Virtual reality engineering summer camp: a pathway to architecture, engineering, and construction

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VIRTUAL REALITY ENGINEERING SUMMER CAMP: A PATHWAY TO ARCHITECTURE, ENGINEERING, AND CONSTRUCTION

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ABSTRACT: *To promote paths to undergraduate degrees in science, technology, engineering, and mathematics (STEM), a university in North California, California State University East Bay, developed the Virtual Reality Engineering Summer Camp (VRES Camp). The camp ran from July 29th to August 9th, 2019, with the goal to offer a model summer high-school camp and engage future undergraduate STEM participants as designers and developers of immersive and interactive environments (i.e., virtual reality simulations). Another goal was to promote and inspire the pursuit and ultimately increase in retention of students wanting to engage in STEM professional or undergraduate degrees by helping them acquire a wide range of knowledge and skills. Using gaming and human-computer interaction design principles, the participants were challenged to engage in fun and interactive activities. For example, the participants had to explore simulation research, talk with professionals and industry representatives, code with C# coding language, and build a virtual reality simulation using SketchUp, Unity, and Oculus Rift S. To support the building of the virtual reality simulation, the participants were introduced to the knowledge, skills, and behaviours necessary to pursue STEM degrees. In particular, the students were introduced to the engineering design process, engineering careers, and theories of multimedia learning, visualisation, virtual reality, and serious gaming. The results from an exit survey reveal a positive impact the camp had on the students. Specifically, the students indicated a strong career interest in STEM disciplines and rated their perceived success and engagement in the camp activities highly. Moreover, students' ability to meet the camp learning objectives by developing virtual reality prototypes demonstrated that the students gained strong problem-solving and work-ready skills, which are key to their success in their advanced educational and professional careers.*

KEYWORDS: *IMMERSIVE VIRTUAL REALITY, ENGINEERING EDUCATION, CONSTRUCTION EDUCATION, STEM PATHWAYS, LEARNING THEORIES*

1. Introduction

With the growing implementation of digital technology in the construction industry, it has become imperative to prepare the next generation of engineers, constructors, and designers for using such technologies and support their pursuit and success in the industry. To meet this industry goal, in the summer of 2019, the team at an Engineering Department at a university in North California, California State University East Bay, developed and hosted an interactive summer camp designed to train incoming high school students to use virtual reality in the architecture, engineering, and construction fields and thus encourage their pursuit of science, technology, engineering and mathematics (STEM) careers. The Virtual Reality Engineering Summer (VRES) summer camp had the following programmatic goals:

1. Train participants in developing virtual reality simulations;
2. Contribute to the acquisition of knowledge, skills, and behaviours necessary to pursue STEM education;
3. Introduce industrial applications of virtual reality and visualisation such as those found in the architectural, engineering, and construction fields; and
4. Encourage high-school participants in their pursuit of STEM degrees.

To meet these programmatic goals, the organising team set several learning objectives for the participants to:

- Explore the latest research in virtual reality (VR);
- Use prototyping design processes to develop VR environments and simulations;

- Evaluate the impact of the simulation through qualitative feedback; and
- Engage with industry professionals to learn about their experiences in leveraging VR.

The skills that the participants acquired in the camp include:

- high proficiency in developing user experience storyboards;
- high proficiency in using SketchUp Make to develop mass models of buildings;
- proficiency in importing SketchUp Make models to Unity;
- proficiency in using Unity to generate virtual walkthroughs and user interfaces; and
- introductory-level use of C# programming and coding language.

The following paper will present the organisers' experience in designing, developing, and implementing the VRES camp. The paper will also present the results from early efforts to evaluate the camp's impacts on the participants.

2. Literature Review

2.1 Virtual Reality in Architecture, Engineering, and Construction Education

In architecture, engineering and construction (AEC) education many research initiatives have explored the adoption of innovative and interactive learning experiences for improving the visual, analytical and problem-solving skills of students. Research in virtual reality and the adoption of virtual prototyping in the AEC industry has substantially grown in recent times. Such a growing interest is also contextual to an increase in offer of low cost, scalable solutions and wearable head-mounted displays (HMD), the proliferation of which makes it even more necessary to question their appropriateness for AEC education in terms of pedagogical goals (Kandi et al. 2020a; b; Mastrolembo Ventura et al. 2022).

