EPiC Series in Built Environment
Volume 7, 2026, Pages 304–311
Proceedings of Associated Schools of Construction 62nd Annual International Conference

Evaluation for High School Students' Perceptions of Augmented Reality for STEM Education: A Three-Year Comparison (2023–2025)

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Over the past few years, Augmented Reality (AR) has garnered increasing attention in Science, Technology, Engineering, and Mathematics (STEM) education for its potential to enhance visualization, engagement, and experiential learning. By transforming abstract STEM concepts into tangible, interactive experiences, AR can foster deeper conceptual understanding and skill acquisition among students. However, to capitalize on these potential student perceptions of AR and its use in education, its use in education must be understood. Therefore, this research objective is to evaluate high school students' perceptions of AR use in STEM education. The study followed a quantitative methodology. The data was collected annually through online surveys administered via Qualtrics over the past three years and analyzed using chi-square. The study population consisted of high school students who participated in STEM summer camps. The survey assessed students' perceived challenges/difficulties and interest in extended use of AR technologies. The intellectual merit of this study lies in its exploration of how students' exposure to and acceptance of AR evolve over time and across multiple cohorts. By exploring students' change in perceptions, this study helps us understand how students accept new/novel technology within the realms of education. The broader impact of the research relates to how high school students perceive technology, with particular attention to ease of use and motivation levels.

Keywords: Augmented Reality (AR), Educational Technology, Math, Science, Education, High School students

Introduction

Emerging technologies are transforming education by creating new opportunities for enhancement and growth. It is important to embrace these innovations to elevate the learning experience to new levels. One of these technologies is Augmented Reality (AR) (Billinghurst & Duenser, 2012). AR combines virtual objects with real objects in real-time, typically displayed in a three-dimensional format. These systems have several key features: they integrate real and virtual elements within a real environment, operate interactively and in real-time, and ensure that virtual and real objects are aligned (Fuge et al., 2012). AR has increasingly been adopted in different educational settings, including secondary education, providing immersive and interactive learning experiences that go beyond traditional teaching methods (Alvarez-Marin & Velazquez-Iturbide, 2021; Di Serio et al., 2013).

Moreover, the growing body of research on AR in K-12 STEM education emphasizes the need for swift adoption and a deeper understanding of its long-term effects on student engagement and learning outcomes (Jiang et al., 2025). A study points out the "*challenges and obstacles*" encountered during the shift, including "lack of experience, lack of resources, anxiety, and difficulties using the new applications"(Al-Ansi, 2022). Specifically, during the COVID-19 pandemic, the integration of AR into educational frameworks was accelerated, amplifying these challenges (Al-Ansi, 2022). A different study provides a multi-year comparative analysis of high school students' perceptions of AR in STEM education, offering insights into evolving attitudes and challenges over time (Tene et al., 2024). It is essential to conduct this investigation to understand how continuous exposure to new technologies influences student acceptance and identify areas for further development in AR-enhanced curricula (Tene et al., 2024). This repeated, multi-year implementation approach helps in identifying trends in student perceptions, showing how initial excitement may transform into lasting engagement or highlight ongoing challenges with the integration of AR in educational settings.

Therefore, this research focuses on high school student groups that participated in STEM summer camps over three years (2023-2025). The overall aim is to gain a deeper understanding of student AR adoption at a cohort level over the last three years. The specific objectives of this research are:

1- Evaluate the challenges and difficulties these students faced while using AR; and
2- Assess their interest in the long-term use of AR technologies.

Ultimately, this study provides practical, student-centered analysis that can inform the development of more effective, engaging, and sustainable AR-enhanced curricula.

Literature Review

Research shows that AR can be especially effective STEM education. It helps students better understand and visualize scientific phenomena that are hard to observe in the real world. Furthermore, AR can connect both the virtual and the physical environments, enabling learners to engage in hands-on activities and experiments that would be challenging to carry out in a traditional classroom setting (Fearn & Hook, 2023).

In addition, AR can enhance students' conceptual understanding, problem-solving skills, collaboration, and communication. The immersive nature of AR allows students to visualize and interact with digital content superimposed on the physical world, which can improve engagement and understanding of complex STEM concepts (Guntur et al., 2020; Shirazi & Behzadan, 2015). AR also boosts motivation, curiosity, and teamwork. Its interactive nature keeps students focused, as many students are drawn to technology. These tools encourage a growth mindset by allowing students to try out ideas, learn from mistakes, and improve their understanding through hands-on experience.

Although AR systems have become more widely available, their implementation in schools remains financially and institutionally limited. Despite these limitations, high school students' interest in AR technology has remained strong and consistent, highlighting the potential of immersive tools such as the XR10 HoloLens to enrich STEM education and support future workforce readiness.

