıkarılırsa yapının soldan görünüşü aşağıdaki gibi olur?



A. 1 ve 3 **B.** 2 ve 4
C. 3 ve 5 **D.** 5 ve 6

APPENDIX D: Sample Spatial Tasks for Surfaces & Vertices Level on SPATIAL-AR Toolkit

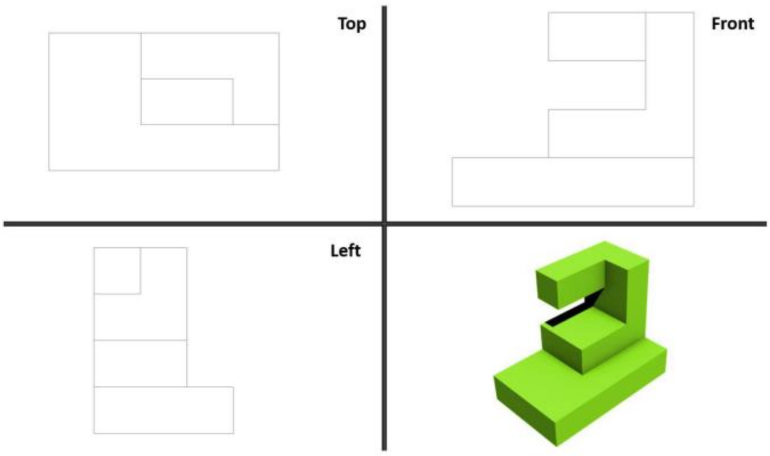
PART-1 PART-1

ACTIVITY 1

5

PART-1 PART-1

Activitiy 1: Write the numbers on surfaces of the virtual object onto orthographic views



TYPE A - ACTIVITY

5

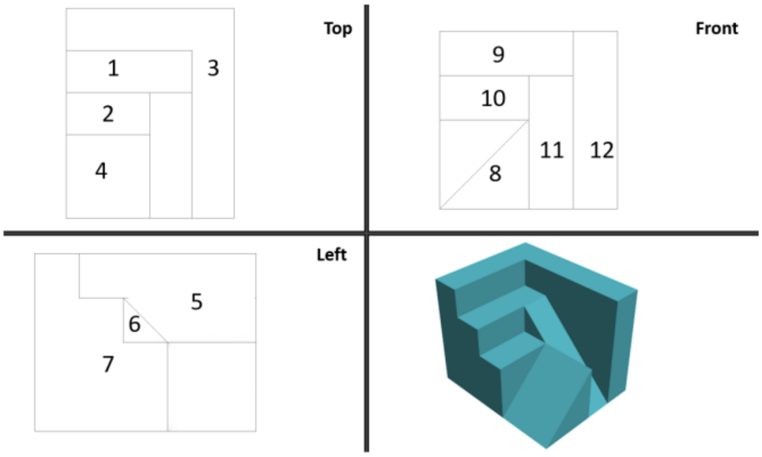
PART-1 PART-1

ACTIVITY 2

6

PART-1 PART-1

Activity 2: Mark the numbers of surfaces on orthographic views onto perspective view via investigating virtual object.



TYPE B - ACTIVITY

6

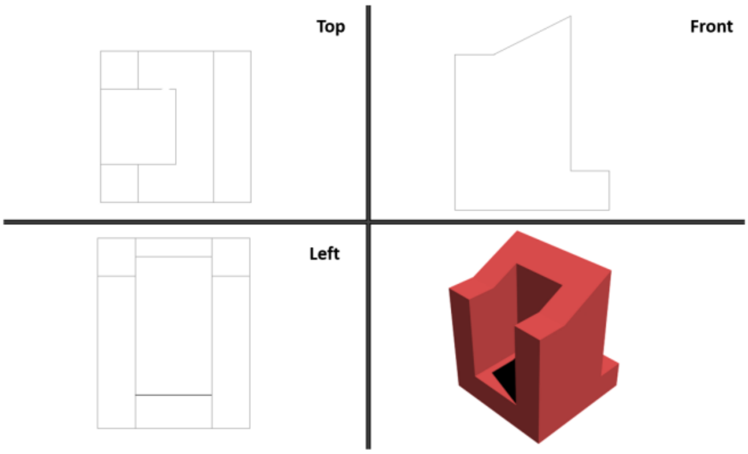
PART-1 PART-1

ACTIVITY 3

7

PART-1 PART-1

Activity 3: Mark the numbered vertices on virtual object onto orthographic views and perspective projection



TYPE C - ACTIVITY

7

APPENDIX E: Sample Spatial Tasks for Counting Components Level on SPATIAL-AR Toolkit

PART-2 PART-2

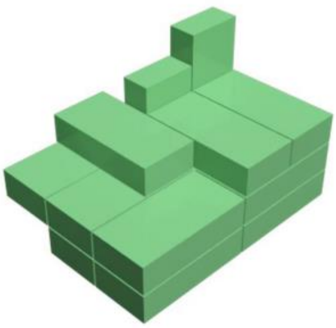
ACTIVITY 4

9

PART-2 PART-2

Activity 4: Write the number of bricks which are in touch with titled bricks

A	
B	
C	
D	
E	
F	
G	



ACTIVITY

9

APPENDIX F: Sample Spatial Tasks for Matching Correct Views Level on SPATIAL-AR Toolkit

PART-3 PART-3

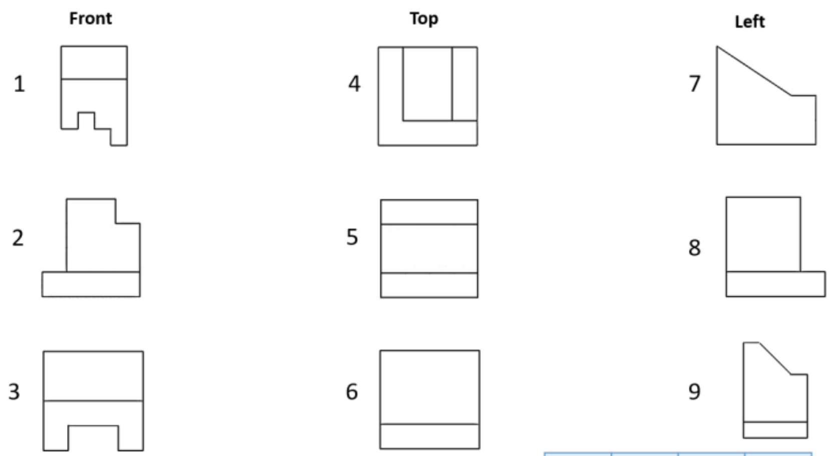
ACTIVITY 5

11

PART-3 PART-3

TYPE A - ACTIVITY

Activity 5: Match side-views with objects.



	Front	Top	Left
A			
B			
C			

11

PART-3 PART-3

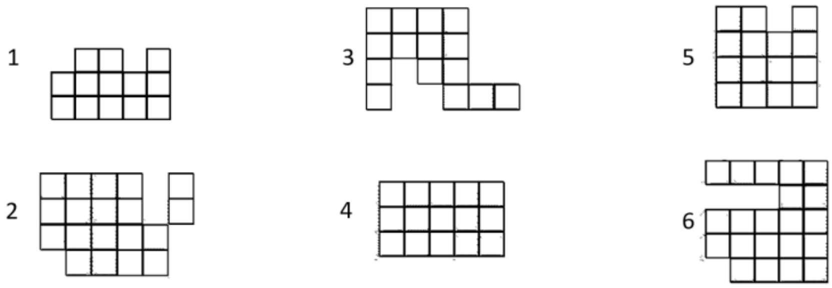
ACTIVITY 6

12

PART-3 PART-3

TYPE B - ACTIVITY

Activity 6: Match side-views with objects.



	Front	Top	Left
A			
B			

12

APPENDIX G: Sample Spatial Tasks for The Second Dimension - Sketches Level on SPATIAL-AR Toolkit

PART-4 PART-4

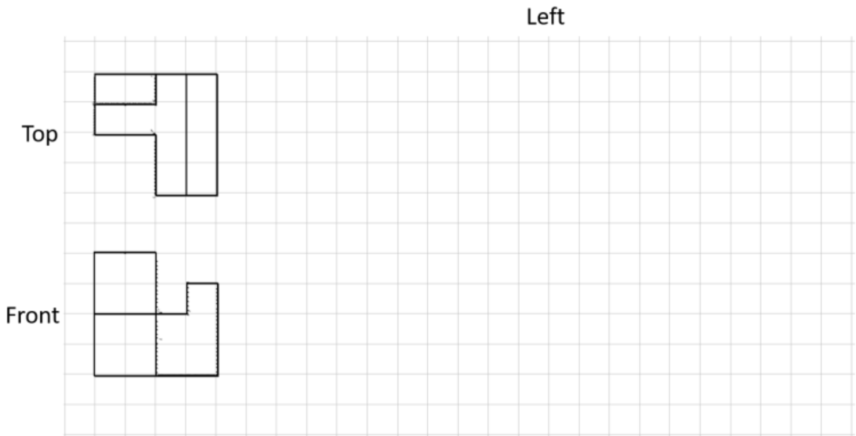
ACTIVITY 7

14

PART-4 PART-4

TYPE A - ACTIVITY

Activity 7: Investigate virtual object via tablet or smart glasses. Sketch missing side-view of the object.



14

ACTIVITY 8

15

Activity 8: Investigate virtual object via tablet or smart glasses.
Sketch top-front-left side-views of the virtual object onto plotting area.

Top

Front

Left

TYPE B - ACTIVITY

15

APPENDIX H: Scripts for Interactivity Layer

DokunmaKontrolAnaKod.cs >>

```
using UnityEngine;
using System.Collections;
//Dokunmatik Kontrol scripti Vuforia AR CAMERA için, Vuforia AR CAMERA ya eklenecek... (Layer
DokunmaFareKontrol.cs ile aynı olmalı)
public class DokunmatikKontrolAnaKod : MonoBehaviour {

        public int Layer;
        int layerMask;

        // Baslangic
        void Start () {
                layerMask = 1<<Layer;
        }

        // frame basi bir guncelleme cagrilir
        void Update () {

             RaycastHit hit = new RaycastHit();
             for (int i = 0; i < Input.touchCount; ++i) {
                if (Input.GetTouch(i).phase.Equals(TouchPhase.Began)) {
                // Dokunma koordinatlarinda bir isin cizer
                Ray ray = Camera.main.ScreenPointToRay(Input.GetTouch(i).position);
                if (Physics.Raycast(ray, out hit, layerMask)) {
                hit.transform.gameObject.SendMessage("DokunmaEylemi");
                Debug.Log("Dokunma Etkilesimi yapildi bu objeye "+ hit.transform.gameObject);
                }
              }
            }
        }
}
```

FareKontrolAnaKod.cs >>

```
using UnityEngine;
using System.Collections;
//Fare Kontrol scripti Vuforia AR CAMERA için, Vuforia AR CAMERA ya eklenecek... (Layer
DokunmaFareKontrol.cs ile aynı olmalı)
public class FareKontrolAnaKod : MonoBehaviour {

        public int Layer;
        int layerMask;
        // Baslangic
        void Start () {
                layerMask = 1<<Layer;
        }
        // frame basi bir guncelleme cagrilir
        void Update () {

            RaycastHit hit = new RaycastHit();
            {
                if (Input.GetMouseButtonUp(0)) {
                // Dokunma koordinatlarinda bir isin cizer
                Ray ray = Camera.main.ScreenPointToRay(Input.mousePosition);
                if (Physics.Raycast(ray, out hit, layerMask)) {
                hit.transform.gameObject.SendMessage("DokunmaEylemi");
                Debug.Log("Dokunma Etkilesimi yapildi bu objeye "+ hit.transform.gameObject);
                }
              }
            }
        }
}
```