Immersion and sense of presence are the two main characteristics of virtual reality, which is defined as a computer-simulated environment where users can explore and experience a full-scale virtual facility (e.g., building, infrastructure) prototype in an intuitive and engaging manner (Paes et al. 2017). This interaction opportunity has been increasingly viewed as a promising way for students to dynamically test concepts and, through real-time feedback, to begin to construct their knowledge and spatial skills (Castronovo et al. 2017a; b). In fact, as design and construction processes work with visual and spatial data, they are considered as an ideal context for studying the effects of VR and simulation technology on spatial cognition. Design visualisation, construction safety training, equipment operation, and structural analysis are among the most implemented use cases for educational VR-based simulations (Mastrolembo Ventura et al., 2022).

The impact VR might have on knowledge retention thanks to the motivational and engagement factors that it could provide, especially when compared to traditional and paper-based learning, represents one of the main factors to evaluate. What tends to make the VR-enable learning experience more effective compared to traditional instruction is that it allows "students to fail, but through in-process reflection". Students can therefore "modify their strategies and repeat the process until reaching the goal. This view of learning, where students build their knowledge through cyclical interactions and feedback, gave way to problem-based, project-based or active learning approaches, which place emphasis on process and perception, rather than on memory" (Mastrolembo Ventura et al., 2022).

2.2 Summer Camps and STEM Pathways

A growing need for skills in allied fields of STEM has presented educators with a challenge to explore effective ways to make these fields more accessible and thus, attract more students to pursue STEM careers. Traditionally low uptake of such careers among students, especially among the underrepresented groups (National Center for Education Statistics, 2019) has prompted explorations into factors that influence students' disposition toward and their decision whether to pursue careers in STEM fields (e.g. Christensen et al. 2014; Kim et al. 2018). For example, peer influence, self-efficacy and inherent attitudes toward STEM-related courses have been seen as some of the potential influences during the earlier stages of education (e.g. Bicer et al. 2015; Bicer and Lee 2019; Vela et al. 2020). As a result, studies have explored ways and strategies to attract students toward STEM fields earlier in their education, suggesting that exposing students to STEM content in their secondary education will largely influence their decision whether to pursue careers in STEM fields (Sarı et al. 2018; Vela et al. 2020). Thus, the implication of such studies is the need to engage and inform students about STEM careers at a younger age and address various factors identified as critical, such as exposure to career options, access to STEM content and information and developing positive perceptions toward STEM through active participation in informal settings (Vela et al. 2020).

Informal learning environments such as field trips and extracurricular activities can engage students in learning about new concepts and raising interest in STEM-related fields. STEM camps are another example of such informal learning environments that aim to provide a fun and engaging setting outside formal classroom settings and engage students in learning about creativity, technology literacy, communication, or leadership (Bicer et al., 2015; Bicer and Lee, 2019) through interactive hands-on experiences. Vela et al. (2020) investigated the impact a week-long camp on information science, technology, engineering and mathematics (STEM) had on students' perceptions of STEM fields and careers and found the outcomes to have been overwhelmingly positive. Such studies have opened questions about devising effective strategies for students to experience the curriculum in a real-world context and not only develop specific technical skills, but also build a scientific identity through the use of the same tools as the professionals in given disciplines (Ghadiri Khanaposhtani et al. 2018; Vela et al. 2020). When STEM camps design the curriculum in a way that resembles the work of STEM professionals and that also incorporates elements of fun and interactivity, they can present a powerful vehicle for engaging students in co-creating an enjoyable and positive experience, critical for shaping future perceptions of STEM fields and the pursuit of related careers (Bandura 1986, 2012; Vela et al. 2020).

