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Learning Concrete Formwork Using 3D Simulation Game

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Abstract
Usage of technology has become an integral part of students' life. Engaging technology savvy students in the concrete formwork learning process with their preferred learning style is a challenging task. This active student engagement challenge can be addressed through three dimensional (3D) concrete formwork simulation game learning environment. This learning environment engages students in active learning processes and helps them to focus on their learning about slab, wall and column formwork components. This helps the students to understand the design assumptions, to learn about reducing the material wastage, to learn about the construction steps, and to learn about the material takeoff of slab, wall and column formwork. It also encourages students to take more responsibility for their own learning process. This ubiquitous learning environment provides anytime time access, facilitates the students to learn at their own pace and promotes learning beyond the regular classroom boundaries. This paper discusses the development of 3D simulation game for concrete formwork to enhance the learning ability of the students. The paper also discusses the users experience of this game for learning the design and construction of concrete formwork.

Keywords
3D, Simulation Game, Concrete, Formwork, Visualization

1. Introduction

Visualization of the built environment and learning the construction processes is critical for students in the architecture, engineering, and construction disciplines (Irizarry et al., 2012; Nikolic et al., 2011). Due to lack of experience, it will be challenging for students to visualize the design assumptions, different components and construction processes of the concrete formwork (Wasim et al., 2011). Usage of technology has become an integral part of students' life. Engaging technology savvy students in the concrete formwork learning process with their preferred learning style is a challenging task. The differences in teaching and learning styles result in problems such as disengagement of students and loss of learning aptitude. Some of these challenges faced by construction programs across the nation and the world can be addressed by using three-dimensional (3D) simulation games in construction education. Studies have demonstrated that the game-based approach can enhance students' learning process through their active participation (De Gloria et al., 2014). Virtual Constructor Simulator (VCS) was developed and implemented to engage students in active learning environment about planning and management of a construction project (Castronovo et al., 2015). 3D game environment was used to impart trench safety education to the construction trade students (Dickinson et al., 2011). The success of these 3D game learning environment in construction education motivated the authors to use 3D simulation game for teaching material quantity take off and construction process of concrete formwork. This 3D simulation game will create visual and kinesthetic learning environments and will actively engage students in the learning process in both in person face to face and online mode. This visual rich learning environment will improve the student visualizations skills and enhances their performance. The 3D simulation game will promote ubiquitous learning environments. For example, anytime time access facilitates the students to learn at their own pace and promotes learning environment beyond the regular classroom boundaries. This

simulation game focuses on the material quantity estimation and construction aspects of concrete formwork. The following sections discusses the 3D concrete formwork simulation game and it's usability study results.

2. 3D Concrete Formwork Simulation Game

Formwork for concrete must be designed to support all applied vertical and lateral loads until these loads can be carried by the concrete structure itself. In general, formwork system consists of sheathing to retain concrete and supporting members necessary to hold the sheathing firmly in place. Based on these concepts a 3D concrete formwork simulation game was developed. This game helps to understand design assumptions and to learn about the slab, wall and column formwork components. This also helps to learn about the formwork material take off and formwork construction steps. In this project, plywood is used for sheathing and lumber is used for joists, stringer, wales, studs and shores. The authors want the game to be deployed on various platforms such as Mac, Windows and mobile phones. This can be accomplished by developing a game on an engine which has capability of publishing on multiple platforms. Considering all these requirements, Unity software was chosen to develop the 3D simulation game. Unity has powerful game development engine which can work on Mac and Windows. It has capability of deploying games on desktop, mobile, web and consoles. It can create standalone desktop game on Windows, Mac and Linux platforms [Unity, 2024]. It can deploy games on major mobile ecosystems such as iOS and Android [Unity, 2024]. It can deploy on consoles such as Nintendo Switch, Xbox and PlayStation [Unity, 2024]. It can provide stable and efficient web deployment on all major browsers such as Edge, Chrome, Safari, and Firefox [Unity, 2024]. The developed 3D concrete formwork simulation game has three levels (i) Slab (ii) Wall and (iii) Column. Each level has five modules. These include (a) Main Menu, (b) Shop, (c) Cut, (d) Assembly and (e) Finish. The details of these modules are discussed below.