[DokunmaFareKontrol.cs >>]

```
using UnityEngine;
using System.Collections;
using System.Collections.Generic;
//Prefab / child olarak nesneye eklenecek, child SphereCollider içermeli… Prefab için Layer
Dokunma ve Fare Ana kod ile aynı olmalı
public class DokunmaFareKontrol : MonoBehaviour {

        public GameObject[] menuButon;
        public GameObject[] iliskiliIcerik;
        public GameObject[] iliskiliButonlar;
        public GameObject[] herzamangizle;
        GameObject buButon;
        SphereCollider GorunmezButon;
        Vector3 ButonYeri;
        float ButonYaricapi;
        public Vector3 CikisButonuYeri;
        public float CikisButonuYaricapi;
        //mode için =>  true = Menu Modu & false = Icerik Modu
        bool mode;
        //goster için => true = Kullanilabilir & false = Kullanilamaz
        bool goster;
        // Baslangic
        void Start () {

            buButon = this.gameObject;
            //Noktalari ana butonun Sphere collider ina ve onun yeri/olcegine getiren kisim
            GorunmezButon = this.GetComponent<SphereCollider>();
            ButonYeri= GorunmezButon.center;
            ButonYaricapi = GorunmezButon.radius;
            //Baslangic Durumunu Ayarla
            mode = true;
            goster = true;
        }
        // frame basi bir kere guncelleme cagrilir
        void Update () {
          //Menu Modu
          if(mode==true && goster==true)
          {
          //Butonun yeri ve buyuklugunu ilk ayarlandigi sekliyle birakir
          GorunmezButon.center = ButonYeri;
          GorunmezButon.radius = ButonYaricapi;

          //menuButon.SetActive(true);
            foreach (GameObject content in menuButon)
            {
                content.SetActive(true);
            }
            foreach (GameObject content in herzamangizle)
            {
                content.SetActive(false);
            }
            foreach (GameObject content in iliskiliIcerik)
                {
                content.SetActive(false);
                }
                buButon.SetActive(true);
          }
        //Icerik Modu
        if(mode==false && goster==true)
        {
        //Butonun yerini ve buyuklugunu cikis butonu yeri ve buyuklugune getirir (butonu
cikis butonu yapar)
        GorunmezButon.center = CikisButonuYeri;
        GorunmezButon.radius = CikisButonuYaricapi;
          //menuButon.SetActive(false);
            foreach (GameObject content in menuButon)
```

```
            {
                content.SetActive(false);
            }
            foreach (GameObject content in herzamangizle)
            {
                content.SetActive(false);
            }
            foreach (GameObject content in iliskiliIcerik)
                                {
                                        content.SetActive(true);
                                }

                                buButon.SetActive(true);
                        }
                        //Gizleme Modu
                        if(mode==true && goster==false)
                        {
            //menuButon.SetActive(false);
            foreach (GameObject content in menuButon)
            {
                content.SetActive(true);
            }
            foreach (GameObject content in herzamangizle)
            {
                content.SetActive(false);
            }
            buButon.SetActive(false);
                        }
                }
        //Iliskili Butonlar (Menu modu gibi dusunulebilir herhalde)
        void DokunmaEylemi()
        {
                mode = !mode;
                if (mode==false && goster==true)
                {
                                foreach (GameObject btn in iliskiliButonlar)
                                {
                                        btn.SendMessage("DoFa");
                                }
                }
                Else {
                                foreach (GameObject btn in iliskiliButonlar)
                                {
                                        btn.SetActive(true);
                                        btn.SendMessage("DoFa");
                                }
                }
        }
        void DoFa ()
        {
                goster = !goster;
        }
}
```

APPENDIX I: Vita

PERSONEL INFORMATION

Surname, Name: Özçakır, Bilal
Nationality: Turkish (TC)
Date and Place of Birth: 11 May 1987, Elmalı
Marital Status: Married
email: bilalozcakir@gmail.com

EDUCATION

Degree	Institution	Year of Graduation
BS	METU, EME	2010
MS	METU, ESME	2013
PhD	METU, ELE	2017

WORK EXPERIENCE

Year	Place	Enrollment
2012-Present	Ahi Evran University	Research Assistant
2011-2012	Celal Bayar University	Research Assistant

FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

1. **Özçakır B.**, and Çakıroğlu E. (2017). Ortaokul 7. Sınıfta Dörtgenlerin Alan Bağıntılarını Oluşturma Sürecinde Dinamik Geometri Yazılımlarının Kullanılması. *Ahi Evran Üniversitesi Kırşehir Eğitim Fakültesi Dergisi, 18*(1), 231-248.
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1. **Özçakır, B.**, and Özdemir, D. (2017). 6. Sınıf Geometri Kazanımıyla İlişkilendirilen Arttırılmış Gerçeklik Uygulamaları Hakkındaki Görüşler. *II. Uluslararası Felsefe, Eğitim, Sanat ve Bilim Tarihi Sempozyumu, 466-467.*
2. **Özçakır, B.**, Çakıroğlu, E., and Güneş E. (2016). Edutainment Applications of Augmented Reality The Case of Augmented Book. 1. *International Academic Research Congress (INES-2016).*
3. Konca A. S., **Özçakır B.**, and Arıkan N. (2016). Investigation effects of technology assisted instruction to 4 6 years children s recognition and discrimination of basic geometric shapes. *1. International Academic Research Congress (INES-2016).*
4. **Özçakır B.**, Konca A. S., and Arıkan N. (2016). Okul öncesinde geometrik şekillerin öğretilmesinde tablet üzerinde etkinlik geliştirilmesi. *1. International Academic Research Congress (INES-2016).*
5. **Özçakır B.**, Özdemir D., and Kıymaz Y. (2016). Investigation The Effects of Dynamic Geometry Activities on Van Hiele Levels and Motivation Towards Mathematics The Case of Gifted Students. *7th World Conference on Learning, Teaching and Educational Leadership (WCLTA-2016).*

6. **Özçakır B.**, Güneş E., and Çitci E. (2016). Implementation of Augmented Reality on Chemistry Education. *International Conference on New Horizons in Education (INTE 2016).*

7. Sözen S., **Özçakır B.**, and Orhan B. (2015). Metacognitive Similarities and Differences between Teachers and Students on Mathematical Problem Solving Skills. *The European Conference on Educational Research*.

8. **Özçakır B.**, and Çakıroğlu E. (2015). Pre Service Elementary Mathematics Teachers Progresses on Dynamic Geometry Activities and Views about Using Dynamic Geometry Regarding Technological Pedagogical Content Knowledge. *International Conference on Education in Mathematics, Science & Technology (ICEMST), 22.*

9. Aytekin C., Altunkaya B., Doruk B. K., and **Özçakır B.** (2014). The Analysis of the Relation between Eight Grade Students Estimation Skills Usage in Triangles and Their Teaching Style Expectations and Sources of Motivation. *3rd International Eurasian Conference on Mathematical Sciences and Applications,* 358-359.

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11. Aytekin C., and **Özçakır B.** (2012). Bilgisayar Cebiri Sistemleri ve Dinamik Geometri Yazılımları Kullanılarak Yapılan Araştırmaların Teknolojik Pedagojik Alan Bilgisi Modeli Çerçevesinde Değerlendirilmesi. *6th International Computer and Instructional Technologies Symposium, 288.*

APPENDIX J: Turkish Summary / Türkçe Özet

MATEMATİK EĞİTİMİNDE ARTIRILMIŞ GERÇEKLİK ORTAMLARI İLE YEDİNCİ SINIF ÖĞRENCİLERİNİN UZAMSAL ZEKALARININ GELİŞİMİ: BİR TASARIM TABANLI ARAŞTIRMA

1. Giriş

Uzamsal kavramlar ders kitaplarında genellikle ortografik ya da perspektif gösterimler gibi iki boyutlu gösterimler ile temsil edilirler. Fakat çalışmalar uzamsal zekası düşük olan öğrencilerin bu tip gösterimlerle yapılan temsillerde, bu gösterimlerin üç boyutlu şekillerin temsili olduğunu anlamalarında zorluklar yaşadıklarını göstermiştir (Ma, Wu, Chen & Hsieh, 2009; Pittalis & Christou, 2010). Geleneksel öğretim ortamlarında üç boyutlu uzamsal kavramların iki boyutlu çizimler yardımı ile öğrenilmesi, öğrenciler için aslında bir çeşit "bilişsel engel" oluşturur (Alcaniz, Contero, Perez-Lopez & Ortega, 2010). Bu bilişsel engeli aşmada ve olumsuz etkilerini ortadan kaldırmada öğrencilerin uzamsal zekalarının geliştirilmesi önemli yer tutmaktadır.

Araştırmacılar uzamsal zekanın farklı yaşlarda bile geliştirebileceğini ortaya koymuşlardır (Battista, Wheatley & Talsma, 1982; Embretson, 1987). Somut materyallerin ve fiziksel modellerin uzamsal zekanın gelişiminde etkili olduğunu yapılan çalışmalar ortaya koymuştur (Maier, 1996). Fakat somut materyaller ve fiziksel modeller genellikle sabit ve değişmez yapıda olmaktadırlar. Bu sebeple, bu materyallerde etkinlikler için çeşitli ve çok sayıda modeller sağlamak her zaman mümkün olmamaktadır. Teknoloji buna olanak sağlayacak etkinliklerin ve materyallerin tasarlanmasında zengin bir içerik ortamı sağlayabilir. Fakat bu engel bilgisayar ekranındaki üç boyutlu cisimlerle çalışırken bile vardır (Shelton & Hedley, 2004). Çünkü bilgisayar ekranındaki sanal uzayda oluşturulan cisimlerin manipülasyonu fare ya da klavye kullanılarak dolaylı etkileşimle gerçekleştirilir.

Gelişen yeni teknolojiler yardımıyla zengin çoklu ortamlar içeren artırılmış gerçeklik uygulamaları bu sınırlılıkları ortadan kaldırabilmeye yardımcı içerik imkanları sağlamaktadır. Artırılmış gerçeklik, bilgisayarda oluşturulan sanal nesnelerin gerçek dünyada eş zamanlı olarak görselleştirilmesini sağlayan, sanal gerçekliğin daha ileri türevi olan bir teknolojidir (Azuma, 1997). Sanal gerçeklikten farklı olarak, kullanıcı artırılmış gerçeklik ara yüzü sayesinde dış çevreyi de bir akıllı telefon ya da artırılmış gerçeklik gözlüğü ile görür ve bu sayede bilgisayar temelli grafikler bu gerçek dünya üzerinde, önceden belirlenen sabit yerlerde çizimlenebilir. Öğrencilere böyle bir öğrenme ortamının sağlanması, öğrencinin hem bilgisayar ile gerçek dünyayı keşfedebilmesine olanak sağlayarak hem de zengin öğrenme deneyimleri yaşanmasına imkan vererek etkili öğrenme ortamını oluşturur (Kaufmann & Schmalstieg, 2003). Üç boyutlu şekillerle doğrudan çalışılması, geleneksel yöntemlere göre karmaşık uzamsal problemler ve uzamsal ilişkilerin daha iyi ve hızlı anlaşılması ve kavranmasını sağlayabilmektedir (Kaufmann, 2004). Artırılmış gerçeklik ara yüzleri ise üç boyutlu nesnelerin öğretiminde daha etkili ve farklı bir öğrenme ortamı sağlamaktadır (Haniff & Baber, 2003; Wang & Dunston, 2006).