3. The Virtual Reality Engineering Summer Camp

The camp aimed at achieving the first programmatic goal by training the participants in developing 3D models in the SketchUp modeling software. Next, the students were trained to bring their models into the Unity game engine and generate graphical user interfaces (such as buttons) using the C# coding language. The second programmatic goal was aimed at getting the participants to engage in several work-readiness competencies such as attendance and timeliness (participants were required to arrive at camp and activities on time every day); critical thinking, and problem-solving (participants were required to solve a design problem for their camp project); and communication skills and quality of work (participants had to work together in teams and present their work to a panel of reviewers). To support the achievement of the third programmatic goal, the organising team engaged and partnered with the local industry. The students had a series of guest lectures where the industry professionals presented their work and path in the industry and provided real-world examples of how innovative technology such as VR and AR is used. The fourth programmatic goal was achieved, as illustrated in the evaluation Results section. Students demonstrated an interest in pursuing engineering degrees and were engaged in the activities provided by the camp.

The camp combined lectures, demonstrations, in-class discussions, projects, site visits, "play" time, and presentations by Industry professionals (see Figure 1). The participants attended an 8-hour session each day for the camp duration. The participants had to focus on the development of the virtual prototypes. Several class periods were available for discussing project presentations and providing specific demonstrations helpful in completing the projects. For example, the participants were presented with the latest research and development efforts in using technology, such as virtual and augmented reality. Additionally, the participants got to work in groups on exercises to develop 3D models, import them into game engines, perform design reviews, and code interactions in C#. The following is a summary of the different activities and lectures that the students participated in. The organisers received permission from the students and their legal guardians to use their photos for publication.

Daily Schedule	Monday July 29th	Tuesday July 30th	Wednesday July 31st	Thursday August 1st	Friday August 2nd
9 AM - 9:30 AM	Breakfast in VBT lobby	Breakfast in VBT lobby	Breakfast in VBT lobby	Breakfast in VBT lobby	Breakfast in VBT lobby
9:35 AM - 10:20 AM	Introduction to Architecture, Engineering, and Construction (AEC)	**Guest Lecture from SANVEO: Visualization to the Construction Site**	Introduction to the VR Design Process	Sketch Up Modeling	**Field Trip to Turner Construction Site**
10:20 AM - 10:35 AM	Engineering Careers	Create Teams	Design Process Activity	Campus Building Tour and Documentation	
10:35 AM - 10:45 AM	Break	Break	Break	Break	
10:45 AM - 11:30 AM	Introduction to Virtual Reality in AEC	**Guest Lecture from Fisk Electric: Design for Electrical Systems**	Storyboarding for User Experience	**Guest Lecture from Turner: Model Coordination in 3D**	
11:30 AM - 11:50 AM	VR Research		Storyboarding Drawing		
12:00 PM - 1:00 PM	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break
1:00 PM - 1:45 PM	Design Review Simulator	Team Building in VR: Keep Talking and Nobody Explodes	Introduction to Modeling in Sketch Up	Sketch Up Modeling	Sketch Up Modeling
1:45 PM - 2:00 PM	World Tour in Google Earth VR		SketchUp Tutorial Series		
2:00 PM - 2:10 PM	Break	Break	Break	Break	Break
2:10 PM - 2:55 PM	BodyVR	Job Simulator	Apollo 11 VR Experience	Tilt Brush from Google	Sketch Up Modeling
2:55 PM - 3:05 PM	Break / Dismissal	Break / Dismissal	Break / Dismissal	Break / Dismissal	Break / Dismissal

