Preliminary Study of JunoBlock: Marker-Based Augmented Reality for Geometry Educational Tool

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Abstract. Augmented reality (AR) is one from many multimedia technologies which allows computer-generated content to be seamlessly overlaid and mixed into humans' perceptions of the real world. In educational field, many researchers believe AR technology can improve user interface technology and has a huge potential implication as well as numerous benefits from the virtual augmentation of learning environments or even a teaching process. However, in the earlier researches about AR geometry educational tool, researchers did not use any pedagogical approach in its application design process. In fact, a pedagogical approach is needed for creating an effective educational application to make sure students' learning time is spent productively. In this research, we try to create AR geometry educational tool by using design-based learning and game-based learning approach to create a better geometry educational tool. Furthermore, the application also used iterative software development lifecycle that requires a series of prototype to find the best AR game mechanics in geometry learning process.

Keywords: Augmented reality · Design-based learning · Game-based learning
Technology-supported learning

1 Introduction

Augmented reality (AR) is one from many multimedia technologies which allows computer-generated content to be seamlessly overlaid and mixed into humans' perceptions of the real world [1]. AR as technology is often associated with expensive hardware that requires significant processing capability, head-mounted displays (HMDs), or even wearable computers. In recent years, with the rapid advances of mobile technologies, a wide variety of AR technology can be implemented by much simpler solutions, such as a laptop with web camera or even a mobile phone [2]. For example, researchers have created location-based AR application which used location-based service on two different mobile operating systems, iOS and Android [3].

In educational field, many researchers believe AR technology can improve user interface technology and has a huge potential implication as well as numerous benefits from the virtual augmentation of learning environments or even a teaching process [1, 4–6]. The number of possible educational benefits regarding the use of AR is related to; being safer and cheaper to reproduce and virtual objects that can easily be animated

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(engage students into learning process), be modified and transformed by users' actions (create interactive learning process), be combined seamlessly with other media (can be integrated with another multimedia technologies) and not constrained by the law of physics like a real object (enable students to have private sandbox for learning). As a technology in educational field, AR is often used to increase the students' interest in certain subjects through the implementation of AR books, games, discovery-based learning apps, object modelling apps, and skill training apps [1].

For example, in discovery-based learning, researchers have created the EXPLOAR project that involves visitors of science museums and science centers in extended episodes of playful learning [4]. By using personalized wearable system that enhances conventional teaching with natural types of learning with virtual content, EXPLOAR is proven to be able to increase intrinsic motivation of the learners. In addition, after using an additional device, to increase users' intrinsic motivation, EXPLOAR also took pedagogical design to use AR system as content delivery system for informal learning for quite diverse target groups. The pedagogical design is implemented in EXPLOAR by allowing the users to easily adjust the information's complexity level of the presented content to meet their learning background.

In another research, through the implementation of object modelling approach, researcher has created Construct3D, a collaborative application that uses see-through head-mounted displays for implementing AR-based geometry education tool [7]. Construct3D also promotes and supports discovery-based learning through dynamic geometry construction using a stylus as an input tool to AR system. Just like EXPLOAR [4], Construct3D is also proven to enhance students' understanding by enabling visualisation and observation of virtual objects to the real world.

In this research, JunoBlock tries to create an AR system by putting object modelling approaches and discovery-based learning approach into a game. The focus of this application is to help the students' learning process about geometry objects. JunoBlock tries to improve the learning process by allowing its users to construct virtual 3D objects to the real world using a 3D object's general properties (nodes and edges). Unlike Construct3D [7] and EXPLOAR [4], JunoBlock is designed to work on mobile devices. JunoBlock takes this approach since three-quarters of all children aged 8 and below have access to some type of "smart" mobile devices at home [8]. By using mobile devices, we are also improving the accessibility level of JunoBlock. Although the system is designed for mobile devices, we keep the performance high so it still provides a better and reliable user experience.

2 Previous Works

Before the design and software implementation of JunoBlock is conducted, our research team conducted a review from the earlier researches related to AR technology in geometry learning. Based on the results of the review, we found some related research that could be used as references in creating a better geometry learning tool. The general information related to these researches can be seen in the Table 1.

Table 1. AR technology implementations in geometry learning.