Artırılmış gerçeklik hala eğitim alanında yeni bir teknoloji olduğundan, uygulanabilir ve etkili artırılmış gerçeklik öğretim araçları geliştirmek için araştırmalar ile şekillenen tasarım yollarına ve ilkelerine ihtiyaç duyulmaktadır. Ayrıca, çalışmada kullanılan akıllı gözlükler hala geliştirme aşamasında olduğundan bu gözlüklerde uygulanabilir artırılmış gerçeklik ara yüzleri için tasarım ilkeleri sunan ve eğitim alanında kullanımını araştıran çalışmaların sayısı kısıtlıdır (Kaufmann & Dünser, 2007). Benzer şekilde, her ne kadar çalışmalar artırılmış gerçekliğin eğitim alanında etkili olduğu ifade etse de, Türkiye'de matematik eğitimi alanında yapılan çalışmaların sayısı da azdır. Bu nedenlerle; akıllı gözlük ve tablet gibi mobil cihazlarda çalışan, matematik eğitimi için artırılmış gerçeklik ara yüzlerinin geliştirilmesine ilişkin tasarım ilkelerini ve bu ara yüzlerin özellikle Türkiye'deki öğrenciler ile olası etkileri üzerine yapılacak çalışmalara ihtiyaç vardır. Bu sebeple, bu eğitsel tasarım araştırması; uygulanabilir ve etkili bir artırılmış gerçeklik öğrenme ortamı için gerekli olan tasarım ilkeleri oluşturmayı ve bu tasarım ilkeleri ile öğrencilerin uzamsal zekalarını geliştirmeye yönelik bir mobil artırılmış gerçeklik ara yüzünü tasarlamayı amaçlamıştır. Bu amaca uygun olarak, alanyazın taranarak uzamsal zekanın gelişiminde artırılmış gerçekliğin uygulanmasına ilişkin taslak tasarım ilkeleri elde edilmiştir. Bu taslak tasarım ilkelerine göre öğrencilerin uzamsal zekalarını geliştirmeye yönelik uzamsal etkinlikler ve bu etkinliklerde kullanılacak olan artırılmış gerçeklik ara yüzü prototipi geliştirilmiştir. Bu ara yüz ve uzamsal etkinlikler çalışma boyunca uzamsal artırılmış gerçeklik (UZAMSAL-AR) öğretim aracı olarak anılacaktır.

Bu çalışmada, aşağıdaki araştırma sorularına prototip geliştirme döngülerinde cevap aranmıştır.

- UZAMSAL-AR ne ölçüde tasarım ilkelerini kapsamaktadır?
- UZAMSAL-AR ne derecede ilgili öğretim programına hitap etmektedir?
- UZAMSAL-AR öğretim programına göre geçerli ve bu programla ilgili midir?
- UZAMSAL-AR mobil cihazlarla kullanıldığında uzamsal zekayı geliştirme de etkili midir?
- UZAMSAL-AR uzamsal zekayı geliştirmede ve öğrenme ortamına çeşitli fırsatlar sağlamada nasıl etkilidir?

2. Yöntem

2.1. Araştırma Yöntemi

Bu çalışma eğitsel tasarım araştırması metodu kullanılarak gerçekleştirilmiştir. Genel olarak eğitsel tasarım araştırması eğitsel bir yeniliğin ya da müdahalenin tasarımı, geliştirilmesi ve değerlendirilmesi için bir sistematik yol olarak tanımlanmaktadır (Plomp, 2013). Eğitsel tasarım araştırmaları pratikte var olan bir problem için teoride var olan bilgiler ışığında çözüm yolları arar. Ayrıca, bu müdahalelerin nitelikleri ve bu tasarım ve geliştirme süreçlerinin özellikleri hakkında bilgi verir. Bu sebeple, eğitsel tasarım araştırmaları hem tasarım hem de uygulama boyutlarıyla teknoloji destekli öğrenme ortamlarının araştırılmasına uygun araştırma yöntemidir (Wang & Hannafin, 2005).

Bu çalışma genel olarak iki evreden oluşacak şekilde tasarlanmıştır. Ön araştırma evresinde pratikte var olan bir problem olarak yukarıda bahsedilen bilişsel engel ortaya çıkarılmış ve bu problemin çözümüne ilişkin tasarım ilkeleri alanyazından derlenmiştir. Prototip geliştirme evresinde ise belirlenen taslak tasarım ilkeleri ışığında uzamsal zekanın gelişimine yönelik bir artırılmış gerçeklik arayüzü ve uzamsal etkinlikler tasarlanmıştır. Tasarlanan bu etkinlikler ve artırılmış gerçeklik arayüzü bu evredeki üç aşamada öğretim programına ve tasarım ilkelerine uygunluğu açısından gözden geçirilmiş ve gerekli yerleri tekrar tasarlanmıştır. Fakat çalışmada kullanılan mobil cihazlar, özellikle akıllı gözlükler, pahalı oldukları ve yaygın kullanılmadıkları için ve bu sebeple çok sayıda öğrenci ile çalışma yapılması şu andaki şartlar nedeniyle kolay olmadığı için bu çalışmada değerlendirme evresi uygulanabilir bulunmamıştır.

2.2. Ön Araştırma Evresi

Ön araştırma evresinde alanyazındaki ilgili çalışmalardan artırılmış gerçeklik öğrenme ortamı ve mobil artırılmış gerçeklik ara yüzlerinin temel elemanlarına ilişkin taslak tasarım ilkeleri derlenmiştir. Ayrıca, bu çalışmadaki uzamsal etkinlikleri tasarlamak için artırılmış gerçeklik ortamıyla uzamsal zekanın gelişimi için bir taslak model oluşturulmuştur.

Öncelikle alanyazın taramasında sanal objelerle uzamsal zeka gelişimine ilişkin birkaç model ve uzamsal içerikler derlenmiştir. Uzamsal işlem kapasitesi (Sack, 2013) ve uzamsal zeka eğitimi (Perez-Carrion & Serrano-Cardona, 1998) modelleri ile Wiesen (2004) tarafından önerilen uzamsal içeriklerden artırılmış gerçeklik ortamıyla uzamsal zekanın gelişimi taslak modeli oluşturulmuştur. Bu taslak model beş seviyeden oluşmaktadır. İlk olarak yüzeyler ve köşeler seviyesi yapıların yüzeylerini ve köşelerini tanımlamaya yönelik etkinlikler şeklinde tasarlanmıştır. İkinci seviye yapıların yüzlerini eşleştirmeye yönelik etkinlikler şeklinde tasarlanmıştır. Üçüncü seviye katı cisimlerin açınımlarını bulma şeklinde tasarlanmıştır. Dördüncü seviye yapıların birbirine dokunan parçalarını saymaya yönelik etkinlikler şeklinde tasarlanmıştır. Son olarak, beşinci seviyede ise yapıların üst-ön-sol görünümlerinin çizilmesine yönelik etkinlikler bulunmaktadır. Bu model hem etkinliklerin tasarlanmasında hem de etkinliklerdeki sanal nesnelerin hazırlanmasında kullanılmıştır.

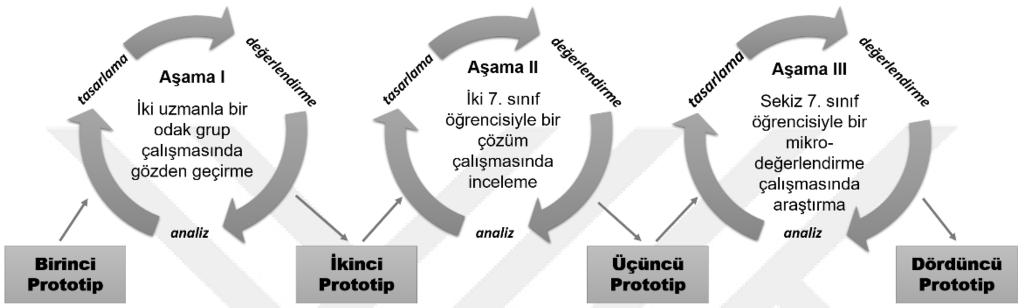
Öğrenme ortamında artırılmış gerçeklik temelli eğitimin uygulanmasına yönelik ise alanyazından işbirlikli öğrenme ve artırılmış gerçekliğin öğrenme ortamına katkılarını konu alan çalışmalar incelenmiş ve artırılmış gerçeklik öğrenme ortamı taslak tasarım ilkeleri derlenmiştir. İlk olarak, artırılmış gerçeklik ortamında öğrenciler benzersiz etkileşimlere sahip olmalıdır. Bu etkileşimler onlara sanal nesneleri gerçek hayattaki nesnelerden farksız olarak taşıma, hareket ettirme, döndürme veya etrafından dolaşma gibi doğal etkileşim yolları sağlama ve bu ortamda birbirleri ile de sürekli işbirliği halinde olmaları ile sağlanabilir (Smith & MacGregor, 1992; Szalavari, Schmalstieg, Fuhrmann & Gervautz, 1998). İkinci olarak, öğrenciler öğrenme ortamında aktif olduklarında sanal nesnelere ilişkin daha iyi anlamalar gerçekleştireceği için öğrenmede aktif bir sürece teşvik edilmelidirler (Smith & MacGregor, 1992). Bu ise öğrencilere ilgi çekici, zorlayıcı ve oyun temelli etkinlikler ile sağlanabileceği gibi artırılmış gerçeklik ara yüzünün sağladığı sanal nesnelere yönelik bağımsız görüş açısı ile de sağlanabilir (Smith & MacGregor, 1992; Szalavari vd., 1998). Son olarak ise artırılmış gerçeklik ara yüzü öğretmenlere de öğrenmeye aracılık etmede önemli fırsatlar sağlamalıdır. Bu fırsatlar da öğretmenlerin öğrenci seviyesine uygun etkinlik seçebilme ve gerekli durumlarda artırılmış gerçeklik ara yüzü aracılığıyla tam zamanında bilgi verebilmeleri ile sağlanabilir (Wu, Lee, Chang & Liang, 2013).

Ayrıca, bu çalışmadaki artırılmış gerçeklik ara yüzü yukarıda bahsedilen uzamsal zeka modeli ile taslak tasarım ilkelerini dikkate alarak ve artırılmış gerçekliğin tanımından gelen iki temel ilke ışığında Unity 3D ve Vuforia SDK ile geliştirilmiştir. Bu temel ilkeler nesneler için sanallık ve ortamın zenginleştirilmesi ilkeleridir (Azuma, 1997; Kaufmann, 2004; Szalavari et al., 1998).

Bu tasarım ilkeleri ve uzamsal zeka modeli doğrultusunda ilk UZAMSAL-AR prototipi geliştirilmiş ve ilk aşama uygulaması için hazırlanmıştır. Temel olarak bu prototip bir mobil artırılmış gerçeklik ara yüzü, etkinlikler ve hedef resimler için öğrenci kitapçığı ve tablet ve akıllı gözlük gibi Android mobil cihazlardan oluşmaktadır.

2.3. Prototip Geliştirme Evresi

Prototip geliştirme evresi üç aşama içerecek şekilde tasarlanmıştır. Bu aşamalar da kendi içlerinde tasarım-değerlendirme-analiz etme şeklinde birçok mikro döngü barındırmaktadır (Şekil 1).



Şekil 1. Prototip geliştirme evresi

2.3.1. Aşama I: Odak Grup Çalışması

Odak grup çalışması UZAMSAL-AR öğretim aracının tasarımını matematik eğitimi uzmanlarının bakış açılarına göre yönlendirmeyi ve geliştirmeyi amaçlamıştır. Bu amaç doğrultusunda aşağıdaki araştırma sorularına cevaplar aranmıştır:

- UZAMSAL-AR ne ölçüde tasarım ilkelerini kapsamaktadır?
- UZAMSAL-AR ne derecede ilgili öğretim programına hitap etmektedir?