Given that AR possesses the ability to improve STEM skills of high school students, this research objective is to evaluate high school students' perceptions of AR use in STEM education with two hypotheses that were established and tested:

1- Hypothesis 1 (H_1): Challenges/Difficulties:
Alternative Hypothesis ($_{Ha1}$): There is a significant association between the year (2023, 2024, 2025) and students' reports of challenges/difficulties; (In other words, the proportion of Students reporting challenges "Yes" versus no challenges "No" differ across all three years.)

2- Hypothesis 2 (H2): Interest in Extended Use:
Alternative Hypothesis (Ha_2): There is a significant association between the year (2023, 2024, 2025) and Students' responses regarding extended use of the XR10 HoloLens (In other words, the proportion of Students reporting interest "Yes" vs. "No/Maybe" differ across all three years.)

Methodology

This study employed a **non-experimental, repeated cross-sectional design**, which is appropriate for examining associations among variables without manipulation (Reio, 2016). A repeated cross-sectional approach was selected because it allows participant data to be collected at a single point in time across multiple independent cohorts, enabling comparisons across years while maintaining sample independence (Thomas, 2020). Data were collected from five independent summer camps for high school students conducted in 2023, 2024, and 2025. Students completed the same activity and survey instruments during the camp. Students differ each year, allowing this design to facilitate a comparative analysis of results across the three years of the same activities and survey instrument, offering insights into evolving patterns in how Students perceived challenges/difficulties while using AR, as well as their interest in extended use. Students engaged with the AR experience for approximately **10 minutes**, however, the overall structure and interaction tasks remained consistent across all camps. The following is the information regarding the methodology:

- *Participants:* High school students from the inner city of San Antonio and the surrounding rural area.
- The Model: A 3D bridge model was developed using Revit, and it was experienced in the AR environment. The 3D bridge model was composed of a slab and six columns. The concrete slab was supported by two concrete, two steel, and two wooden columns.
- *Preparation for the AR use:* An introductory interactive activity was given to the Students, demonstrating the basic controls and gestures in Trimble XR10 with HoloLens 2.
- *AR STEM experience:* After the introductory, Students were guided through the model using the Trimble XR10 equipped with a HoloLens 2 headset. Students launched the application and navigated to the project. Once the model was loaded, Students were instructed to place it in their physical environment in this case it was the classroom for safe movement and to allowing students to focus on spatial reasoning, and structural interpretation without environmental constraints.
  During the Activity, students interacted with the bridge model by resizing and rotating the model. Students were tasked to select specific elements, using the measurement tool to calculate distances between two points, and capture screenshots. These actions encourage the development of students spatial awareness
- *Post-test:* Immediately after the experience in the AR environment, the Students were asked to complete an online survey that measured their experiences and perceptions.
- *Data Collection:* The data were collected using Qualtrics, an online survey
- *Research Variables:* To describe challenges and interest for extended use, questions were closed and contained two/three options: yes, no, or/and maybe.
- *Statistical Analyses:* A chi-square test was implemented using Python. The collected data were used to determine whether significant associations existed between Students' responses and camp year.
  The formula for the chi-square test statistic (Franke et al., 2012)is as follows:

$$x^2 = \sum (O - E)^2 / E$$

Where:

x^2 = Chi-Square
O = Observed frequency for each category
E = Expected frequency for each category, calculated based on a hypothesized Distribution

Another important element of the chi-square test is the degree of freedom (df). It is the number of categories minus one and is represented as follows:

$$df = k - 1$$

Where: K = Number of categories.

The conventional standard for determining statistical significance accepts a p-value of 0.05 or lower (Bonovas & Piovani, 2023). When a result has a p-value at this threshold, it suggests that the observed differences are unlikely to have occurred by chance, indicating that the result is statistically significant.

Results and Discussion

The results included responses from sixty-one (61) high school students who participated in five summer camps for the years 2023, 2024, and 2025. In the year 2023, there were 18 responses; in the year 2024, 33 responses; and in the year 2025, 10 responses. The analysis focused on the challenges/difficulties of using Trimble XR10 with HoloLens 2, over the past three years, as well as the interest in extended use across the same timeframe.

Demographic Information

Most Students were between 14 and 15 years old, with 15-year-old students representing the largest proportion (33%), followed closely by 14-year-old students (31%). Students aged 16 years accounted for 15% of the sample, while 13-year-old students comprised 10%. Smaller proportions of Students were 17 years old (8%) and 18 years old (3%). As in Figure 1.