2.1 Main Menu

This module provides the details of the slab or wall or column to be formed. These include design assumptions, cross section dimensions of members, plan and elevation views. Using this information, the player estimates the required quantities of materials. A sample screen shot of the main menu interface is shown in Figure 1.

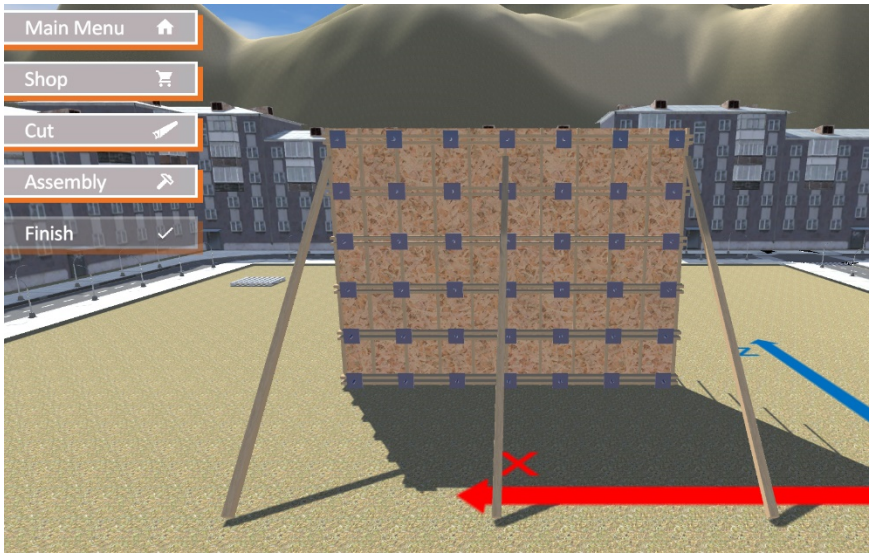

Fig. 1. A sample screenshot for Main Menu window of wall formwork

2.2 Shop Module

This module of the game tests the players' understanding of the concept of material loss due to resizing and cutting, and the necessary additions to material dimensions for proper construction of the formwork, such as overlapped edges and how to maximize component pieces usage to reduce wastage. For example: The player is asked to input the amount for each type of material which the player believes to be necessary to build the formwork with as little waste as possible and without having to return to purchase additional materials. A sample screen shot of the shop interface is shown in

Figure 2. Penalty is imposed once the player buys the material and returns to the shop module to purchase more materials.

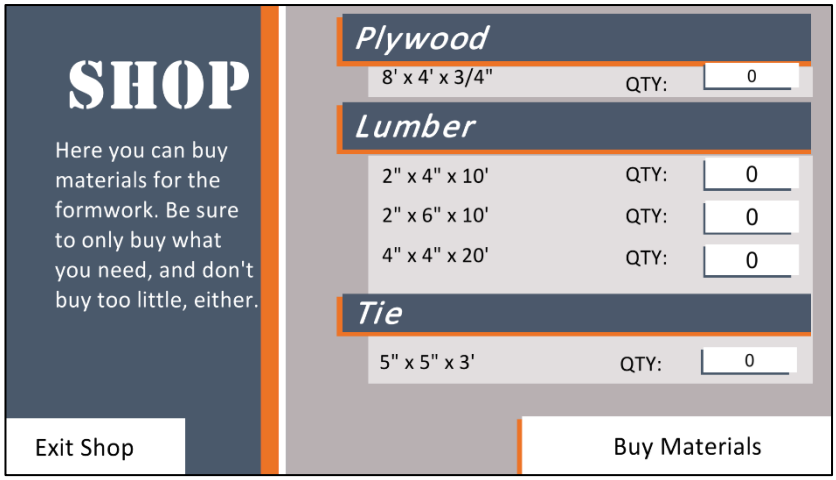

Fig. 2. A sample screenshot for shop window

2.3 Cutting Module

This component of the game deals with the cutting of the materials. Based on the size calculations, the player is given the option to cut the materials to the required dimensions size as necessary to build the formwork. Player must account for excess material needed for proper construction. A sample screen shot of the cutting interface is shown in Figure 3. Based on the purchased materials from shop module, the player is presented with the number of available materials on left side. On right side, player have drop down boxes to enter the required cut dimensions and quantity.