Bu odak grup çalışmasına iki matematik eğitimcisi katılmıştır. Bu matematik eğitimcileri İç Anadolu Bölgesi'ndeki iki üniversitede görev yapmakta olan iki araştırma görevlisidir. Ayrıca, bu katılımcılar matematik eğitiminde yüksek lisans derecesine ve en az üç yıl Milli Eğitim Bakanlığına sahip okullarda öğretmenlik deneyimine sahiplerdir. Bu odak grup çalışmasındaki örneklem amaçlı olarak belirlenmiştir. Önceki çalışmalar uzamsal zeka ile matematik başarısında güçlü bir ilişki olduğunu ortaya koymuşlardır (Battista, 1990; Clements & Battista, 1992). Bu yüzden, bu katılımcıların da uzamsal zekanın matematik eğitimindeki öneminden haberdar oldukları düşünülmüştür. Bu sayede prototipin uzamsal zekanın geliştirilmesi amacına yönelik daha etkili ve verimli veriler sağlayacakları gerekçesiyle bu özelliklere sahip katılımcılar belirlenmiştir.

Çalışma esnasında katılımcılara UZAMSAL-AR öğrenme aracının ilk prototipi ve etkinlikler ile sanal nesneleri yedinci sınıf öğretim programı çerçevesinde değerlendirmeleri için değerlendirme listesi verilmiştir. Bu prototip 73 uzamsal etkinlik ve bu etkinliklere ait 111 sanal nesneyi içermektedir. Katılımcılar etkinlikleri hem tablet hem de akıllı gözlük kullanarak tamamlamışlardır. Bu çalışmada gözlem notları, değerlendirme listeleri, tablet ve gözlüklerin ekran video kayıtları, görev-temelli görüşme ve geriye dönük görüşme ile araştırma verileri toplanmıştır. Odak grup çalışması 2015-2016 öğretim yılının güz döneminde gerçekleştirilmiş ve yaklaşık üç hafta sürmüştür. Genel olarak, odak grup çalışması ile UZAMSAL-AR öğrenme aracının ilk prototipinin hatalı, problemli ya da yanlış tasarlanmış yerlerine ilişkin değerli veriler toplanmış ve buna göre prototip güncellenmiştir.

2.3.2. Aşama II: Çözüm Çalışması

Çözüm çalışması UZAMSAL-AR öğretim aracının tasarımını yedinci sınıf öğrencilerinin bakış açılarına göre yönlendirmeyi ve geliştirmeyi amaçlamıştır. Bu amaç doğrultusunda aşağıdaki araştırma sorusuna cevaplar aranmıştır:

- UZAMSAL-AR öğretim programına göre geçerli ve bu programla ilgili midir?

Bu çözüm çalışmasına iki yedinci sınıf öğrencisi katılmıştır. Bu öğrenciler ilk aşamadan sonra araştırmacı tarafından geliştirilmiş olan ve 14 sorudan oluşan çoktan seçmeli bir uzamsal zeka testinden aldıkları puanlara göre 66 yedinci sınıf öğrencisi arasından en yüksek puanları alanlardan seçilmiştir. Bir önceki aşamaya benzer olarak örneklem amaçlı olarak belirlenmiştir. Yine benzer şekilde prototipin uzamsal zekanın geliştirilmesi amacına yönelik daha etkili ve verimli veriler toplayabilmek için uzamsal zekası yüksek katılımcılar belirlenmiştir.

Çalışma esnasında katılımcılara UZAMSAL-AR öğrenme aracının ikinci prototipi verilmiştir. Bu prototip ilk aşama sonrası yeniden tasarlanmış ve 36 uzamsal etkinlik ve bu etkinliklere ait 44 sanal nesneyi içerecek şekilde güncellenmiştir. Öncelikle bu çalışma katılımcıların artırılmış gerçekliği ilk defa gördükleri için katılımcılara artırılmış gerçekliğin ne olduğu ve kendilerine verilen tablet veya gözlüklerle UZAMSAL-AR öğretim aracını nasıl kullanacakları kısaca anlatılmıştır. Katılımcılardan biri etkinlikleri tablet kullanarak tamamlarken diğeri akıllı gözlük kullanarak tamamlamıştır. Bu çalışmada gözlem notları, tablet ve gözlüklerin ekran video kayıtları ile ortamın video kaydı, görev-temelli görüşme ve geriye dönük görüşme ile araştırma verileri toplanmıştır. Çözüm çalışması 2015-2016 öğretim yılının bahar döneminde gerçekleştirilmiş ve yaklaşık iki hafta sürmüştür. Genel olarak, çözüm çalışması ile UZAMSAL-AR öğrenme aracının ikinci prototipinin öğrencilerin ihtiyaçlarına yönelik eksiklikleri ve içermesi gereken tasarım özelliklerine ilişkin değerli veriler toplanmış ve buna göre prototip güncellenmiştir.

2.3.3. Aşama III: Mikro Değerlendirme Çalışması

Mikro değerlendirme çalışmasında UZAMSAL-AR öğretim aracının yedinci sınıf öğrencilerinin uzamsal zekaları ve onlara öğrenme ortamında ne gibi olası etkiler sağladığının ortaya çıkarılması amaçlanmıştır. Bu amaç doğrultusunda aşağıdaki araştırma sorularına cevaplar aranmıştır:

- UZAMSAL-AR mobil cihazlarla kullanıldığında uzamsal zekayı geliştirme de etkili midir?
- UZAMSAL-AR uzamsal zekayı geliştirmede ve öğrenme ortamına çeşitli fırsatlar sağlamada nasıl etkilidir?

Bu mikro değerlendirme çalışmasına sekiz yedinci sınıf öğrencisi katılmıştır. Bu öğrenciler uzamsal zeka testinden aldıkları puanlara göre 26 yedinci sınıf öğrencisi içinden düşük, orta ve yüksek uzamsal zekaya sahip olarak belirlenenlerin arasından seçilmiştir. Bu şekilde uzamsal zeka seviyesinde farklılık gösteren bir örneklemin seçilmesinin amacı çalışmaya hedef grubu temsil edebilecek ve uzamsal zekada çeşitlilik gösteren farklı katılımcıların belirlenmesidir.

Çalışma esnasında katılımcılara UZAMSAL-AR öğrenme aracının üçüncü prototipi verilmiştir. Bu prototip ikinci aşama sonrası yeniden tasarlanmış ve 33 uzamsal etkinlik ile 6 örnek etkinlik ve bu etkinliklere ait 47 sanal nesneyi içerecek şekilde güncellenmiştir. Öncelikle bu çalışma katılımcıların artırılmış gerçekliği ilk defa gördükleri için katılımcılara artırılmış gerçekliğin ne olduğu ve kendilerine verilen tablet veya gözlüklerle UZAMSAL-AR öğretim aracını nasıl kullanacakları kısaca anlatılmıştır. Katılımcılar kullanılan cihaz temelli ikili olarak gruplara ayrılmışlardır. Bu çalışmada gözlem notları, tablet ve gözlüklerin ekran video kayıtları ile ortamın video kaydı ve geriye dönük görüşme ile araştırma verileri toplanmıştır. Mikro değerlendirme çalışması 2015-2016 öğretim yılının bahar döneminde gerçekleştirilmiş ve yaklaşık beş hafta sürmüştür. Genel olarak, mikro değerlendirme çalışması ile UZAMSAL-AR öğrenme aracının öğrencilerin uzamsal anlamaları ve öğrenme ortamındaki fırsatlar üzerindeki olası etkilerinin belirlenmesine yönelik veriler sağlamıştır.

2.4. Veri Analizi

Bu çalışmada veri toplama ve analiz süreci ilk evreden itibaren başlamış ve UZAMSAL-AR öğrenme aracı prototipi kararlı ve sorunsuz bir araç haline gelene kadar devam etmiştir. Çünkü eğitsel tasarım araştırmalarının doğası gereği, çalışmanın aşamaları boyunca da bulgular prototipi şekillendirirken, prototipin gelişimi de çalışmayı etkilemiştir. Genel olarak, her bir aşamanın çıktısı bir diğer aşamanın girdisi haline gelmiştir. Ayrıca bu aşamalar, tasarım, değerlendirme ve analiz mikro döngüleri içermektedir. Bu sebeple, her bir aşamada verinin sürekli olarak analiz edilme gerekliliği oluşmuştur. Bu sayede UZAMSAL-AR öğrenme aracı prototipinin hem tasarımında hem de uygulanmasında tespit edilen sorunlar, aşama bitmeden bir sonraki uygulama gününe kadar tespit edilip düzeltilmeye çalışılmıştır.

Bu çalışmada birçok farklı veri toplama aracı kullanılmıştır. İlk olarak, katılımcılarla yapılan görev temelli ve geriye dönük görüşmeler transkript edilerek yazıya dökülmüştür. Çalışma ortamında katılımcılar etkinlikler üzerinde çalışırken kaydedilen video görüntüleri ile katılımcıların kullandıkları tabletler veya akıllı gözlüklerin ekran video kayıtları eşleştirilmiş ve katılımcıların uygulama esnasındaki sözel olmayan hareketleri ve etkileşimleri ile sanal objeleri incelerken ki bakış açılarının çözümlenmesi gerçekleştirilmiştir. Ayrıca katılımcıların çalışma kağıtları ve gözlem notları da veri havuzuna eklenerek üçgenleştirme yöntemiyle bulguların güvenirliliği artırılmış ve elektronik olarak kayıt altına alınan ve saklanan verilerdeki kopmaları ve eksik yerleri tamamlama da kullanılmıştır. Bu nitel veriler, MAXQDA yazılımında ele alınarak işlenmiş ve verilerden ortaya çıkan kod ve kategoriler yine bu yazılımda tanımlanarak kodlar arası karışıklığı önlemek için not edilmiştir. Verilenden ortaya çıkan bu kodlar ve kategoriler alakalarına göre eşleştirilerek gruplanmış ve araştırma sorularına ile aşamaların amaçlarına göre şekillenen temalar altında analiz edilmişlerdir. Bu temalar, ilk ve ikinci aşama için UZAMSAL-AR öğrenme aracı prototipinin tasarlanma ve geliştirme sürecine odaklanırken, son aşama için ise son prototipin öğrencilerin uzamsal zeka gelişimine ve öğrenme ortamına sağladığı fırsatlara odaklanmıştır.

Bu çalışmanın son aşamasında öğrencilerin uzamsal zeka gelişimlerini anlamak için yine çalışma sürecinde geliştirilen ve 14 sorudan oluşan bir uzamsal zeka testi ön test ve son test olarak uygulanmıştır. Son aşamadaki örneklem küçük olduğu için öğrencilerin uzamsal zeka kazanımları Wilcoxon işaretli sıralar testi ile analiz edilmiştir.

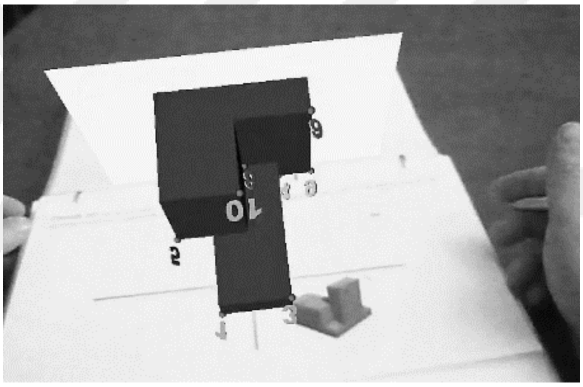
3. Bulgular

Çalışmanın bulguları prototip evresindeki üç aşama altında incelenecektir. İlk aşama bulgularında UZAMSAL-AR öğrenme aracının ilk prototipinin tasarlama ve gelişim süreci matematik eğitimi uzmanlarından toplanan verilere göre ele alınırken ikinci aşamada ikinci prototipin tasarlama ve gelişim süreci yedinci sınıf öğrencilerinden elde edilen verilere göre ele alınmıştır. Son aşamada ise son prototipin uzamsal zeka ve öğrenme fırsatları açısından olası etkileri ele alınmıştır.