Figure 1. Age of Students

Challenges/Difficulties with AR use

The Students were asked the following question: "*Did you encounter any difficulties or challenges while using the Trimble XR10 HoloLens?*" Based on the Alternative Hypothesis 1 (Ha1), the Null Hypothesis 1 ($H_0$1) for the statistical test was derived as follows:

- *Null Hypothesis (H_o1):* There is no significant association between the year (2023, 2024, 2025) and Students' reports of challenges using the Trimble XR10 HoloLens (In other words, the proportion of Students reporting challenges "Yes" versus no challenges "No" is the same across all three years.)

The responses were categorized as Yes or No and expressed as percentages for each year. Figure 2 shows that the proportion of Students reporting challenges remained relatively stable across the three years. In 2023 and 2025, approximately 60% of Students reported experiencing challenges, whereas in 2024 the percentage was slightly lower (around 50%). A Chi-square test ($p = 0.770$) fails to reject the null hypothesis. Therefore, there is no statistically significant difference in the distribution of responses over the three years. This suggests that Students' perceived difficulty with the XR10 HoloLens did not change significantly between 2023 and 2025.

The high percentage of "Yes" responses indicates the Students experienced some usability challenges while interacting with the system. These findings identify opportunities to enhance the effective implementation of AR in educational settings

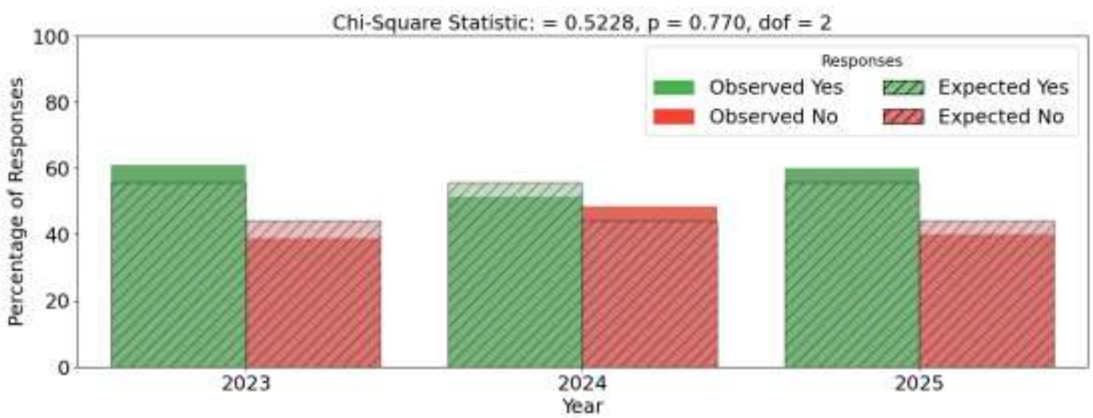

Figure 2. Challenges/Difficulties Responses

Interest in Extended Use

The Students were asked the following question: "*If given the opportunity, would you like to try the XR10 HoloLens for a longer duration?*". Based on the Alternative Hypothesis 2 (Ha2), the Null Hypothesis 2 (H_o2) for the statistical test was derived as follows:

- *Null Hypothesis (H_o2):* There is no significant association between the year (2023, 2024, 2025) and Students' responses regarding extended use of the Trimble XR10 HoloLens. (In other words, the proportion of Students reporting interest "Yes" vs. "No/Maybe" is the same across all three years.)

The responses were categorized as Yes or No/Maybe and expressed as percentages for each year. The No/Maybe category was due to the very small number of "No" responses (only one) over the years. Therefore, it was not feasible to conduct a valid Chi-square test with three separate response categories: "Yes," "Maybe," and "No." As the Chi-square test requires that all expected cell frequencies be greater than zero, with at least 80% of the cells having expected frequencies of 5 or more. To address this, "Maybe" responses were combined with "No" responses to create a single category called "No/Maybe." This grouping reflects the fact that "Maybe" responses typically indicate uncertainty or hesitation rather than a clear intention to extend use, aligning more closely with the negative or neutral end of the response scale. After this combination, the resulting 3×2 table (comparing Yes to No/Maybe from 2023 to 2025) satisfied the minimum expected-frequency requirement, making it appropriate to perform the Chi-square test of independence.

Figure 3 shows that Students' interest in extended use of the Trimble XR10 HoloLens remained consistently high across the three years. In 2023 and 2024, approximately 70–75% of Students expressed willingness to continue using the device, while in 2025 the percentage decreased slightly to around 50%.