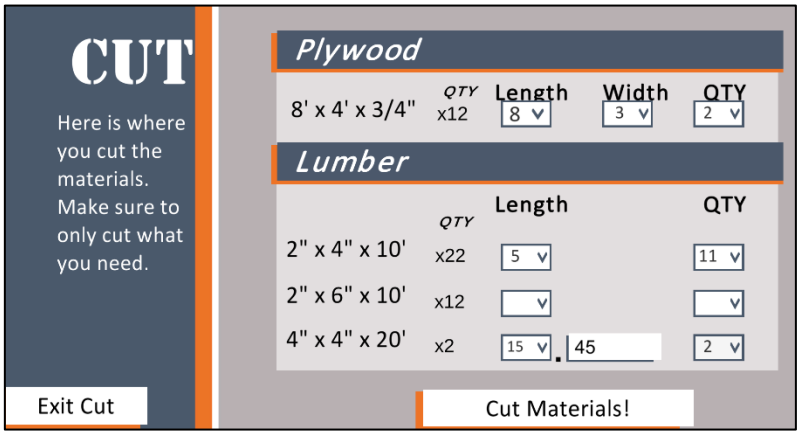

Fig. 3. A sample screenshot for Cut interface window

2.4 Assembly Module

In this module, using the stockpiles of cut formwork component pieces, the player builds the formwork needed for the concrete slab or wall or column. A sample screen shot of the assembly interface is shown in Figure 4. Based on the shop and cut module inputs, available materials inventory are presented at bottom. In this view, a ghost image of the components to be placed is displayed. This guides the player to snap the formwork components. The stockpile of the materials gets dynamically updated as the player utilizes the material. Once the player snaps the component color changes to assigned material color. The player has option to go to shop or cut module for making additional purchase or cut. However, these additional visits come with a penalty.