3.1. Aşama I: Odak Grup Çalışması

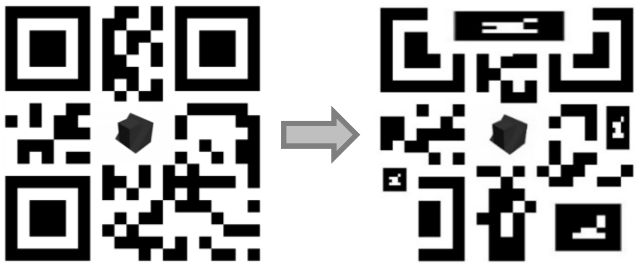
Bu aşamadaki veriler ışığında bulgular artırılmış gerçeklik ara yüzüne, kitapçığa ve uzamsal etkinliklere ilişkin bulgular şekline üç grupta ele alınmıştır.

Öncelikle, artırılmış gerçeklik ara yüzüne ilişkin bulgulara göre üç ana sorun ön plana çıkmaktadır. Bunlar, tanıma ve yansıtma sorunları, gecikme sorunları ve tasarımdan kaynaklanan iş yükü sorunlarıdır. İlk olarak, bu çalışmada hedef resimler gerektiren bir artırılmış gerçeklik ara yüzü Unity 3D oyun geliştirme yazılımı ve Vuforia yazılım geliştirme kiti kullanılarak tasarlanmıştır. Bu ara yüze hedef resimler olarak birbirinden kodlama olarak farklı olan kare kodlar kullanılmıştır. Fakat bu odak grup çalışmasında elde edilen verilere göre görsel olarak birbirine benzeyen hedef resimlerin kullanımı artırılmış gerçeklik ara yüzünde hedef resimleri tanımada ve bu hedef resimlerin üzerine ilişkili sanal cisimleri yansıtmada hatalara sebep olmuştur. Bu hatalar sebebiyle sanal cisimler ya yanlış hedef resimlerin üzerine yansıtılmış ya da doğru hedef resim üzerinde yanlış konumlara yansıtılmıştır (Şekil 2).



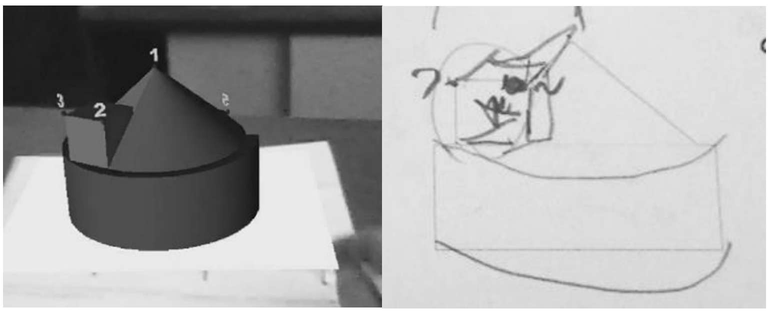
Şekil 2. Tanıma ve yansıtma sorunları

Aslında kare kodlar kodlama olarak birbirlerinden tamamen farklı olsalar da, geliştirilen ara yüz sadece görsel tanımlamalar ile hedef resmi belirlediği için bazı kare kodları ayırt edemediği görülmüştür. Bu sebeple, görsel olarak birbirlerinden tamamen farklı olacak şekilde kare kodları güncellemenin bu sorunu çözebileceği görülmüş ve kare kodlar bu şekilde yeniden tasarlanmıştır (Şekil 3).



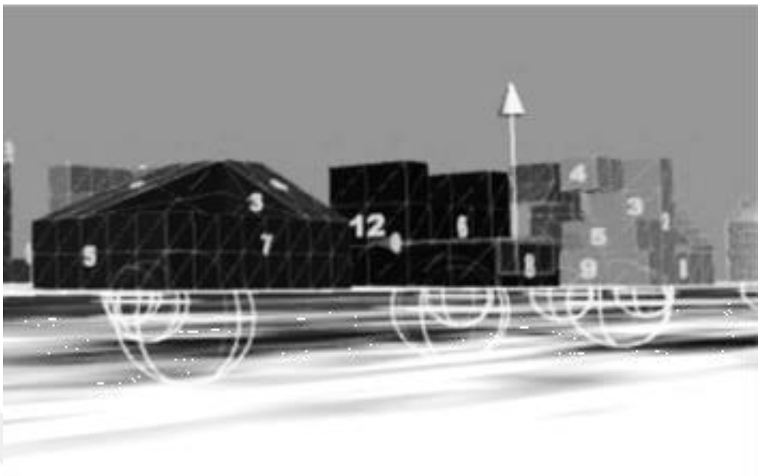
Şekil 3. Kare kodların görsel olarak yeniden tasarlanması

Bu odak grup çalışmasında gözlenen bir diğer tanıma ve yansıtma sorunu da katılımcıların sanal cisimleri her açıdan incelerken zorlukla karşılaşmalarıyla alakalıdır. İlk prototipteki artırılmış gerçeklik ara yüzü tasarlanırken sanal cisimler sanal uzayın başlangıç zemininden çizimlenmişlerdir. Bu zemin gerçek dünyada hedef resimlerin tam üstünü ifade etmektedir. Çalışmada ise katılımcılar sanal cisimleri tam ön, arka, sol ya da sağ tarafından incelemeye çalıştıklarında arayüz hedef resimleri göremediği için sanal cisimleri yansıtamamış ve katılımcılar tam ön olarak görebildikleri en alt seviyedeki görüntüyü ele almışlar ve bu perspektif çizim nedeniyle yanılgıya düşmüşlerdir. Hatta katılımcı çalışma kağıdında verilen ön yüz görünümün hatalı olduğunu savunarak ara yüzden görebildiği en son görüntüye göre bu ön yüz görünümünü düzeltmeye çalışmıştır (Şekil 4).



Şekil 4. Bir sanal cismin görülebilen tam ön yüzüne en yakın noktadaki son görüntü ve katılımcının yaptığı ön görünümü düzeltme hatası

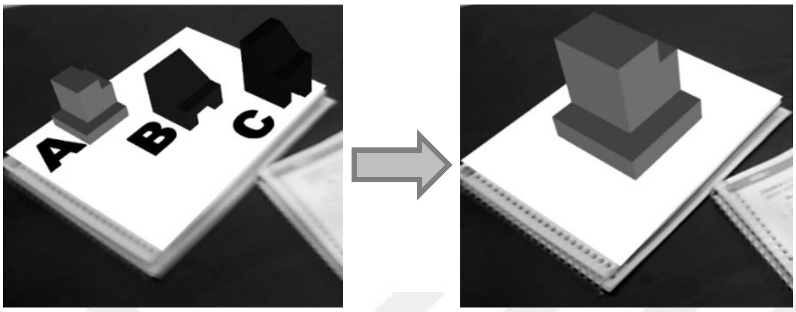
Bu sorunu önlemek ve artırılmış gerçeklik ara yüzünün hedef resmi kaybetmeden ön, arka, sol ve sağ görünümleri yansıtabilmesi için sanal uzayda bu cisimler birkaç seviye yükseğe çizimlenmiştir (Şekil 5). Bu sayede katılımcılar yan yüzleri incelerken sanal cisim hedef resmin biraz üzerine yansıtılacağı için artırılmış gerçeklik ara yüzünün de hedef resmi görmeye devam etmesi sağlanmıştır.



Şekil 5. Sanal cicimlerin sanal uzayda yeniden konumlandırılması

Artırılmış gerçeklik ara yüzüyle ilgili bir diğer sorun da hedef resimleri tanıma ve hedef resme ait olan sanal cismin yansıtılması arasında geçen sürenin beklenenden fazla olmasıdır. Bu sorunun olası sebebi olarak tek bir yazılım içinde 111 sanal nesne ve bu nesnelere ait hedef resimlerin kodlanmış olması düşünülmüş ve bu sebeple yazılımın uzamsal etkinlik seviyelerine göre beşe ayrılmasıyla, hedef resim veri tabanının küçültülmesi ile bu sorunun çözülebileceği düşünülmüştür. Böylece yazılım uzamsal etkinlik seviyelerine göre yüzeyler ve köşeler, yapıların yüzlerini eşleştirme, açınımlar, sayma ve ikinci boyut – çizimler şeklinde beş parçaya ayrılmıştır. Bu değişiklikten sonra da bu gecikme problemiyle bir daha karşılaşılmadığı gözlem notlarında görülmüştür.

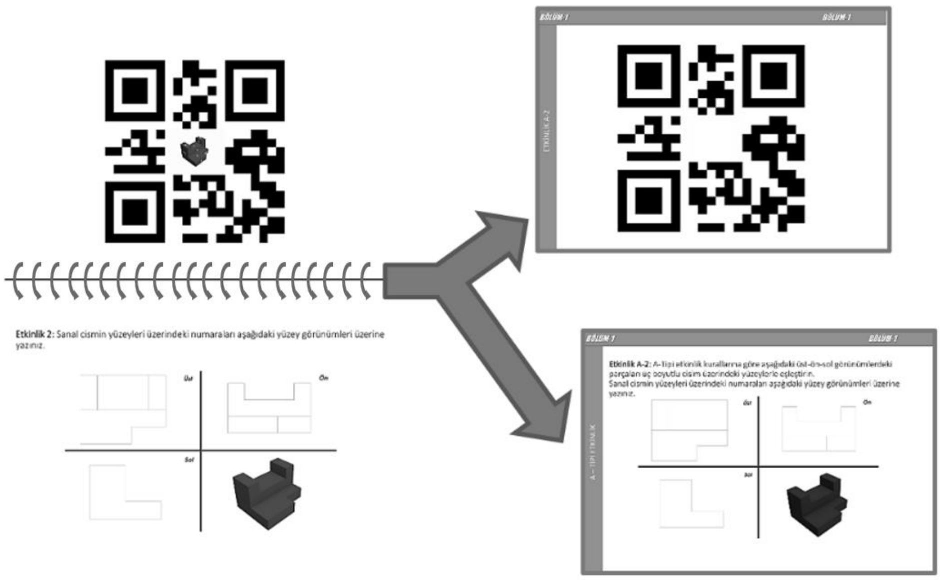
Bu ara yüz ile ilgili karşılaşılan son sorun ise tasarımdan kaynaklı nedenlerle katılımcıların fazla iş yükü ile karşılaşmaları ve etkinliğin amacından uzaklaşmalarıdır. Özellikle yapıların yüzlerini eşleştirme seviyesinde birden fazla sanal nesne tek bir sahnede yansıtılmış ve bu sanal nesnelerin ön, üst ve sol yüzey görünümleri de çalışma kağıtlarında verilmiştir. Bu seviyedeki etkinliklerde katılımcıların bu çoklu sanal nesnelerin yüzey görünümlerini bulmaları istenmiştir. Fakat çok sayıda nesnenin aynı sahnede verilmesinin fazladan iş yüküne sebep olduğu ve nesnelerin bazı yüzeylerinin incelenmesinde katılımcıların zorlandığı görülmüştür. Bunun önüne geçebilmek için çoklu nesneli sahnelerde gerektiğinde tek tek nesneleri seçip ayrıntılı bir şekilde incelenebilmesine olanak sağlamak için dokunmatik veya fare kontrol sistemleri için yeni kodlar yazılıma eklenmiştir (Şekil 6).