Title	Context	Limitations	Findings
Collaborative Augmented Reality in Education	First use of AR technology in geometry education	Performance, size and weight of hardware technology in early 2000	See-through HMD is preferable by users. AR applications that uses see-through HMD can cause several usability problems
Development of an Interactive Book with Augmented Reality for Teaching and Learning Geometric Shapes	Interactive AR book to support learning of main geometric shapes	Only focusing on spatial visualization	AR book capable of contributing effectively to the development of educational supportive system. AR book also has a highly promising resource compared to other educational system with AR
Geometry Learning Tool for Elementary School using Augmented Reality	AR application for creating virtual protractor to measure angle	Only focus on line and angle visualization Application user interface is not well defined	The use of AR technology increases students' motivation in geometry learning. AR could make learning process become faster compared to using conventional method
Cyberchase Shape Quest: Pushing Geometry Education Boundaries with Augmented Reality	AR game for elementary school children	The game requires a set of printed physical paper block	AR can cause a major problem related to game mechanics that involves AR. Designing AR games requires an iterative design process. AR developers need to conduct testing early and often as well as to involve different domain experts in the development process
An Augmented Reality Application with Hand Gestures for Learning 3D Geometry	Framework for learning geometry using AR and hand gestures recognition technologies	Framework needs additional devices to recognize users' hand gestures as an input	AR technology can be well integrated with other technologies. Combination of AR technology and hand gesture recognition devices can increase students' level of understanding in geometry learning application

As we can see from the Table 1, first use of AR technology as geometry learning supportive tools was done in 2003 [7]. In this research, researchers created mobile collaborative AR system called Construct3D. Construct3D focuses on improvement in the learners' spatial abilities at high school and university level. Construct3D takes a basic assumption that the learning process will take place naturally through the simple exploration and discovery of the virtual environment. Based on this basic assumption, Construct3D takes the constructivist theory to create such system that enables the learning activities through process of building 3D objects. To achieve natural communication among its users and combine virtual objects into real world, Construct3D uses see-through HMDs that is connected via cable to single distributed system that has a capability to overlay computer-generated images into the real world [7, 9].

By the Construct3D evaluation process, there are several problems related to the technical aspect and affective parameter in the uses of AR technology. The problems are related to unpredictable software's response time, the requirement of the software which is little time to learn, and motion sickness that is caused by several factors such as accommodation problems; low frame rate and lag or bad fitting helmets. Despite of the negative effects, majority of students think Construct3D is "easy to use", "encourages learners to try new functions" and "can be used consistently". Although the researchers have not yet focused on evaluating the use of AR, the researchers have a thesis that mentioned by working directly in a 3D space provided by AR technology, complex spatial problems can be better understood and faster compared to traditional methods [9].

In 2012, researchers have developed an interactive AR book for learning geometric shapes called GeoAR [10]. GeoAR enriches the contents presented in a traditional book by the uses of AR markers to augment virtual 3D objects into the real world. GeoAR uses images, animations, 3D objects, narrated explanations and sound effects to explain basic concepts of Geometry related to the main geometric shapes and its calculations. GeoAR utilization requires GeoAR printed book and a computer with a webcam and a video monitor. Through the evaluation process of GeoAR, researchers consider that the use of AR book has a great capability to contribute effectively in supporting the teaching and learning process.

The next two years after GeoAR research, other researchers, have created a geometry learning tool to visualise (augmenting digital lines to the real world) and measure 180-degree angle by the uses of AR marker as a vertex [11]. As the researchers have concluded, because students and teachers do not need to redraw the lines every time the vertex changed, the learning process becomes faster. This research uses a projector, a wooden box with mirror as a projection's reflector from a projector, computer that runs the application and a webcam. The research found that AR can be used to increase the students' interest in mathematics and to make the learning process become faster compared to conventional methods.

In 2015, researchers have created a collection of mini games that contain AR games as one of its collection, known as Cyberchase Shape Quest [12]. Cyberchase Shape Quest is a free game that is available for camera-enabled Android, iOS and Kindle tablets. The AR game in Cyberchase Shape Quest has a focus in solving 3D geometry and spatial cognition problem. The core idea of the game is to encourage children to engage in spatial problem thinking in a fun puzzle game environment. The game is built based on game design theory, the flow channel. At the beginning of the game, the puzzle inside the game is relatively easy, later it become more challenging as players gain mastery.

The evaluation process confirmed that AR game can deliver learning material through multiple levels in the game in a fun way and reinforce students' learning motivation to beat multiple puzzles that are provided in game.

Besides the findings about AR application on geometry learning process, researchers who created the Cyberchase Shape Quest also mentioned a Software Development Lifecycle method that can be used for creating AR application. This SDLC method involved a team of producers, game designers, technological experts and educational specialists in the earliest stage of the software design process. The group of experts discussing about which math topic was best suited for AR technology and its potential as well as the game mechanics which utilize AR technology. After the discussion session, this team of experts also created a series of prototype. Each of the prototypes is evaluated to the target users to find the best mechanics, usability and level design provided in the final game.