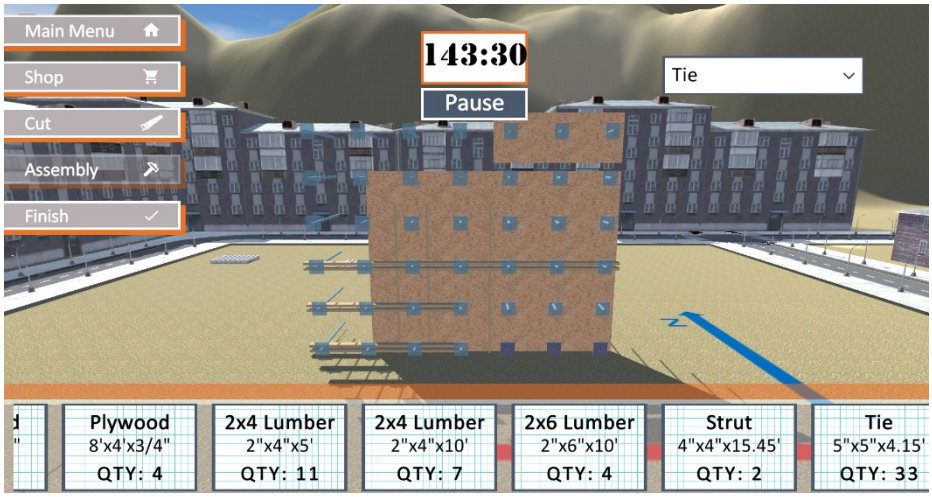

Fig. 4. A sample screenshot for assembly of wall formwork

2.5 Results Module

This module focuses on the assessment of the player's ability to learn concepts of concrete formwork. This is accomplished by grading shop, cut and assembly modules. In shop module, players are graded on how efficiently they select the quantities. Once the player purchases estimated quantities, then these quantities are compared with actual quantities for scoring. A penalty is imposed for inaccurate quantity estimation and purchase. Inaccurate estimate includes a positive error (when the player estimates more than the actual) or negative error (when the player estimates less than the actual). In cut module, players are graded on how efficiently they choose what dimensions to cut. This is done by calculating how much waste material remains when cutting is completed and comparing it to a known lowest waste amount. In assembly module, players are graded based on the construction sequence of the formwork. The player construction sequence is compared with correct sequence and appropriate score will be awarded. A sample screen shot of the results interface is shown in Figure 5. In this screen, points gained in each step and overall points are displayed.

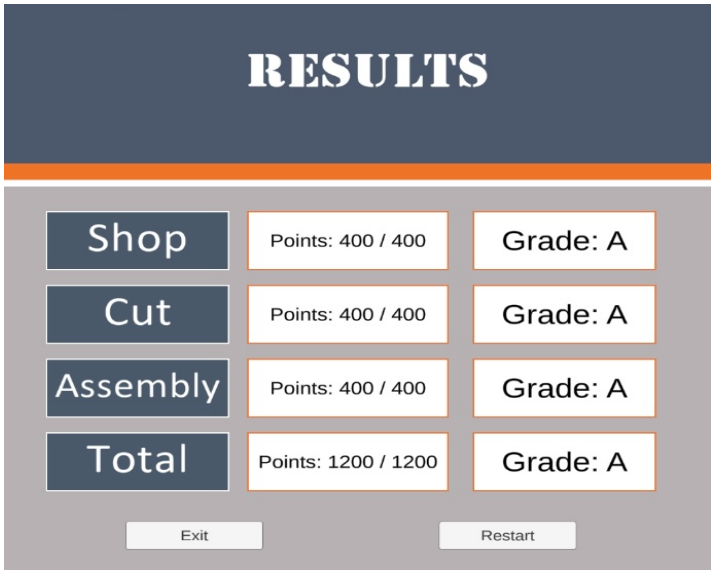

Fig. 5. A sample screenshot for Results of Slab formwork

3. Usability Study Collection and Analysis

The game was developed by using Unity software. The game was evaluated by conducting several play test sessions. Once the evaluation was completed, an usability study was conducted to learn about the students' experiences of usage of the 3D simulation game for learning the design and construction of concrete formwork. In this study about twelve students played the game and provided feedback of their experiences through a survey. In the survey, the students were asked to express their satisfaction with 5-point Likert-type scale (1= Strongly Agree, 2 = Agree, 3=neutral, 4= Disagree, and 5=Strongly Disagree). The analyses of the data are provided below.

Figure 6 shows the results of the survey on the usefulness of simulation game. Most of the students expressed that the simulation game is useful to understand design assumptions (72% strongly agreed and 18% agreed), to learn about the formwork components (72% strongly agreed and 18% agreed), to learn about the reducing the material wastage (72% strongly agreed and 18% agreed), to learn about the formwork construction steps (81% strongly agreed and agreed 9%), and to learn about the formwork material takeoff (81% strongly agreed).