Şekil 6. Çoklu nesnelerde çalışma ve etkileşim

Odak grup çalışmasındaki bulgulara göre katılımcıların tasarlanan kitapçıkların kullanımında bazı sorunlarla karşılaştıkları görülmüştür. UZAMSAL-AR öğrenim aracının ilk prototipi hem hedef resimlerin hem de uzamsal etkinliklerin yer aldığı bir taslak öğrenci kitapçığı içermektedir. Ama katılımcıların sanal nesnelerin her yüzünü incelemelerini gerektiren etkinliklerde kitapçık büyük olduğu için ve etkinliklerle hedef resimler beraber verildiği için hedef resimleri hareket ettirmekte zorlandıkları durumlar olduğu gözlemlenmiştir. Bu sorunu aşmak için uygulama esnasında hedef resimler kitapçıktan kopartılmış ve katılımcılara ayrı ayrı verilmiştir.

Hedef resimler taşınabilir olduğu zaman sanal cisimleri incelemenin daha kolay olduğu bu sayede görülmüş ve kitapçık tasarımında tasarım ilkeleri belirlenerek kitapçık ikiye ayrılmış ve yeniden tasarlanmıştır (Şekil 7).



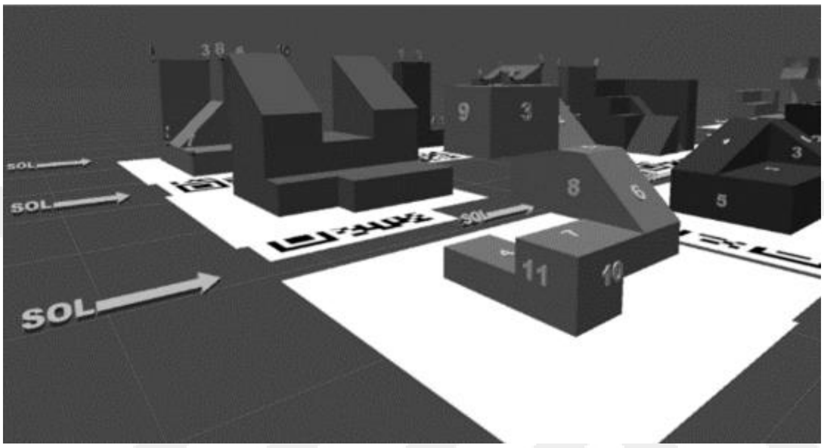
Şekil 7. Kitapçıkta tasarım değişikliği

Son olarak odak grup çalışmasının bulgularına göre uzamsal etkinliklerde de düzenlemeler yapılmıştır. Öncelikle bu çalışmada katılımcılara uzamsal etkinlikleri ve sanal nesneleri müfredata uygunluk açısından değerlendirmeleri için değerlendirme listeleri verilmiştir. Bu listedeki verilere göre katılımcılar açınımlar seviyesini yedinci sınıf kazanımlarına uygun bulmamışlar ve aslında buna yönelik kazanımların beşinci sınıf seviyesinde yer verildiği için o sınıf seviyesinde uygulanması gerektiğini ifade etmişlerdir. Bu sebeple açınımlar seviyesinde yer alan uzamsal etkinlikler çalışmadan çıkarılmışlardır. Ayrıca, bu listedeki sanal nesnelere ilişkin değerlendirmelere göre sanal nesnelerden bazıları ve dolayısıyla uzamsal etkinliklerden bazıları çalışmadan çıkarılmışlardır. Bu değişikliklere göre etkinlikler, kitapçıklar ve artırılmış gerçeklik ara yüzü yani UZAMSAL-AR öğrenim aracı yeniden tasarlanmış ve ikinci prototip hazırlanarak ikinci aşamaya hazır halde getirilmiştir.

3.2. Aşama II: Çözüm Çalışması

Bu aşamadaki verilere göre bulgular iki ana bölümde açıklanmıştır. Bunlar artırılmış gerçeklik ara yüzü, kitapçık ve etkinliklerle ilgili bulgulardır.

Öncelikle, artırılmış gerçeklik ara yüzünün kullanımında iki tür sorun ile karşılaşılmıştır. İlk olarak, öğrenciler artırılmış gerçeklik ara yüzü ile etkinlikleri uygularken bazı etkinlik tiplerinde sanal cisimlerin neresinin sağ neresinin sol olduğu karıştırdıkları görülmüştür. Bu sebepten sanal cisimlerin yönlerine ilişkin ipuçlarına ihtiyaç duymalardır. Başka bir deyişle eğer sanal cisimlerin yönleri etkinliklere etki eden bir durum ise bu cisimlerin yönlerine ilişkin ipuçlarıyla ilgili bir ihtiyaç ortaya çıkmıştır. Bu bulgu ışığında artırılmış gerçeklik ara yüzü sanal cisimlerin yönleriyle ilgili ipuçları verecek şekilde yeniden tasarlanmıştır (Şekil 8).



Şekil 8. Sanal nesnelerin yönleriyle ilgili ipuçları

Bir diğer sorun ise bir önceki aşamanın bulgularına göre parçalara bölünen yazılımın kullanımında yaşanan sıkıntılarla ilgilidir. Bu çözüm çalışmasında, öğrencilerin bir etkinlik seviyesinden diğerine geçerken yazılımı değiştirmeleri gerektiği için uzamsal etkinliklerden uzaklaştıkları ve dikkatlerinin dağıldığı tespit edilmiştir. Bunun önüne geçmek için yazılımlar arası geçişi kolaylaştırmak için bir açılış menüsü tasarlanmış ve geçişlerde öğrencilerin dikkatini dağıtmayacak hale getirilmiştir. Bu tasarım düzenlemesinde yazılım hala parçalar halinde olsa bile kullanıcı tarafından menüdeki butonlar yardımıyla geçiş yapılabildiği için bu ayrım fark edilmemiş ve yazılımlar arası geçişteki olası zaman kayıpları engellenmiştir.

Bu çözüm çalışmasında öğrencilerin kitapçıklarda verilen çalışma kağıtlarındaki etkinlik tipini ve öğrenciden beklenenlerin yazıldığı kısımları çoğunlukla göz ardı ettikleri gözlemlenmiştir. Bu sebeple, öğrenciler etkinlik tipi değiştiğinde kendilerinden beklenen etkinlik görevlerinin değiştiği bazı durumlarda fark etmeyerek, bir önceki etkinlik tipinin görevlerini yerine getirmeye devam etmiş ve bu nedenle etkinlikleri tamamlamakta zorluk yaşamışlardır. Bu sorunu çözmek için ise her bir etkinlik seviyesine birer giriş sayfası ve her bir etkinlik tipi içinde o etkinlikte öğrencilerden beklenenin ne olduğunu onlara gösterecek örnek etkinlikler tasarlanmasına karar verilmiştir. Bu sayede öğrenci açıklamaları okumasa bile örnek etkinlikler ile etkinlik tipinde beklenen görevleri görebilecek ve etkinlikler arası geçişlerin daha rahat farkına varabilecektir.

Ayrıca bu çalışmada öğrenciler uzamsal etkinlikleri beklenenden daha hızlı tamamlamışlardır. Bu durum büyük gruplarda çalışırken sıkıntılı olabilir. Çünkü büyük gruplarda öğrencilerin uzamsal zekaları arasındaki farklar, onların etkinliklerdeki performansını etkileyerek bazılarının erken bazılarının geç bitirmesine sebep olabilir ve bu durumda sınıf yönetimi zorlaşabilir. Bu nedenle bir önceki çalışmada çıkarılan bazı etkinliklerin kitapçığa ve artırılmış gerçeklik ara yüzüne tekrar dahil edilerek ek etkinlikler olarak UZAMSAL-AR öğrenim aracında bulunmasının daha uygun olacağı düşünülmüştür.

3.3. Aşama III: Mikro Değerlendirme Çalışması

Mikro değerlendirme çalışmasındaki bulgulara göre tasarlanan UZAMSAL-AR öğrenim aracı üçüncü prototipinin tasarım amacına ulaştığı ve düzenlenen tasarım ilkeleriyle uyumlu olduğu görülmüştür. Öğrenciler bu prototipi herhangi bir zorluk yaşamadan kullanabilmiş ve etkinlikleri takılmadan tamamlayabilmişlerdir. Bu sebeple UZAMSAL-AR öğrenim aracının artık bir son ürün olarak kullanılabileceği bu çalışmanın bulguları dahilinde söylenebilir. Bu nedenle, mikro değerlendirme çalışmasında toplanan veriler UZAMSAL-AR öğrenim aracının öğrencilerin uzamsal zekalarına olan olası etkileri ve öğrenme ortamına sağladığı olası katkılar açısından değerlendirilmiştir.

Öncelikle, öğrencilerin uzamsal zekalarına olan olası etkiler öğrencilerin kullandıkları uzamsal stratejiler, uzamsal zeka testinden aldıkları puanlar ve geriye dönük görüşmede verdikleri yanıtlara göre analiz edilmiştir. İlk olarak mikro değerlendirme çalışmasında öğrencilerin dört tip uzamsal strateji kullandıkları görülmüştür. Bu stratejiler “bir referans belirleme”, “bir yol takip etme”, “sayma ya da tahmin” ve “çerçeve veya ana hat çizme” stratejileri olarak adlandırılabilir. Bir referans belirleme stratejisini kullanarak öğrenciler sanal nesne üzerinde yer alan yüzler, yüzeyler, köşeler veya parçalardan kendilerine göre önemli olan birini belirleyerek bu sanal nesnede yer alan diğer parçaların yerlerini bu seçilen yeri referans alarak ve uzamsal ilişkili kullanarak ya da kullanmayarak bulmaya çalışmışlardır. Bir yol takip etme stratejisini kullanarak öğrenciler yine bir başlangıç noktasını belirlemişler ve bu başlangıç noktasından uzamsal ilişkileri dikkate alarak ya da almadan bir yol üzerinde ilerleyerek diğer parçaların yerlerini bulmuşlardır. Sayma ya da tahmin stratejisini kullanarak öğrenciler yapıları oluşturan birim küpleri sayarak ya da parçaların uzaklıklarını ve büyüklüklerini birim küp cinsinden tahmin etmeye çalışarak etkinlikleri gerçekleştirmişlerdir. Son olarak, çerçeve veya ana hat çizme stratejisini kullanarak öğrenciler sanal nesnelerin yüzey görünümlerini çizerken öncelikle nesnenin belirli bir yüzünü etrafından dolanırmışçasına bir çerçeve veya ana hat ile gösterip ardından bu çerçeve veya ana hattaki fazlalık ve eksiklikleri belirleyip iç ayrıntıları çizerek çizimi tamamlamışlardır.

Öğrencilerin çalışma süresince uzamsal zekalarındaki değişimi anlamak için öğrencilere bir uzamsal zeka testi hem ön test hem de son test olarak uygulanmıştır. Bu çalışmadaki örneklem küçük olduğu için Wilcoxon işaretli sıralar testi ile bu uzamsal zeka testinin puanları analiz edilmiştir (Tablo 1).