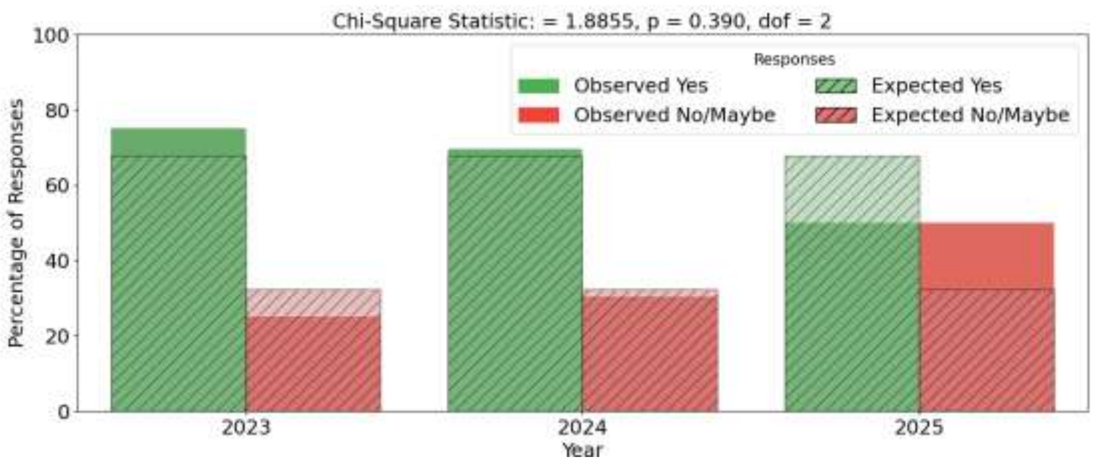

Figure 3. Interest in Extended Use Responses

A Chi-square test (p = 0.390) fails to reject the null hypothesis. Therefore, there is no statistically significant difference in Students' interest in extended use across the three years. This suggests that Students' enthusiasm for using the XR10 HoloLens for a longer duration remained generally stable over time, with no significant increase or decline in extended-use interest between the year 2023 and the year 2025. The slight decline in "Yes" responses observed in 2025 may not indicate less interest but rather reflect a shift from novelty-driven curiosity to pragmatic evaluation as AR technologies become more widespread and accessible.

Summary

This study of high school students' experiences with the Trimble XR10 HoloLens 2 demonstrated a consistent pattern. This consistency suggests that the learning environment, instructional design, and the AR experience provided by the Trimble XR10 HoloLens 2 were replicable across the three years. Variation among students did not produce significant differences in reported challenges/difficulties or interests in extended use, underscoring the repeatability of the AR learning setup.

The lack of a statistically significant improvement over the years suggests that technological advancements have not yet enhanced students' learning experiences. AR systems have become more widely available, but yet still financially and institutionally limited. Overall, the findings show that high school students' interest in AR technology has remained strong and consistent, highlighting the potential of immersive tools like the XR10 HoloLens to improve STEM education.

Future implementations should focus on aligning this technology with curricular needs, improving accessibility, and optimizing user experience. This approach could help transform AR into a stable, long-term instructional technology. Moreover, as AR tools become more affordable, future studies should investigate whether the current limited access evolves into broader and more sustained use in various learning environments.

Limitations and Future Research

While the findings of this study offer valuable insights into students' perceptions and experiences with the Trimble XR10 HoloLens 2, during multiple independent summer camps, future research could consider increasing the exposure time to AR technology, as the participating students' exposure to AR was limited, which may have constrained their ability to explore the system's capabilities fully. In addition, the sample size was limited to Students within a small number of Students in the summer camps, which may have constrained the generalizability of the findings.

Future research could employ longitudinal studies to investigate how participating high school students perceive the learning gains across multiple sessions. Further experimental research could compare different levels of training, exposure duration, or AR task complexity to identify conditions that enhance both usability and learning outcomes. An additional direction for future research is a detailed examination of the challenges encountered during AR use. Such studies could systematically analyze difficulties related to navigation, model manipulation (e.g., rotating and resizing), element selection, and measurement accuracy. The feedback would provide deeper insight into which AR interactions present the greatest barriers for students and how targeted training could mitigate these challenges.

Acknowledgment

The research team is very thankful for the support of the Texas Education Service Center of Region 20, the Charlotte Independent School District, and the U.S. Department of Agriculture. This research was supported by the intramural research program of the U.S. Department of Agriculture, National Institute of Food and Agriculture, Women and Minorities in STEM Program, award #: 2022-38503-37903. The findings and conclusions in this preliminary publication have not been formally disseminated by the U. S. Department of Agriculture, and should not be construed to represent any agency determination or policy.

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