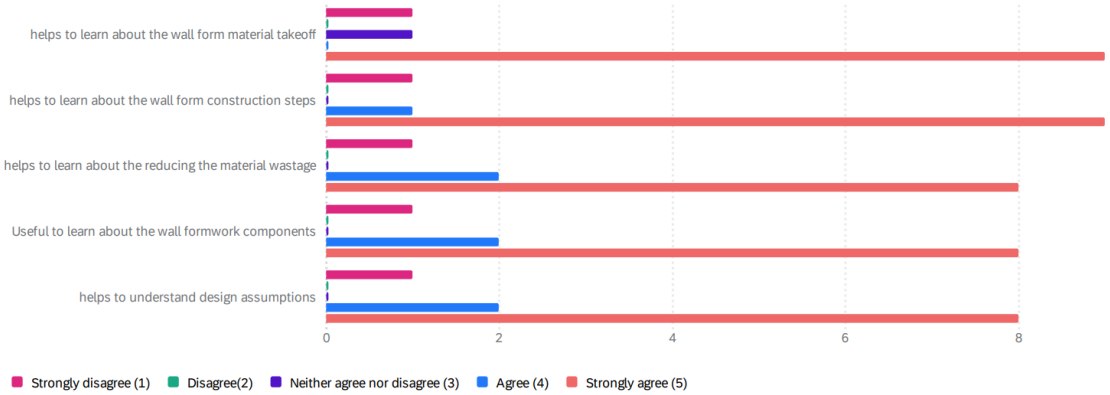

Fig. 6. Usefulness of simulation game survey results

Figure 7 shows the results of the survey on the ease of learning to play the simulation game. Most of the students expressed their agreement with the statement "Overall, I am satisfied with ease of learning" (36% strongly agreed and 45% agreed). About 36% strongly agreed and 54% agreed with the statement "I quickly became skillful with it." About 54% strongly agreed and 36% agreed with the statement "It is easy to learn to use it." About 54% strongly agreed and 36% agreed with the statement "I easily remember how to use it." About 45% strongly agreed and 36% agreed with the statement "I learned to use it quickly."

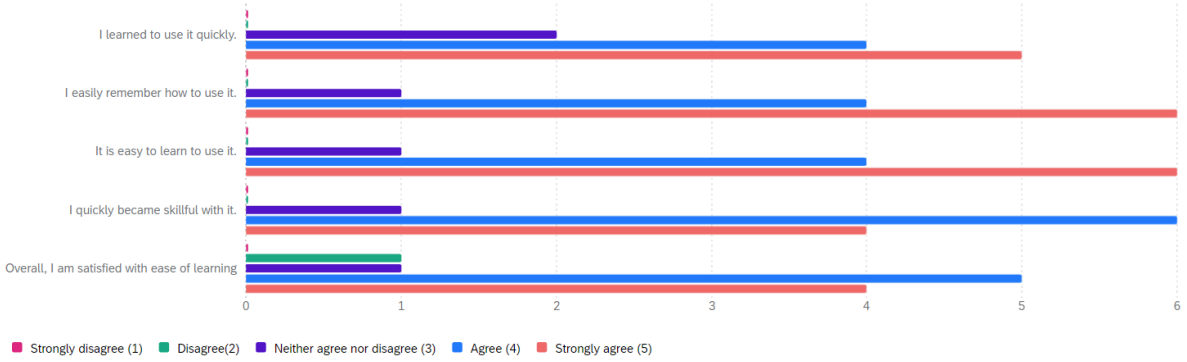

Fig. 7. Ease of learning to play the simulation game survey results

Figure 8 shows the results of the survey on the challenge provided by the simulation game. Most of the students expressed their agreement with the statement "Makes me work at a level close to what I am capable of" (45% strongly

agreed and 27% agreed). About 54% strongly agreed and 18% agreed with the statement "Feels like test of my ability." About 54% strongly agreed and 18% agreed with the statement "Calls for a lot of effort in order for me to be successful." About 54% strongly agreed and 18% agreed with the statement "Pressures me in a positive way by its high demands." About 45% strongly agreed and 27% agreed with the statement "Makes me push my limits." About 54% strongly agreed and 27% agreed with the statement "Challenges me."