Daily Schedule	Monday August 5th	Tuesday August 6th	Wednesday August 7th	Thursday August 8th	Friday August 9th
9 AM - 9:30 AM	Breakfast in VBT lobby	Breakfast in VBT lobby	Breakfast in VBT lobby	Breakfast in VBT lobby	Breakfast in VBT lobby
9:35 AM - 10:20 AM	Sketch Up Modeling	**Guest Lecture from Microdesk Inc.: Virtual Design and Construction**	**Guest Lecture from Spire Consultants: Intro to Project Management**	**Field Trip to RAD Urban Visualization to Construction Site**	Presentations Rehearsal
10:20 AM - 10:35 AM					
10:35 AM - 10:45 AM	Break	Break	Break		Break
10:45 AM - 11:30 AM	Introduction to Unity Game Engine and C# Coding	VR Prototype Development	VR Prototype Development		Presentations Rehearsal
11:30 AM - 11:50 AM					
12:00 PM - 1:00 PM	Lunch Break	Lunch Break	Lunch Break	Lunch Break	Lunch Break
1:00 PM - 1:45 PM	Unity Game Engine Tutorial	VR Prototype Development	VR Prototype Development	Presentations Preparation	Presentations
1:45 PM - 2:00 PM					
2:00 PM - 2:10 PM	Break	Break	Break	Break	Break
2:10 PM - 2:55 PM	Unity Game Engine Tutorial	VR Prototype Development	VR Prototype Development	Presentations Preparation	Presentations
2:55 PM - 3:05 PM	Break / Dismissal	Break / Dismissal	Break / Dismissal	Break / Dismissal	Break / Dismissal

Figure 1. Camp Schedule

Lecture: Introduction to Architecture, Engineering, and Construction

The participants were exposed to what engineers do and received examples of common careers for engineers. They were presented with the important traits of successful engineers and the different habits and strategies that would lead to a good career in an engineering profession. In particular, they were presented with the professional duties of architectural engineers, civil engineers, and construction managers.

Lecture: Introduction to Virtual Reality in Architecture, Engineering, and Construction

The participants were presented with the current applications of virtual reality and visualisation tools in the architecture, engineering, and construction industry. In particular, the participants were presented with the basic theory of virtual reality, stereoscopy, immersion, and different types of VR systems for designing and constructing buildings, see Figure 2.

Figure 2. Students Using VR Headsets for Architectural Walkthroughs

Lecture: Introduction to the VR Design Process

In this lecture, the participants were exposed to the engineering and virtual reality design process, see Figure 3. In particular, they were introduced to a variation of the Human-Centered design process, including analysis, design, and development iterative cycles. This process is specific to designing virtual reality solutions within the architectural, engineering, and construction fields.

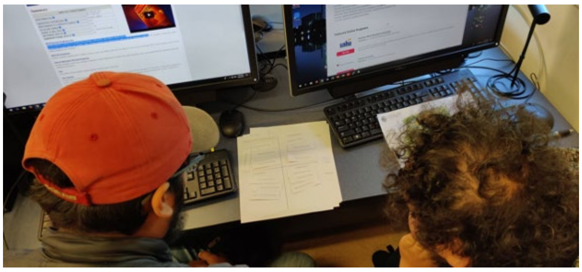

Figure 3. Students Learning the Engineering Design Process

Lecture: VR User-Center Analysis

The lecture introduced participants to the process of evaluating future users and the implementation environment see Figure 4. Additionally, participants got to learn the three ways to collect user data to influence VR design, such as interviews, questionnaires, and observations.

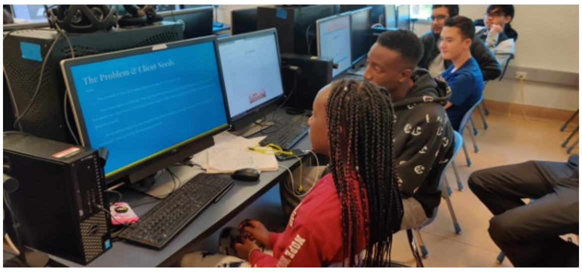

Figure 4. Students Presenting on their User Analysis Process

Activity: Storyboarding for User Experience

The participants were trained in the process of developing user interfaces and experiences through the use of storyboarding techniques. In particular, the participants had to develop a user experience for a prototype that challenges the user to learn about architecture in virtual reality.

Activity: Introduction to Modeling in SketchUp

To support the prototyping process, participants were introduced to the modelling basics of SketchUp, see Figure 5. SketchUp is an easy-to-learn prototyping tool used by architects and engineers to develop an early concept design and portrays future prototype use.