Ön test – Son test	N	Ortalama Sıra	Sıralamaların Toplamı	z	p
Negatif Sıralar	0	0,00	0,00	-2,539	0,011
Pozitif Sıralar	8	4,50	36,00		

Yukarıdaki tabloda görüldüğü üzere Wilcoxon işaretli sıralar testi analiz sonuçları, UZAMSAL-AR öğrenim aracı öğrencilerin uzamsal zekalarına ilişkin ön test puanları (Mdn = 7.50) ile son test puanları (Mdn = 9.50) arasında anlamlı bir artış olduğunu meydana çıkarmıştır (W=36, Z = -2.539, p = 0.011, r=0.63). Bu sonuçlar çalışmada hem karşılaştırma grubunun eksikliği hem de örneklemin küçük olması sebebiyle genellemede sıkıntılarla karşılaşabilir olmasına rağmen bu örneklem içerisinde tasarlanan UZAMSAL-AR öğrenim aracının uzamsal zeka gelişimi konusunda etkili olduğuna ilişkin önemli ipuçları sağlamaktadır.

Bunlara ek olarak, öğrencilerle gerçekleştirilen geriye dönük görüşmede uzamsal zeka testini çözerken zihinlerinde ne gibi şeyler canlandırdıklarına ilişkin birkaç soru sorulmuştu. Öğrencilerin bu sorulara verdikleri cevaplar ise çok önemli bulgulara ulaşılmasına neden oldu. Öğrenciler çalışma sonrasındaki uzamsal zeka testindeki soruları cevaplarken UZAMSAL-AR öğrenim aracındaki deneyimlerinden yola çıkarak üç boyutlu nesnelere yanlardan bakmanın ne demek olduğunu, üç boyutlu nesnelerin yanlardan nasıl görünebileceklerini ve iki boyutlu yüzey görünümlerin veya perspektif çizimlerin üç boyutlu nesneleri nasıl temsil ettiğini hatırladıklarını söylemişlerdir.

Bu nedenlerle öğrencilerin hem UZAMSAL-AR öğrenim aracı kullanırken hem de sonrasında uzamsal zeka testini çözerken üç boyutlu nesneleri uzamsal olarak düşünebildikleri ve iki boyutlu gösterimleriyle ilişkilendirebildikleri bu bulgularda ortaya çıkmıştır. Fakat uzamsal zekaya olası katkılar incelendiğinde, bu araştırmada kullanılan tabletler ve akıllı gözlükler arasında herhangi bir farklılığa ilişkin bulguya rastlanmamıştır. Çalışma süresince ve sonrasında öğrenciler kullanılan cihazın uzamsal anlamalarına etkisi konusunda olumlu ya da olumsuz geri dönütlerde bulunmamışlardır.

UZAMSAL-AR öğrenim aracının öğrenme ortamına sağladığı olası katkılara ilişkin bulgularda ise kullanılan mobil cihaza ilişkin iki tip farklılık gözlemlenmiştir. Öncelikle tablet kullanan öğrenciler öğrenme ortamında genel olarak ayakta ve kitapçığın etrafında tabletleri ile gezerek sanal nesneleri incelemişlerdir. Aynı zamanda akıllı gözlük kullanan öğrenciler ise genel olarak sandalyelerinde oturarak ve kitapçıkları ellerinde hareket ettirerek ya da çevirerek sanal nesneleri incelemişlerdir.

Ayrıca bir diğer farklılık da öğrencilerin inceledikleri sanal nesnelere ilişkin kullandıkları cihazın ekranındaki bakış açılarını grup arkadaşlarına ifade şekillerinde ortaya çıkmıştır. Tablet kullanan öğrenciler tabletin ekranını direk olarak grup arkadaşına gösterebildikleri için el hareketleri ile ekranı işaret ederek bu bakış açılarını diğerleriyle paylaşabilme imkanına sahip olmuşlardır. Fakat akıllı gözlük kullanan öğrenciler sanal nesnelere ilişkin bakış açılarını grup arkadaşına ekranı göstererek paylaşma imkanına sahip olmadıkları için bu bakış açılarını yol ya da adres tarif edercesine üstünde, altında, sağında, solunda ve benzeri nesne temelli ifadelerle grup arkadaşlarına açıklamışlardır.

3.4. Bulguların Özeti

Özet olarak bu prototip geliştirme evresi boyunca UZAMSAL-AR öğrenim aracı ve bu araca çerçeve oluşturan tasarım ilkeleri bulgulara göre biçimlendirici bir şekilde değerlendirilmiş ve son halleri verilmiştir. Son aşamada, bu araç yedinci sınıf öğretim programıyla ilgili, tasarım aşamasında tutarlı, uygulamada pratik ve öğrencilere de olası etkileri olduğunu göstermiştir. Bulgulara göre, son aşamaya gelindiğinde bu araçtaki önemli sorunların düzeltilmiş ve uygulamada sorunsuz ve tutarlı olduğu görülmüştür. Bu nedenle hem bu aracın hem de bu araca yol gösteren tasarım ilkelerinin doygunluğa ulaştığı söylenebilir.

4. Tartışma ve Öneriler

Bu bölümde araştırmanın bulguları uzamsal zekanın geliştirilmesine yönelik artırılmış gerçeklik öğrenme ortamının özellikleri, UZAMSAL-AR öğrenim aracının uzamsal zekaya ve öğrenme ortamına olası katkıları ve öneriler olmak üzere üç ayrı grupta ele alınmıştır.

4.1. Artırılmış Gerçeklik Öğrenme Ortamının Özellikleri

Ön araştırma evresinde artırılmış gerçeklik öğrenme ortamlarında uzamsal zekanın gelişimine ilişkin taslak tasarım ilkeleri alanyazından derlenmiş ve eğitsel tasarım araştırması boyunca bulgulara göre süzgeçten geçirilerek ve gerekli eklemeler yapılarak düzenlenmiştir. Bu tasarım ilkeleri UZAMSAL-AR öğrenim aracının tasarlanmasında ve uygulanmasında bir çerçeve sağlayarak bu çalışmanın teorik çerçevesini oluşturmuştur. Son UZAMSAL-AR öğrenim aracı prototipi aşağıda bahsedilen son tasarım ilkelerine göre yeniden düzenlenmiş ve tasarlanmıştır.

Öncelikle artırılmış gerçeklik öğrenme ortamının uygulamaya yönelik özellikleri olarak üç ana ilkeden bahsedilebilir. Bunlar; etkileşimler, aktif öğrenme ve öğretmenin düzenleyici rolüdür. İlk olarak, artırılmış gerçeklik öğrenme ortamı uygulama esnasında öğrencilere eşsiz öğrenme ve etkileşim fırsatları sağlamalıdır. Bu fırsatlar artırılmış gerçeklik ara yüzü aracılığıyla sanal nesnelerle doğal yollardan etkileşimde bulunma ile sağlanabilir. Öğrenme ortamının sağladığı bu fırsatlar Lai (2011)'nin de ifade ettiği yüz-yüze etkileşim ve Matcha ve Rambli (2011)'in belirttiği artırılmış gerçekliğin öğrenme ortamına katkılarıyla benzerlik göstermektedir. İkinci olarak, öğrenciler bu öğrenme ortamı içerisinde aktif öğrenmeye teşvik edilmelidir. Bu araştırmada, Szalavari ve diğerleri (1998) ve Smith ve MacGregor (1992)'un da ifade ettiği gibi, öğrenciler zorlayıcı etkinlikler ve artırılmış gerçeklik ara yüzünden kendi özel ve eşsiz bakış açılarını seçebilme özgürlüğüyle aktif öğrenmeye teşvik edilmişlerdir. Son olarak, artırılmış gerçeklik ara yüzleri öğretmenlere de öğrencilerin öğrenmelerini düzenlemede etkinlikler seçmede ve ek bilgileri zamanında sağlamada eşsiz fırsatlar sağlamalıdır. Bu çalışma da tasarlanan mobil artırılmış gerçeklik uygulaması öğretmenlere, öğrenci seviyesine uygun etkinlik sağlayabilme ve gerektiği durumlarda ek bilgi verebilme gibi olanak sağlamıştır. Böylece, Smith ve MacGregor'un (1992) da belirttiği gibi öğretmen zihinsel öğrenme deneyimlerinin tasarımcısı rolüne bürünmüş ve öğrenmeyi düzenlemiştir.

Artırılmış gerçeklik öğrenme ortamı yukarıdaki bahsedilen özellikleri sağlayabilmek için bir artırılmış gerçeklik ara yüzüne ihtiyaç duymaktadır. Bu ihtiyacı karşılamak için tasarlanan ara yüz araştırma boyunca şekillenen artırılmış gerçeklik ara yüzlerinin temel elemanlarına ilişkin tasarım ilkeleri dikkate alınarak tasarlanmıştır. Bu ilkeler ilk ikisi artırılmış gerçekliğin tanımından gelen ve temel unsurları oluşturan nesnelerin sanallığı ve ortamın zenginleştirilmesi ilkeleridir. Bu iki ilke en basit manadaki bir artırılmış gerçeklik ara yüzünü tanımlayan ve bu ara yüzü sanal gerçeklikten ayıran ana elemanlardır. Bu iki temel elemana ek olarak dört tasarım ilkesi de bu araştırmanın sonuçlarına göre düzenlenmiştir. Bunlardan ilki tanıma ve yansıtma ilkesidir. Bu ilkeye göre, eğer hedef temelli bir artırılmış gerçeklik ara yüzü tasarlanacaksa, hedef resimler ara yüz tarafından tanımlanabilecek şekilde ayrıntılı ve farklı olmalıdır.

Ayrıca sanal nesnelerin sanal zeminden daha yüksek konumlarda çizimlenmesi yansıtmada daha akıcı ve gerçekçi sonuçlar doğuracaktır. Diğer bir ilke ise referans bilgi ilkesidir. Bu ilkeye göre artırılmış gerçeklik ara yüzü öğrencilerin bu öğrenme ortamına alışmasını kolaylaştıracak ve artırılmış gerçekliğin temel mantığını fark ettirecek referans bilgiler içermelidir. Bir diğer ilke ise etkileşim ilkesidir. Buna göre, artırılmış gerçeklik ara yüzleri özellikle çoklu sanal nesnelerin incelenmesini içeren sahnelerde bu nesneler arasında seçimler yapılmaya imkan veren etkileşim özelliklerine sahip olmalıdır. Son ilke ise tasarımda birlik ilkesidir. Bu ilkeye göre, artırılmış gerçeklik ara yüzleri etkinliklerin ilerleyişine uygun şekilde tasarlanmalı ve öğrencilerin etkinlik geçişlerinde dikkatlerini dağıtacak unsurlar barındırmamalıdır. Görüldüğü üzere bu ilkelerden bazıları direk olarak öğrenme ortamındaki eşsiz fırsatları desteklerken diğerleri kusursuz ve düzgün çalışan bir yazılım sağlayarak bu ortamı dolaylı yoldan desteklemektedir. Bu özellikler ve ilkeler Azuma (1997), Kaufmann (2004), Hedley (2003), Shelton (2003) ve Szalavari ve diğerlerinin (1998) belirttiği artırılmış gerçeklik arayüzlerinin özellikleriyle benzerlik göstermektedir.