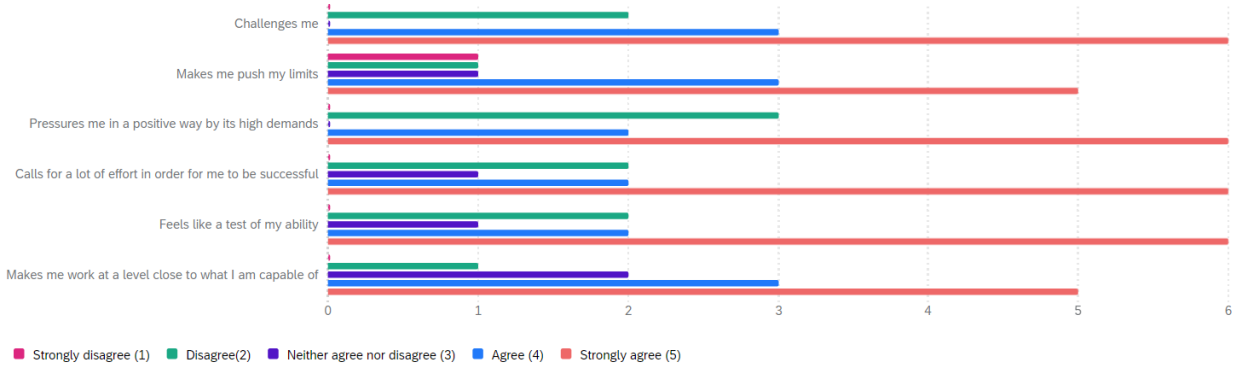

Fig. 8. Challenge provided by the simulation game survey results

Figure 9 shows the results of the survey on the accomplishment provided by the simulation game. Most of the students expressed their agreement with the statement "Pushes me to strive for accomplishments" (45% strongly agreed and 36% agreed). About 45% strongly agreed and 36% agreed with the statement "Motivates me to progress and get better." About 45% strongly agreed and 36% agreed with the statement "Makes me above to take myself to the next level." About 45% strongly agreed and 27% agreed with the statement "Inspires me to maintain my standards of performance."

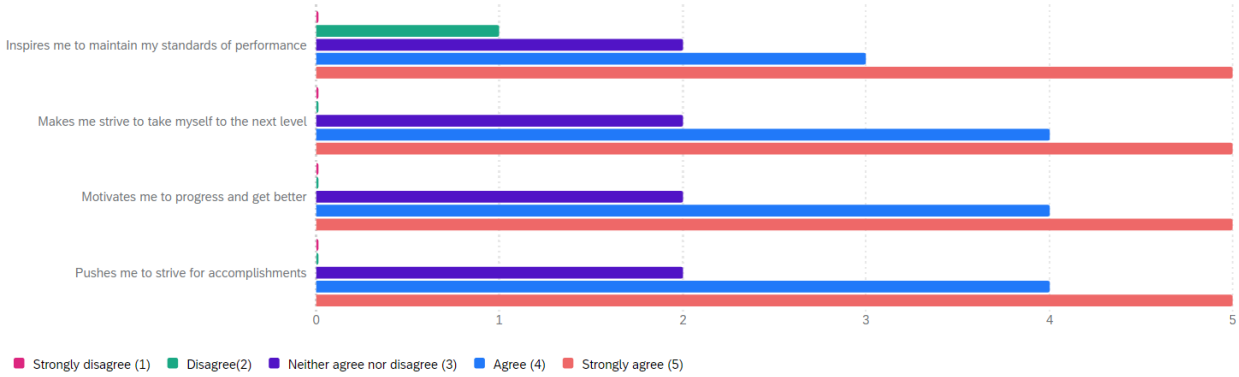

Fig. 9. Accomplishment provided by the simulation game survey results

Figure 10 shows the results of the survey on the guidance provided by the simulation game. Most of the students expressed their agreement with the statement "Gives me a sense of knowing what I need to do better" (36% strongly agreed and 36% agreed). About 36% strongly agreed and 36% agreed with the statement "Makes me fell guided." About 36% strongly agreed and 36% agreed with the statement "Pushes me in the right direction." About 36% strongly agreed and 27% agreed with the statement "Gives me useful feedback so I can adapt." About 36% strongly agreed and 36% agreed with the statement "Gives me feeling that I have an instructor." About 36% strongly agreed and 36% agreed with the statement "Gives me sense of being directed."

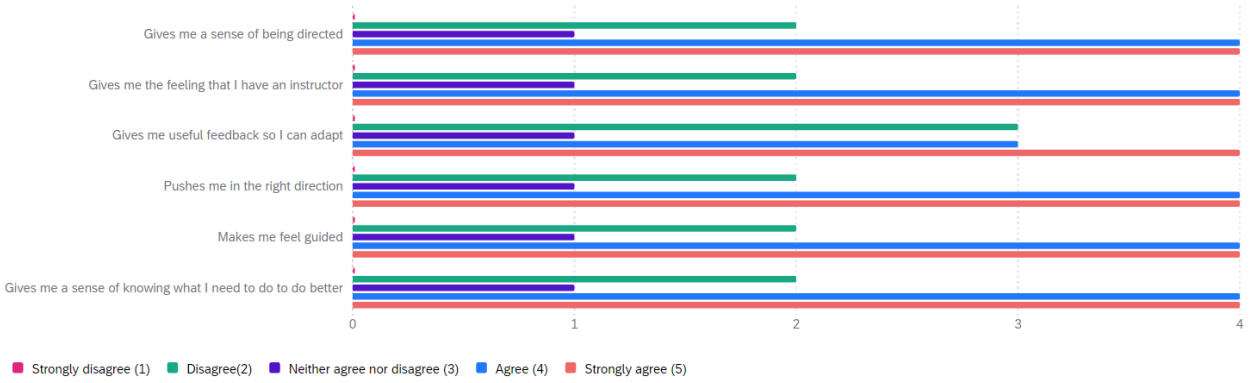

Fig. 10. Guidance provided by the simulation game survey results

Figure 11 shows the results of the survey on the immersion provided by the simulation game. Most of the students expressed their agreement with the statement "Captivates me" (36% strongly agreed and 54% agreed). About 36% strongly agreed and 45% agreed with the statement "Grabs all my attention." About 54% strongly agreed and 36% agreed with the statement "Makes me feel immersed."

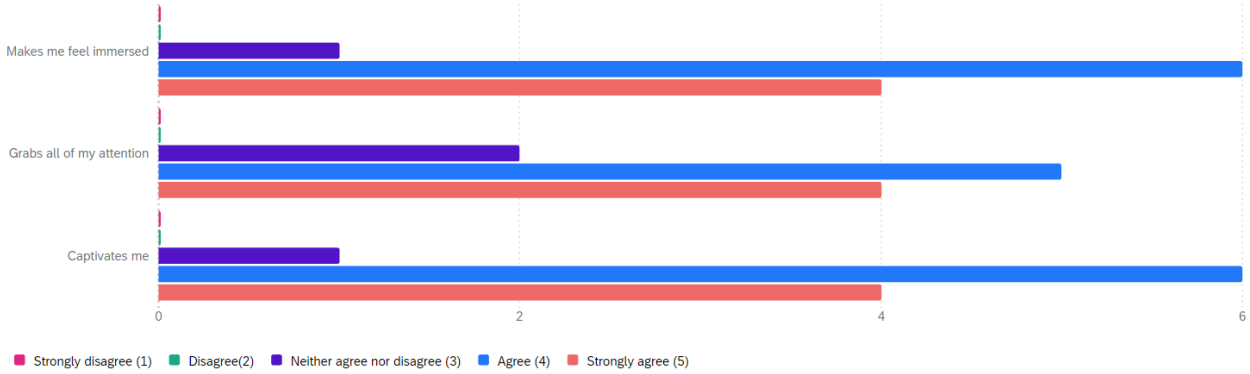

Fig. 11. Immersion provided by the simulation game survey results

4. Conclusion

Concrete formwork 3D simulation game serves as a new teaching tool and helps to be more effective in communicating the information to the students. This learning environment provides 3D visualization and helps students to engage actively in the learning process. The 3D simulation game environment has the potential to make a paradigm shift in teaching and learning process. The usability study results indicated the effectiveness of this 3D simulation game to help the students to understand design assumptions, to learn about the formwork components, to learn about the reducing the material wastage, to learn about the formwork construction steps, and to learn about the form material takeoff for slab. wall and column.

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