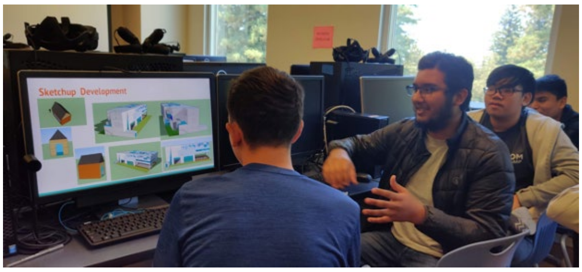

Figure 5. Students Presenting on their SketchUp Development

Activity: Introduction to Unity Game Engine and Prototype Development

The activity aimed at showing how professional settings leverage the Unity Game Engine for the development of VR prototypes. The participants were introduced to the structure of visualisation experiences in Unity, see Figure 6. The participants learned how to code basic graphical user interactions in Unity. Additionally, the participants learned to export their 3D prototypes from SketchUp to Unity and activate VR walkthroughs in the space.

Figure 6. Student Coding in C# with the Unity Game Engine

Activity: Industrial Engagement

To support the achievement of the camp goals and objectives, the organising team engaged and partnered with the local industry. The students had a series of guest lectures during which industry professionals presented their work and path in the industry and provided real-world examples of how innovative technology such as VR and AR are used. Additionally, the students took two field trips to construction sites.

Figure 7. Construction Site Field Trip

4. Results

The VRES camp focused on attracting students from all backgrounds to STEM and retaining them. The VRES Camp organisers aimed at capturing several impact indicators, such as 1) career interest, perceived success, values, and engagement; 2) problem-solving and work-ready skills; and 3) achievement of pertinent learning objectives and goals. The camp team set forward an assessment plan for the evaluation of the aforementioned goals and their successful implementation by capturing quantitative data through an exit survey at the end of the camp. The VRES Camp assessed the impact on the student's career interest, perceived success, values, and engagement quantitatively using the surveys developed by the Lawrence Hall of Science (LHS) Activation Lab (Moore et al. 2011). The surveys asked questions on a 4-point scale (0 - NO!, 1 - No, 2 - Yes, 3 - YES!). The organisers collected in-class activities and projects to evaluate the students' gain of problem-solving skills and work-ready competencies and the achievement of the learning objectives. The meeting of the programmatic goals 1, 2, and 3 can be reviewed in the previous section.

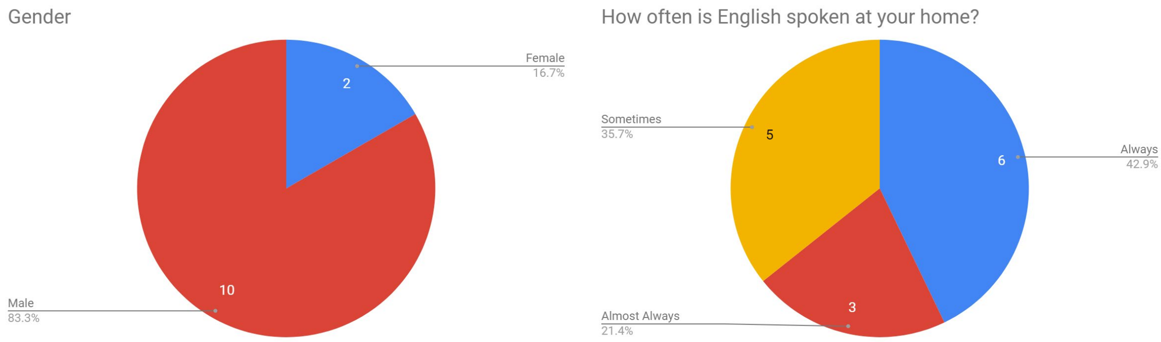

Figure 8. Results for gender and language spoken at home

The camp was successful in recruiting 15 students from the Hayward High School District. The camp was composed of 16.7% female and 83.3% male students representing a diverse cohort including Hispanic, Asian, Black, African American, and White students. The students' diversity is also represented by the language spoken at home, where English is spoken 35.7% some of the time, 21.4% almost always, and 42.9% all of the time, see Figures 8 and 9.

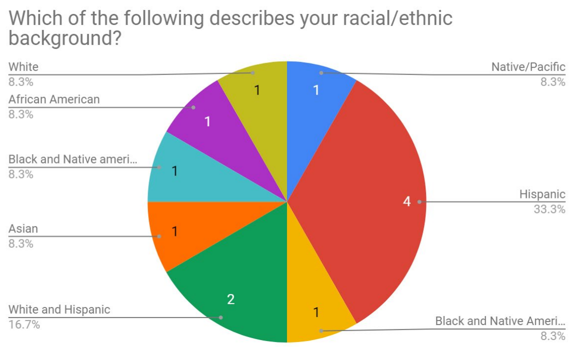

Figure 9. Results for racial/ethnic background and schooling of the male parent

The students' families also represented a wide range of educational backgrounds, see Figure 10. Most of the students' male adults completed college, 72.7%, while 18.2% completed high school, and 9.1% did not complete high school. Meanwhile, 58.3% of the female adults completed college, and 41.7% completed high school. When looking at the data, 2 students had adult guardians that did not attend college, making them the first in their family structure to attend a college course.

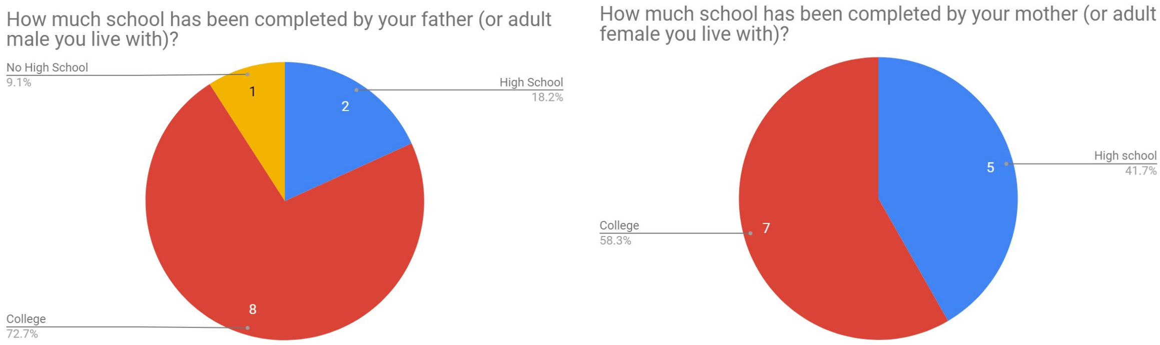

Figure 10. Results for the schooling of the female parent and career interests

In regards to career interest, 50% of the cohort expressed that they had not decided what major to pursue in the future, see Figure 11. Meanwhile, 33.2% expressed an interest in pursuing an engineering degree, such as astronautical, software, or audio engineering. Out of the entire cohort, 16.6% expressed an interest in the medical field. When asked if they wanted to pursue science, math, engineering, technical design, and programming jobs, the average answer was around 2 or Yes. In the future, the organisers will administer the survey at the beginning and end of the camp to evaluate if the camp promoted the pursuit of these disciplines. However, even though the organisers could not make such an analysis, the current results indicate that the recruitment process was successful in selecting students interested in the STEM disciplines.

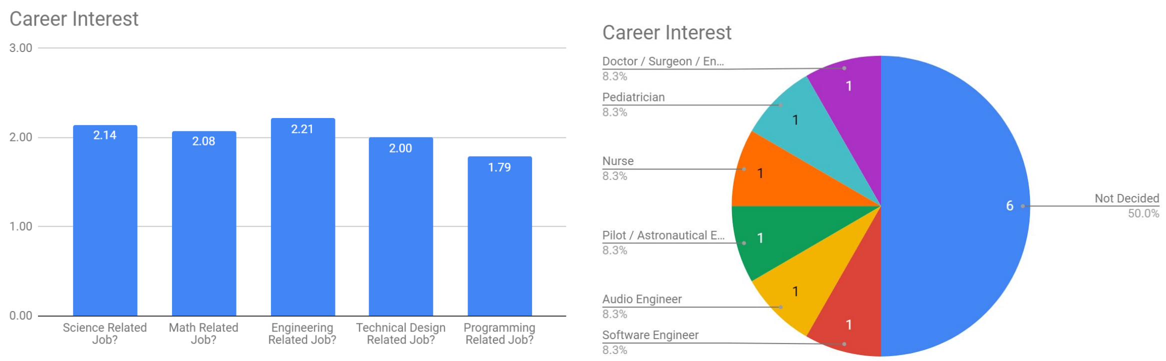

Figure 11. Results for career interests and perceived success

The organisers were interested in evaluating the participants' perceived success, STEM values, and engagement. Using the surveys developed by the LHS Activation Lab, the organisers captured the students' beliefs. The surveys asked questions on a 4-point scale (0 - NO!, 1 - No, 2 - Yes, 3 YES!). Starting with perceived success, see Figure 12, the scores for the "I did a good job", "I felt I was successful", and "I did everything well" were all around an average of 2 (Yes). Meaning that students believed they did a good job, that they were successful, and that they overall did well. The students also believed that camp was not difficult nor easy, as shown by the average score of 1.62 (between Yes and No) for the "It was easy for me". The scores for the "I did a better job than the others" and "I was more successful than everyone else" were at 1.46 and 1.36, again (between Yes and No). These scores indicate that the students found the camp challenging constructively and not a barrier to achieving the goals set by the camp.

When looking at student engagement, see Figure 12, further validation of the camp's success can be found. The students answered with an average of 1 (No) when asked if they were bored during the camp. Similarly, the students answered with an average of 1 (No) when asked if they were busy doing other tasks besides the camp tasks. When asked if they were daydreaming, the average answer was 1.50 (between Yes and No). In the future, to further evaluate this question, the organisers will include a question if the daydreaming was related to the topics of the camp or others. The most positive outcome of this camp comes from the average scores of above 2 (Yes) given to the "I felt happy", "I felt excited", "I was focused on the things we were learning all of the time", and "Time went by quickly". These scores are indicative that the camp engaged and motivated the students.

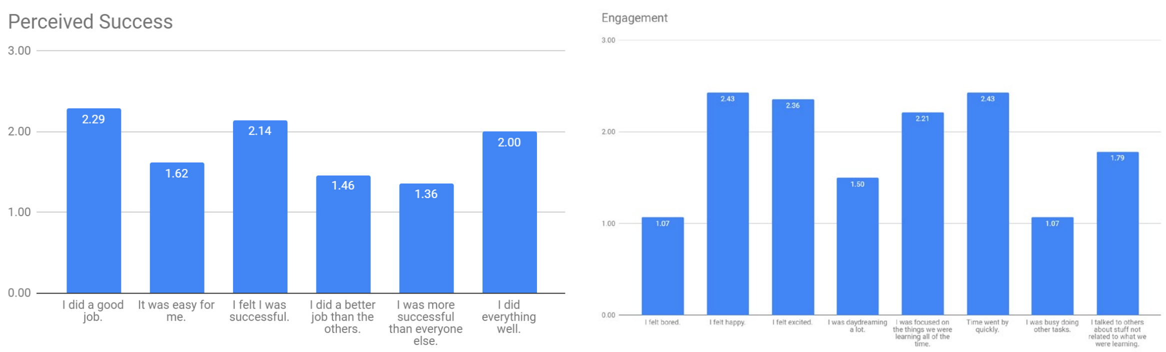

Figure 12. Results for student engagement

The organisers evaluated the students' perceptions and values as they relate to STEM disciplines and education, see Figure 13. Based on the survey results, the students indicated a strong belief that learning engineering, science, and mathematics is going to be important for their future. These three scores received an average of around 2 (Yes). Similarly, the students believe that making things work better is the most important value with an average score of 2.64 (between Yes and YES!), with engineering and technology making the world better values also above between Yes and YES!. Technology and thinking like a scientist were two values that scored neither positively nor negatively, both being close to 1.50 (between Yes and No). The values that had an average between 1 (No) and 2 (Yes) were values such as scientists having the most important job, technology being the most important thing, and knowing science being important for being a good citizen. These scores are indicative that the students really valued engineering knowledge and jobs.

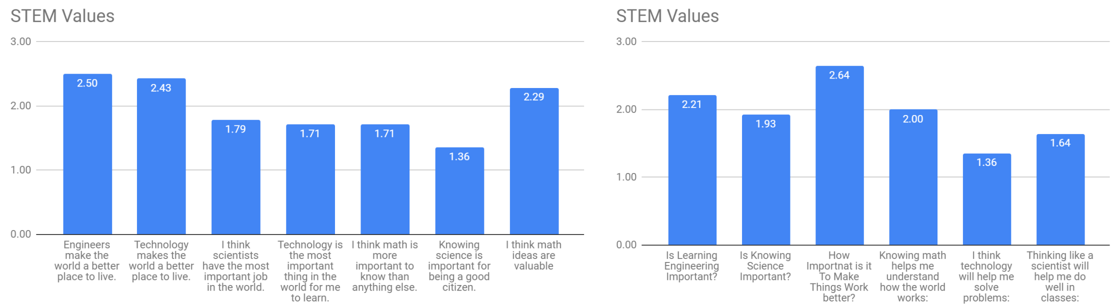

Figure 13. Results for STEM values

5. Conclusion

Based on the results from the survey, the student's projects, and lectures, the organisers can confidently conclude that the camp was a success. First, the organisers were able to evaluate that the students in the camp have a substantial career interest in STEM disciplines, their own perceived success was high, and the camp activities stimulated their engagement. Second, based on the students' ability to meet the camp learning objectives through the development of virtual reality prototypes, the organisers can confidently say that the students gained strong problem-solving and work-ready skills, which will be critical to their success in their high school and college careers. In the future, the organisers will make sure to collect pre-test data before the start of the camp. This would help the organisers understand the camp's impact on the students. In the next section, the organisers will address some of the changes necessary for making the camp even more successful.

The VRES Camp leadership organisers were able to achieve the goals and objectives mentioned in Section 3. The camp trained the participants in generating virtual reality simulations; supported the acquisition of knowledge, skills, and behaviours necessary to pursue STEM education; introduced industrial applications of virtual reality and visualisation in the architectural, engineering, and construction fields; and promoted the pursuit of STEM degrees. The following are the steps the organisers will take next year to go beyond meeting the goals and exceeding expectations.

Future efforts in the development of the camp will focus on improving and optimising the students' experience. As a first measure, the organisers will start recruiting students earlier in the academic year to reach the desired number of 20 students. Earlier recruitment would allow the organisers to recruit the most motivated students. The organisers will also work on recruiting a strong female representation and improving the diversity of the future cohorts. In another step, the organisers will focus on inviting guest lecturers that engage and activate the students' learning. Some professionals tend to engage the participants in a traditional lecture-based presentation that is less appealing to this year's participants. Therefore, the organisers will choose guest lectures in the next camp that provide hands-on experiences and activities. Another measure that the camp will take to improve the camp will be the inclusion of more games and pure fun moments for the students. This game time would support the students in taking an active break between the intense design sessions. Another step that the organisers will take will be minimising the lecture time and prioritising the design and development phases with SketchUp and Unity. In the future, the organisers will make sure to collect pre-test data before the start of the camp. This data collection would help the organisers understand the camp's impact on the students.

Lastly, the organisers plan to continue to grow the camp by testing it in other countries (e.g., UK and Italy) as a preliminary step to propose it as an exemplary program worldwide, which other institutions would be interested in starting in their communities. Additionally, by implementing the program in the countries represented by the co-authors could allow the authors to compare the results from different educational contexts.

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