Recent researches related to AR technology in learning have been done by researchers in 2017 [13]. The focus of this research was to develop an AR and hand gesture based application for learning 3D geometry in an easy and convenient way. With combination of both technologies, the students can understand the basic concepts of 3D objects interactively and intuitively through AR ability to provide a dynamic visualization of 3D structures in a real world and direct 3D objects manipulation using their hand gesture. The application offers several functions related to 3D geometry learning process including constructive solid 3D geometry using union, subtraction and intersection operation as well as 3D construction process from a set of 2D shapes. Based on the evaluation process, AR application with hand gestures recognition is proven to provide an easy and convenient way of learning 3D geometry compared to traditional method by the uses of pen, paper and imagination. Researchers also suspect that through the addition of collaborative method (remote cooperation between students) in AR application will improve the learning quality in it.

The use of HMD devices in AR application can surely raise several problems as mentioned by other researchers [9]. However, referring to the capabilities of HMD devices to naturally combine virtual objects into the real world, preferably, an AR application is designed to support the usage of HMD devices. To solve several technical problems in the use of HMD devices, unpredictable software response time and all technical factor that cause motion sickness in AR application must be identified. AR application should be developed by the uses of fundamental and optimal process of AR application [14, 15]. In addition to the uses of see-through HMD devices, to increase interactivity between player and AR application, AR application can be integrated with hand tracking recognition devices [13]. The combination of AR technology with these devices is certainly able to increase students' motivation in geometric learning through the immersive experience.

To keep students' motivation high along with the increasing level of difficulty of the material presented in the AR application, an application can be designed as a game [12]. By putting students into game's flow channel, a game will reinforce students to stay focus in solving the learning material as its difficulty level increased. However, many researchers [16, 17] state that designing a flow channel that fits every player's skill and its development is a very challenging process. Fortunately, using software development lifecycle (SDLC) method that has been used by the earlier research [12], AR game's flow channel could be developed to fit target users' needs.

By creating AR application that supports see-through HMD as well as hand tracking recognition devices and the use of SDLC method for creating game's flow channel that fits target users' needs, an AR application is expected to be able to reinforce students' motivation and all the good benefits mentioned in the earlier researches [7, 10–12].

3 Proposed Augmented Reality Design Methodology in Geometry Learning

Design process of JunoBlock follows some requirements needed in designing process of an educational application. Previous researcher stated that design process of an educational application requires pedagogy approach to make sure that the application used by students is spent productively during students' learning time [18]. In application design process, all criteria based on the chosen pedagogy approach are defined. In addition to the definition from pedagogical approach, the design phase also describes how AR technology is implemented to integrate with other technologies, as well as benefits of such integrations.

3.1 Pedagogy Approach

Although previous researchers did not really mention any pedagogy approach used in the earlier researches, it was found that the previous studies primarily used design-based learning pedagogy to interact and deliver the subject to the students. Design-based learning (DBL) is rooted in the educational principles of problem-based learning (PBL) and found as constructionist pedagogical paradigm [19, 20]. In the context of higher education, PBL takes learner-centered active method as its educational principles. The benefit from learner-centered active method is to encourage learners to gather information and apply knowledge by conducting explorations, generating data and evaluating the learning process [21]. On the other hand, constructionist pedagogical paradigm has been shown to improve student learning outcomes in the domain of practice [19].

DBL is an educational approach that engages students in solving real-life design problems while reflecting the learning process using design activities as means of acquiring engineering knowledge [22]. DBL approach consists of the design element through interactive or iterative methodology; open-ended, hands-on, authentic and multidisciplinary design tasks, teachers who facilitate both the process of gaining domain-specific knowledge and the process to propose innovative solutions, assessment by both formative and summative assessment, and the social context of DBL projects [23]. As a pedagogy approach, design-based learning (DBL) can increase student's performance, conceptual understanding and desire to learn about a specific subject.

According to previous research, there are several mechanisms found on DBL that have positive effects. Through several mechanisms such as discussing, problem-solving, theorizing, and drawing conclusions, these mechanisms can promote intellectual quality of the students. Another mechanism such as conceptual analytic is also proven to improve students' depth of understanding [24]. Like the previous research that has been done, JunoBlock is also designed using DBL approach.

As many researchers' state that optimal solution for AR system may not reside on one pedagogy approach but rather a blending of pedagogy approaches [6, 19, 25], Juno-Block adapts game-based learning (GBL) as a complementary pedagogy. In previous researches, GBL is proven to create high and active engaging system as well as pace tailored system for each individual student [26]. Other researches also mention that GBL can increase development level of critical thinking, creative thinking and problem solving of the students [2]. GBL through its environments can provide all benefits mentioned above because it improves a person's motivation and engagement level, draws individual or thousands of students into a kind of focused, highly engaged state of mind, a pleasant and self-motivating condition called "flow" as well as improves expertise and expert performance of a learner by facilitating the development of learner's mental models and schemata [27–30].

The design process of GBL is very different compared to pure entertainment games. The formation of GBL requires the designer to combine game formal and dramatic elements with elements of learning aspects [28]. There are seven core elements of well-designed games in terms of learning. Those elements are presented below [31]:

1. Interactive problem solving: requires an architecture that enables interaction between the player and the game by series of problems and creates those series of problems to dance around the outer limit of player's abilities [32].
2. Specific goals/rules: have rules to follow and consist of series of goal that guide the player to focus on what to do and when, on their discovery and application through virtually embodied transactions in the game itself. Goals can be implicit or explicit.
3. Adaptive challenges: balance difficulty level to match player's ability and keep the player just at the edge of their capabilities [33].
4. Control: encourages player's influence over gameplay, game environment and learning experiences. The element of control indicates that players should have a sense of control over the characters and movements in the game world and game interface.
5. Ongoing feedback: provides timely information to players about their performance.
6. Uncertainty: evokes suspense and player engagement. If a game "telegraphs" its outcome, or be predictable, it will lose its appeal.
7. Sensory Stimuli: combine all kind of multimedia content, such as graphics, sounds, and/or storyline to excite the players' senses.

3.2 Application Design

To interact with users, JunoBlock uses marker-based augmented reality. Marker-based augmented reality is used since application is designed to be able to run on mobile devices. On mobile devices, real-time computer vision for area learning and depth perception are computationally expensive, even for an algorithm dedicated to solve a very specific problem [34]. By using a specific marker that has been designed to be easily recognized by computer, application can take advantage of the remaining resources left for virtual objects transformation and animation process.

Not only designed to work on mobile devices, JunoBlock also supports the uses of see-through HMD device and hand-gestures recognition device on mobile devices by the integration with GoogleVR SDK and LeapMotion SDK. With GoogleVR SDK, users can choose to play a game using Google Cardboard (virtual reality platform used with a head-mount for smartphone) or just a fully functioning AR game without it. If a user chooses to play using Google Cardboard, they can also choose to extend their playing experience using hand-gestures recognition device.

To implement DBL approach as well as to fulfill the criteria of design elements through interactive and iterative methodology, JunoBlock uses GBL approach as a second pedagogy approach since GBL approach can create highly and actively engaged system [26]. To fulfill the rest of DBL criteria, application will provide free exploration mode where students can create any 3D object that they want using unlimited resources (nodes and edges). Through free exploration mode, teacher can create both formative and summative assessment to help both the process of gaining domain specific knowledge and the process to propose innovative solutions. The social context of DBL can also be achieved by enabling users to collaborate with one another to build a specific object in a free exploration mode.

To implement GBL approach in the application, the application needs to be developed as a game. For an application to be considered as a game, the application needs to have an essential structural function of a game or known as game's formal elements [35]. In JunoBlock, each of the formal element and its implementation are presented as below:

1. Players: players can play a game as a single player or multiplayer. Based on Bartle taxonomy of player types, JunoBlock will target players who love to interact with other players or game's environments (socializers and explorers) [36].
2. Objectives: in normal game mode, players have an objective to build a specific 3D object with some limited resources given. In free exploration mode, players have no objective and can create any 3d objects that they want.
3. Procedures:
   a. players start the game by clicking the game's icon,
   b. players can adjust background music volume and sound effects volume through settings menu,
   c. players choose the game mode that they want (normal or free exploration mode),
   d. players choose to play alone (single player mode) or together with their friends (multiplayer mode),
   e. in play mode, players must direct their device's camera to a predefined marker to play a game over the marker,
   f. players can build a node by touching a generated platform when marker is detected,
   g. players can select a node by touching a node,
   h. connect each node, lifting and lowering the node's position, remove node and connections and create another node above the currently selected node via the UI button provided on the screen,

   i. in normal mode, players will be given 3 opportunities to evaluate the 3d objects they have created and given unlimited opportunities in free exploration mode.
4. Rules:
   a. in normal mode, every time players make a wrong evaluation, players will lose some of their score and one opportunity,
   b. if players' opportunities have run out, they will lose the game,
   c. if players evaluate correctly, their score will increase and they will move to the next stage,
   d. if players have completed all the stages, their score will be recorded into the leaderboard.
5. Resources: player's opportunities to evaluate the 3d objects they have created.
6. Conflict: players must complete several levels provided by them before their chances run out.

To apply seven core elements of well-designed games in terms of learning, implementation details that applied to each element are presented below [31]:

1. Interactive problem solving and adaptive challenges: game presents several levels in which the levels of difficulty will increase in each level.
2. Specific goals/rules: game presents a formal element related to the objectives, procedures, and rules in the game completely in a section above.
3. Control and ongoing feedback: game provides the actions needed to complete all levels within the game via input directly onto the platform that have been provided or through buttons that have been provided. Every time players perform an action (pressing a button, making a mistake or moving to the next level) then the game will emit a specific sound as a feedback to them.
4. Uncertainty: the game will automatically select a problem from several alternative problems on each level related to a geometrical concept that is introduced within it. By doing this step, every level in the game will become unpredictable by the player and keep the player interested to finish it.
5. Sensory Stimuli: game uses 3d low poly assets that attract children's attention, sound effects as feedback to users and background music with soothing rhythm to increase players' concentration.
6. Conflict: players must complete several levels provided to them before their chances run out.

Based on the DBL and GBL approach as well as the application design definition above, all images from the first prototype that has been developed can be seen in the Fig. 1 below.

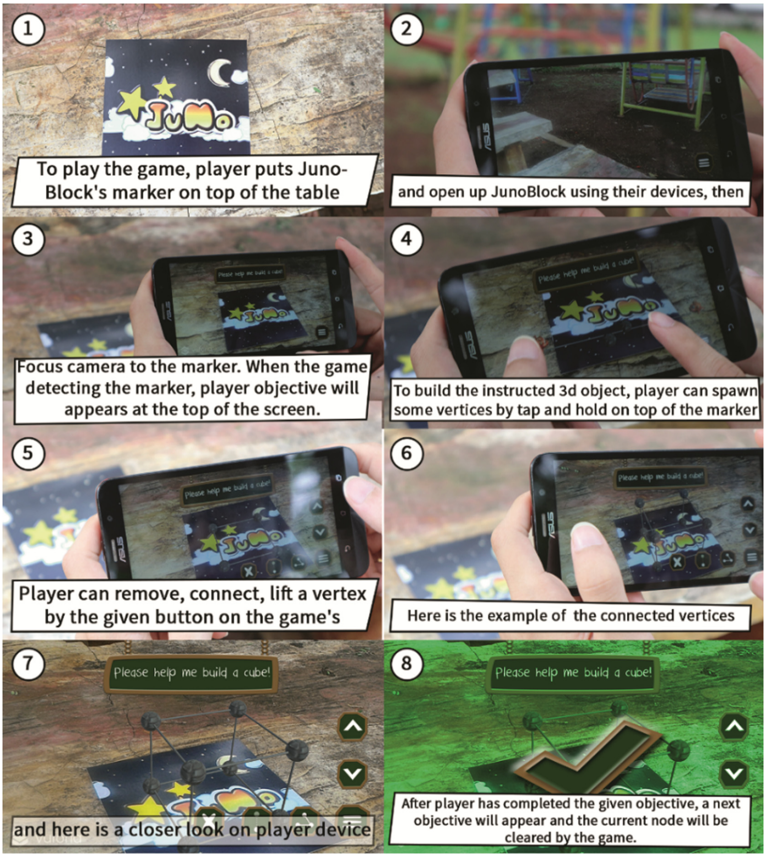

Fig. 1. First prototype of JunoBlock

4 Conclusion

By the proposed design methodology, the first prototype of JunoBlock has been successfully created and ready to be evaluated. The focus of this first prototype evaluation is to find some issues related to appropriateness of AR technology as an educational tool. By using DBL and GBL in the application design process, JunoBlock is expected to increase students' learning motivation. Furthermore, with AR technology, JunoBlock is also expected to support students in understanding learning materials through the visualization of interactive virtual objects in the real world.

5 Future Works

After the evaluation of the first JunoBlock prototype, JunoBlock will be improved based on user suggestions related to aspects of usability, design or mechanics in the application.

Moreover, Junoblock will also be integrated with VR technology through the help of Google Cardboard SDK. By the integration with VR technology in the application, the comparison between AR and VR technology as educational tool and the discovery of the advantages and disadvantages for each technology can be done.

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