Bu araştırmadaki artırılmış gerçeklik ara yüzü hedef temelli olduğundan sanal nesneleri yansıtmak için gerekli konum bilgilerini bulmak için gerçek dünyadan hedef resimlere ihtiyaç duymaktadır. Bu sebeple hem etkinlikleri hem de hedef resimleri içeren kitapçık tasarlanmıştır. Araştırma başında tek bir kitapçıkta kullanıcıya sağlanan bu etkinlikler ve kare kodlar araştırmanın bulguları ışığında ikiye ayrılmış ve iki kitapçık arasında geçişleri kolaylaştırmak için bazı tasarım ilkeleri oluşturulmuştur. Bu tasarım ilkelerine göre hedef temelli artırılmış gerçeklik ara yüzlerinde çalışma kağıdı kullanılacaksa taşınabilirliği artırmak açısından hedef resimler ve çalışma kağıtları öğrencilere ayrı ayrı verilmelidir. Bu ayrı ayrı sağlanan hedef resimleri ve çalışma kağıtlarını öğrencilerin eşlemeleri ve karıştırmamaları için bu kağıtlar görsel ipuçları içerek şekilde tasarlanmalıdır. Ayrıca bu çoklu tasarımda görsel tasarım ve sayfalama hedef resimler ve çalışma kağıtları arasında benzer olmalıdır. Bu sayede öğrenci hangi hedef resmin hangi çalışma kağıdına ait olduğunu sadece görsel ipuçlarını kullanarak kolaylıkla bulabilir. Ek olarak, birden fazla etkinlik çeşidi öğrencilere sağlanacaksa her bir etkinlik çeşidi için, eğer gerekliyse, örnek etkinlik uygulamaları tasarlanmalıdır. Bu tasarım ilkelerinin sağladığı fırsatlar Sugimoto, Hosoi ve Hashizume'nin (2003) ifade ettiği aktif öğrenme ve taşınabilirlik arası ilişkilere benzemektedir.

Son olarak, bu öğrenme ortamının özelliklerinden biri olan zorlayıcı etkinlikler sağlama alanyazındaki uzamsal zeka geliştirmeye yönelik olan modellerden ve önerilen uzamsal içeriklerden derlenmiş ve araştırmanın bulgularına göre de düzenlenerek artırılmış gerçeklik ortamıyla uzamsal zekanın gelişimi için bir model çerçevesinde hazırlanmıştır. Bu model dört seviyeden oluşmaktadır. İlk iki seviye olan yüzeyler ve köşeler ile sayma etkinlikleri öğrencilerin artırılmış gerçeklik ortamlarına uyumunu hızlandıracak sanal nesneleri mümkün olan her açıdan incelemeye yönelik içeriklerden oluşmaktadır. Bu seviyelerdeki etkinliklerin Dunleavy, Dede ve Mitchell'in (2009) de belirttiği gibi öğrencilerin artırılmış gerçekliğe alışmasını sağladığı ve bu farklı ortamın yenilikçi etkilerini belirli bir kullanımdan sonra ortadan kaldırdığı görülmüştür. Öğrenciler belirli bir yerden sonra artırılmış gerçekliği sanki aşina oldukları bir materyalmişçesine kullanmaya başlamışlardır. Diğer son iki seviye olan yapıların yüzlerini eşleştirme ve ikinci boyut çizimler ise öğrencilere iki boyutlu gösterimler ile üç boyutlu nesneler arası ilişkileri ve iki boyutlu uzamsal bilgilerin üç boyuta aktarılmasına yönelik bilgiler ve deneyimler sağladığı belirlenmiştir. Benzer şekilde, bu modelin başlangıç noktası olan modeller ve uzamsal içeriklerde de (Perez-Carrion & Serrano-Cardona, 1998; Sack, 2013; Wiesen, 2004) bu tip katkıların sağlanabildiği belirtilmiştir. Bu model ile öğrenciler sanal nesneler ile artırılmış gerçeklik ortamına hızlı bir şekilde alışabileceği gibi uzamsal zekalarını da kullanabilecekleri fırsatlar elde edebilmektedirler.

4.2. Uzamsal Zekaya ve Öğrenme Ortamına Olası Katkılar

Bu araştırma tabletler ve akıllı gözlükler kullanılarak gerçekleştirilmiştir. Fakat kullanılan cihazın uzamsal anlamaya herhangi bir olumlu ya da olumsuz etkisi olduğuna dair bir sonuca ulaşılamamıştır. Bu bulgular ışığında, UZAMSAL-AR öğrenim aracının cihaza özel bir farklılığının bulunmadığı ve her iki cihazda da benzer şekilde etki oluşturduğu söylenebilir. Ayrıca son aşamada uzamsal zeka seviyeleri birbirinden farklı olan öğrenci gruplarıyla çalışılmıştır. Bulgulara göre öğrenciler uzamsal zeka seviyeleri fark etmeden UZAMSAL-AR öğrenim aracından benzer şekilde yararlanmışlardır. Bu sebeple, bu aracın uzamsal zeka farkı gözetmeksizin uzamsal zekanın iyileştirilmesinde kullanılabileceği söylenebilir. Bu sonuçlara göre, tasarlanan bu araç alanyazında yer alan "telafi edici olarak uzamsal zeka" (Hays, 1996; Mayer & Sims, 1994) ve "geliştirici olarak uzamsal zeka" (Mayer & Sims, 1994) hipotezlerinin ikisine de benzer şekilde hitap edebilmektedir. Ayrıca, öğrencilerin uzamsal etkinlikler boyunca çözümsel ve bütünsel yaklaşımları barındıran farklı tip stratejileri oluşturabildikleri, kullanabildikleri ve etkinlik tipine göre düzenleyebildikleri görülmüştür. Bu stratejilerin alanyazında da benzerleri veya türevleri bulunmaktadır (Glück & Fitting, 2003; Workman & Lee, 2004). Öğrencilerin kullandıkları stratejileri etkinlik tipine göre ve istenilen görevlere göre düzenleyebilmeleri uzamsal zekanın işe koşulduğunun birer göstergesidir (Glück & Fitting, 2003). Yine benzer şekilde, öğrencilerin bir önceki etkinlik tipindeki deneyimlerini ve stratejilerini bir sonraki etkinlik tiplerindeki yeni durumlara aktarabilmeleri de Khoza ve Workman (2009) ile Strong ve Smith'e (2002) göre onların uzamsal zekalarının geliştiğini gösteren durumlardandır.

Araştırmanın bulguları, UZAMSAL-AR ara yüzünün öğrenme ortamlarına da olası katkılarda bulunduğunu göstermiştir. Bu katkılar beş nitelik ile tanımlanabilir. İlk olarak doğallık, öğrenme ortamında gerçekliği taklit ederek sanal nesnelerin sağlanmasını ifade eder. Bu sayede, Kaufmann'ın (2004) da belirttiği gibi öğrenciler bu artırılmış ortamda sanal nesnelerle doğal etkileşimlerde bulanabilir. Bireysellik, her bireyin sanal nesneler için kendine has bakış açısının olması demektir. Szalavari ve diğerleri (1998) görüş açısındaki bağımsızlık yapısı ile bundan bahsetmişlerdir. İşbirliği, ortamdaki her bir bireyin aynı sanal ortamı paylaşmaları ve birbirileriyle direk etkileşime girebilmeleri ile ilgilidir. Benzer şekilde bu özellik Szalavari ve diğerleri (1998) tarafından belirtilen paylaşma ve bireysellik, Davidson (1994) tarafından belirtilen işbirlikli davranış yapılarıyla benzerlik göstermektedir. Destekleyicilik ise öğrencinin anlama seviyesine uygun etkinlikler sağlamak ve gerektiğinde yardımda bulunmakla ilgilidir. Davidson (1994) tarafından da belirtildiği gibi öğretmen ve öğrenci arası bir olumlu bağımlılık bulunmaktadır. Son olarak taşınabilirlik de öğrenme ortamında serbest şekilde dolaşabilmeyi ifade eder. Bu sayede, Sugimoto ve diğerlerinin (2004) belirttiği gibi öğrenciler sanal nesneleri istedikleri bakış açılarından inceleyebilir ve bu sayede öğrenme ortamının esas ve aktif katılımcıları olurlar.

4.3. Öneriler

Araştırmanın bulguları UZAMSAL-AR öğrenim aracının pratik uygulamalarını ve yedinci sınıf öğrencileri üzerindeki olası katkılarını göstermiştir. Bu sebeple, matematik derslerinde öğrencilerinin uzamsal zeka farklarını telafi etmek ve geliştirmek isteyen öğretmenler bu aracı derslerinde uygulayabilirler. Ayrıca bu araç iki boyutlu gösterimlerle üç boyutlu nesneleri ilişkilendirememekten ortaya çıkan bilişsel engel sorununa önerilen bir çözüm yolu olarak gösterilebilir. Genel olarak, öğretmenler bu aracı Fatih projesi kapsamında dağıtılmaya devam eden tabletlerde kullanılacak yeni bir öğretim aracı olarak ve öğrencilerde yenilikçi bir öğrenim aracı olarak deneyimleyebilirler. Bunun dışında, öğretim programı geliştirmede artırılmış gerçeklik ortamlarına yönelik deneyimler sağlamak için bu araştırma kapsamında düzenlenen tasarım ilkeleri yol gösterici olarak kullanılabilir. Ayrıca ders kitaplarını hedef temelli artırılmış gerçeklik ortamlarına uyarlamada da kitapçıklar için düzenlenen tasarım ilkelerinden faydalanılabilir.

Araştırmacılar ise bu araştırma kapmasında geliştirilen UZAMSAL-AR öğrenim aracının farklı sınıf seviyelerinde ne gibi etkilere sahip olduğunu araştırabilirler. Ayrıca düzenlenen tasarım ilkelerini başka sınıf düzeyleri ve başka konulara veya derslere uyarlayarak kendi çalışmaları için başlangıç noktası olarak kullanabilirler. Bu çalışmada bir değerlendirme evresi olmadığı için bu çalışma UZAMSAL-AR öğrenim aracının ve tasarım ilkelerinin gerçek etkilerini açıklamada yetersiz kalmaktadır. Bu sebeple araştırmacılar daha büyük örneklem ile hedef öğrencilerde kendi sınıf ortamlarında bu aracın gerçek etkilerini araştıran çalışmalar yapabilir.

Son olarak, artırılmış gerçeklik özellikle Türkiye'de ve eğitim ortamlarında yeni gelişen bir alan olduğu için, araştırmacılar farklı sınıf düzeyleri için farklı derslerde ve farklı alanlarda artırılmış gerçeklik ortamlarına ilişkin yol gösterici ilkeleri ve bu ilkeler doğrultusunda geliştirilen ortamların etkilerini ortaya çıkaracak tasarım araştırmaları yaparak, bu yenilikçi alana katkı yapabilirler. Bu sayede eğitimciler tasarım araştırmaları ile geçerliliği, güvenirliliği ve etkileri araştırılmış olan artırılmış gerçeklik uygulamaları ile derslerini zenginleştirebilir ve öğrencilerin öğrenmelerini yenilikçi yollarla destekleyebilirler.

APPENDIX K: Tez Fotokopisi İzin Formu

ENSTİTÜ

Fen Bilimleri Enstitüsü	☐
Sosyal Bilimler Enstitüsü	☐
Uygulamalı Matematik Enstitüsü	☐
Enformatik Enstitüsü	☐
Deniz Bilimleri Enstitüsü	☐

YAZARIN

Soyadı : ÖZÇAKIR
Adı : BİLAL
Bölümü : İLKÖĞRETİM BÖLÜMÜ

TEZİN ADI (İngilizce) : Fostering Spatial Abilities of Seventh Graders Through Augmented Reality Environment in Mathematics Education: A Design Study

TEZİN TÜRÜ : Yüksek Lisans ☐ Doktora ☐

1. Tezimin tamamından kaynak gösterilmek şartıyla fotokopi alınabilir. ☐
2. Tezimin içindekiler sayfası, özet, indeks sayfalarından ve/veya bir bölümünden kaynak gösterilmek şartıyla fotokopi alınabilir. ☐
3. Tezimden bir bir (1) yıl süreyle fotokopi alınamaz. ☐

TEZİN KÜTÜPHANEYE TESLİM TARİHİ: