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Assessing High School Students' Familiarity, Proficiency, Satisfaction, and Learning with Augmented Reality Devices

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The rapid advancements in Augmented Reality (AR) have introduced new possibilities for educational use to improve student learning. There is an opportunity for its use as an educational tool, as mathematics scores for United States (US) high school students have reached an all-time low on international exams. Based on the need, the research identified the level of familiarity, proficiency, satisfaction, and learning potential of US high school students with using AR technology to explore its adoption in math and science as an educational tool. The research used a non-experimental method, with data collected through a cross-sectional online survey. The students were allowed to interact with a model of a bridge using AR technology. The collected data was analyzed using Chi-Square, allowing the hypothesis to be tested by comparing expected data to actual observed data. The finding from this statistical analysis demonstrated that: (1) There is no statistically significant evidence that students are unfamiliar with AR devices, contrary to expectations; (2) Students tend to have an average level but still need development; (3) The observed responses significantly deviate from the assumption of being "average" in students' initial experiences; (4) The use of AR has shown an average level of improvement in understanding and learning.

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

Introduction

Student academic performance in the United States (US), particularly in math and science, has been concerning for many years. Studies indicate US high school students often lag behind their peers in other industrialized nations in these subjects (Carnoy & Rothstein, 2013). According to data from the National Assessment of Educational Progress, the average mathematics test scores for US 13-year-olds dropped sharply since 2020 (Carrillo, 2023). These findings of lower science and mathematics scores are concerning as they could have significant implications for the future of the US job market and its ability to remain at the forefront of scientific innovation (Carnoy & Rothstein, 2013; NSF, 2024).

One potential solution to address this issue is the integration of emerging technologies with education, such as Augmented Reality (AR). AR has been recognized as a practical and supplementary teaching tool that can significantly improve traditional teaching methods (Di Serio et al., 2013). AR is considered a promising tool for enhancing Science, Technology, Engineering, and Mathematics (STEM) education by providing students with interactive, immersive learning experiences to help them better visualize and understand complex concepts (Guntur et al., 2020; Mystakidis et al., 2022).

However, the adoption and implementation of these technologies successfully in the context of the education system depends on students' familiarity, proficiency, level of interaction, and enhanced learning potential with AR devices. Understanding student's exposure and proficiency with AR is critical, as this can help reduce the achievement gap in math and science. Therefore, the research explores US high school students' familiarity, proficiency, satisfaction, and learning potential of AR technology to explore its use in math and science as an educational tool.

Literature Review

Studies indicate AR can be particularly effective in Science, Technology, Engineering, and Mathematics (STEM) education, as it can help students better understand and visualize scientific phenomena that are difficult to observe in the real world. Additionally, AR can bridge the gap between virtual and physical environments, allowing learners to participate in hands-on activities and experiments that would be difficult to conduct in a traditional classroom setting (Fearn & Hook, 2023). In research conducted by Karagozlu (2017), the effectiveness of AR in enhancing problem-solving skills was examined among 147 seventh-grade students. The post-test results in the experimental group indicated significant improvement in students' problem-solving abilities compared to their pre-test results (Karagozlu, 2017). This is supported by Dunleavy et al.'s (2009) research, which concluded that AR could enhance problem-solving abilities; they also argued that AR could uniquely improve these skills. Another research study, conducted on 61 high school students in Iowa, US, demonstrated increased learning achievement through the use of AR in their learning activities (Estapa & Nadolny, 2015). A review paper that analyzed 52 publications on the use of AR in engineering education found that 17 of these studies examined AR's impacton students' academic performance, resulting in improvements in students' spatial and technical skills, as well as knowledge acquisition, particularly when students can directly interact with AR elements (Alvarez-Marin & Velázquez-Iturbide, 2022).

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 (Estapa & Nadolny, 2015; Guntur et al., 2020; Shirazi & Behzadan, 2015). In the research conducted by Vakaliuk et al. (2020), several AR software options were identified for mathematics, offering students interactive and immersive learning experiences. One example is Geo-AR, a tool designed to enhance the study of 3D geometry through AR technology (Vakaliuk et al., 2020).

Given that AR possesses the ability to improve the mathematics and science learning and skills of high school students, the research aimed to determine the level of familiarity, proficiency, satisfaction, and learning potentials of US high school students with AR technology, with four hypotheses that were established and tested:

- <u>Level of Familiarity</u>
  Alternative Hypothesis 1 (Ha1): High school students are unfamiliar with AR devices.
- <u>Level of Proficiency</u>
  Alternative Hypothesis 2 (Ha2): High school students tend to have minimal proficiency with AR devices.
- <u>Level of satisfaction with their initial experience</u>
  Alternative Hypothesis 3 (Ha3): High school students have a poor initial experience with AR devices.

- Level of improvement in their understanding and learning
  Alternative Hypothesis 4 (Ha4): High school students who used AR devices feel it significantly improved their understanding and learning.

Methodology

The research employed a non-experimental research methodology, as it does not manipulate variables but rather observes them as they naturally occur (Reio, 2016). This approach helps identify associations and guide future research. However, since variables cannot be manipulated, casual relationships cannot be established due to the lack of control (Reio, 2016). A cross-sectional study was employed because it allows for participant data collection at a single point in time (Thomas, 2020), providing a snapshot of how students interact with AR technology during a limited session, which aligns with the four research hypotheses. Furthermore, in cross-sectional research, the researcher observed variables without influencing them (Thomas, 2020). The following is the information regarding the cross-sectional survey study methodology:

a. Participant Population: High school students participating in two optional summer camps. Participant demographic information is provided in the results section of this paper.
b. AR Model Content: Participants engaged with a pre-designed 3D model of a bridge within the AR environment. The 3D bridge model was composed of a slab and columns. The concrete slab was supported by six columns: two made of concrete, two of steel, and two of wood. The different materials allowed students to determine the differences in columns and experience the material differences in an AR environment.
c. AR Equipment: The Trimble XR10 HoloLens was used as the AR device due to its advanced capabilities, including a 43-degree field-of-view (among the highest currently commercially available devices), integrates hand and eye tracking sensors, and provides access to Trimble Connect for interaction with 3D models (BuildingPoint SouthEast, 2024).
d. AR Software: Trimble Connect for HoloLens software was used, as it is a part of the Trimble Connect AR platform for construction, enabling teams to collaborate and visualize 3D BIM models within real-world environments. This technology, integrated with HoloLens devices, overlays digital designs onto physical spaces, improving accuracy and on-site coordination (Trimble Inc., 2022).
e. Survey Instrument: Immediately following the AR experience, students completed an online survey hosted on Qualtrics. The survey consisted of both demographic questions and items related to their AR experience and included 25 questions (a combination of Likert scale, multiple-choice, and open-ended questions) designed to capture participants' familiarity, proficiency, interaction, and enhanced learning potential using AR.
f. Variables: The variables measured included the levels of: Familiarity, Proficiency, Satisfaction with initial experience, and Improvement in their understanding and learning. All variables were measured through ordinal data to identify trends and patterns.
g. Statistical Analysis: A chi-square test was implemented using Python. The collected ordinal data was used to determine if the observed distribution of responses was significantly different from what was expected based on a hypothesized distribution. 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 df influences the shape of the chi-square distribution, which helps determine the critical chi-square value for a given significance level. This research helped determine the significant value (p-value) for a given chi-square and df. The chi-square distribution table is provided in Figure 1.

Accept Hypothesis | Reject Hypothesis

Percentage Points of the Chi-Square Distribution

Degrees of Freedom	Probability of a larger value of x^2								
	0.99	0.95	0.90	0.75	0.50	0.25	0.10	0.05	0.01
1	0.000	0.004	0.016	0.102	0.455	1.32	2.71	3.84	6.63
2	0.020	0.103	0.211	0.575	1.386	2.77	4.61	5.99	9.21
3	0.115	0.352	0.584	1.212	2.366	4.11	6.25	7.81	11.34
4	0.297	0.711	1.064	1.923	3.357	5.39	7.78	9.49	13.28
5	0.554	1.145	1.610	2.675	4.351	6.63	9.24	11.07	15.09

Figure 1. Finding the p-value for a chi-square of 1.2335 with 1 degree of freedom (Namuth et al., 2024)

According to the conventional standard for statistical significance, a p-value of 0.05 is commonly accepted (Bonovas & Piovani, 2023). If a result has a p-value of 0.05 or lower, we can conclude that the observed differences are unlikely to have occurred by chance, making the result statistically significant.

Results

The survey included responses from thirty-six (36) students from two summer camps. Three students did not complete the survey. Therefore, their answers were included only in the first and second hypotheses. The participants in the study ranged in age from 13 to 17 years old. Most participants were 15 years old (44% of respondents), followed by 14 years old (25% of respondents), and 16 years old being (17% of respondents). A smaller number of participants were 13 years old (11% of respondents), while the smallest group of three percent (3% of respondents) were 17 years old. This age distribution provides insight into the adolescent demographic engaging with the AR technologies in this study. Fifty-eight percent (58%) of the participants were males, and forty-two percent (42%) were females. Seventy-eight percent (78%) of the participants identified as Hispanics, and twenty-two percent (22%) as Whites.

Hypothesis 1 (H_1): Level of Familiarity

In the survey, we focused on using AR devices. Participants were asked (Question 5) whether they had previously used any AR devices, such as the Trimble XR10, Microsoft HoloLens, or Apple Vision Pro. Based on the Alternative Hypothesis 1 (Ha_1) the Null Hypothesis 1(H_{01}) for statistical test was derived as follows:

- Null Hypothesis 1 (H_{01}): High school students show a balanced familiarity with AR devices (50% are familiar with 'yes' and 50% are not familiar with 'no').

The results (Figure 2) indicate a difference between the observed and expected values. Sixty-one percent

(61%) of respondents reported using AR devices, while thirty-nine percent (39%) stated they had not. This suggests that more than half of the students are familiar with AR technology. However, a chi-square test yielded a chi-square value of 1.7778, with one degree of freedom, resulting in a p-value of 0.18242. Since the p-value exceeds 0.05, the null hypothesis (H_o1) cannot be rejected. This implies that the alternative hypothesis (Ha1) is rejected, indicating no statistically significant evidence that students are unfamiliar with AR devices. In other words, although most student responses suggest familiarity with AR technology, this finding is not statistically significant enough to confirm that most students are indeed familiar with AR.

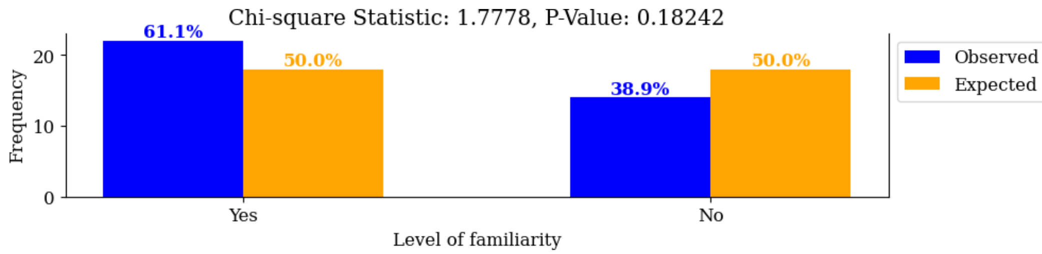

Figure 2. Level of Familiarity with AR - Observed vs Expected Responses (n=36)

Hypothesis 2 (H_2): Level of Proficiency

Participants who had used AR and answered "yes" to Question 5 were asked (in Question 5.2) to describe their proficiency with AR devices. Based on the Alternative Hypothesis 2 (Ha_2), the Null Hypothesis 2 (H_{o2}) for the statistical test was derived as follows:

- Null Hypothesis 2 (H_{o2}): High school students have an Average proficiency with AR devices

The results presented in Figure 3 indicate a discrepancy between the observed and expected values. Nearly twenty-four percent (24%) of participants reported having "Basic knowledge" of AR devices. Additionally, almost twenty-nine percent (29%) indicated they had "Limited knowledge." Another twenty-nine percent (29%) rated their proficiency as "Intermediate knowledge," making these three the most common responses. About fourteen percent (14%) considered themselves to have "Advanced knowledge," while a small proportion, five percent (5%), identified as "Experts" in AR technology. These findings suggest that while most respondents have at least a basic understanding of AR, relatively few consider themselves highly proficient or expert users.

However, a chi-square test yielded a chi-square value of 4.4762 with four degrees of freedom, resulting in a p-value of 0.34538. The results suggest as the p-value is greater than 0.05, there is a difference between the observed and expected values, and the null hypothesis (H_o2) cannot be rejected. This implies that the alternative hypothesis (Ha2) is rejected. In other words, although most student responses suggest proficiency with AR technology, this finding is not statistically significant enough to confirm that most students are indeed proficient with AR.

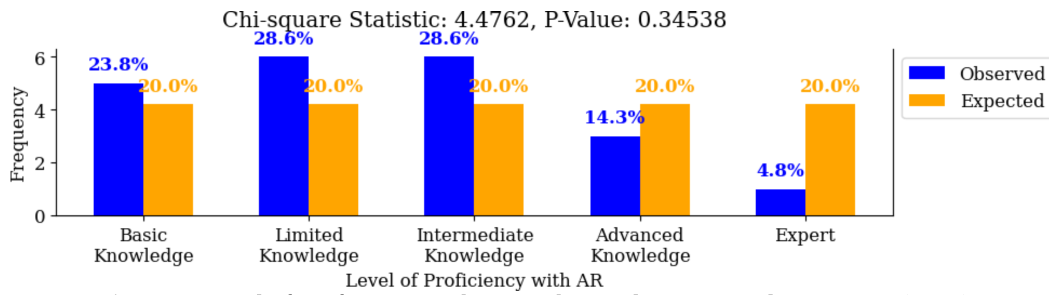

Figure 3. Level of Proficiency with AR - Observed vs Expected Responses (n=36)

Hypothesis 3 (H3): Level of Satisfaction with their Initial Experience

The participants were asked (Question 7) to rate their experience on a scale from 1 (Very Poor) to 5 (Very Good) while using the Trimble XR10 HoloLens. Based on the Alternative Hypothesis 3 (Ha3), the Null Hypothesis 3 (H_o3) for the statistical test was derived as follows:

- Null Hypothesis 3 (H_o3): High school students had average satisfaction with their initial experience.

The data indicates that most participants had a positive experience (Figure 4). Only six percent (6%) reported a "Very Poor" experience, while eighteen percent (18%) rated their experience as "Poor." Forty-nine percent (49%) described their experience as "Average," and twelve percent (12%) rated it as "Good." Notably, fifteen percent (15%) of respondents rated their experience as "Very Good." These results suggest that most users had at least an average or better experience with the device, though a small percentage encountered significant challenges. This feedback provides valuable insight into user satisfaction and areas for improvement in the deployment and usability of AR technologies like the Trimble XR10 HoloLens. Yet, a chi-square test produced a chi-square value of 18.0606 with four degrees of freedom, leading to a p-value of 0.00120. Since the p-value is less than 0.05, the null hypothesis (H_o3) is rejected. This suggests that the alternative hypothesis (Ha3) is not rejected, indicating the observed responses significantly deviate from the assumption of "Average." The findings are congruent with literature demonstrating that using AR in classroom environments can enhance motivation (Estapa & Nadolny, 2015).

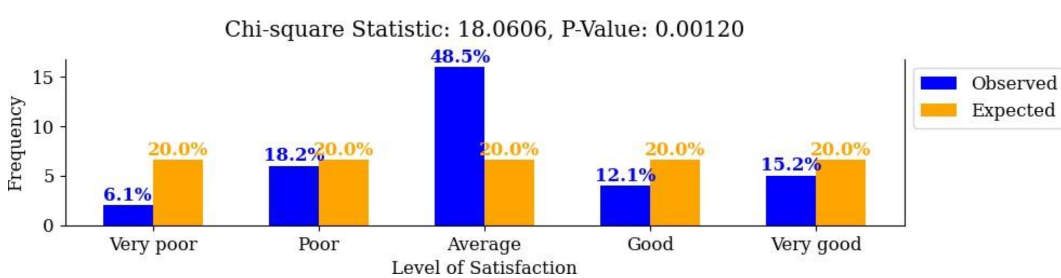

Figure 4. Level of Satisfaction with AR Initial Experience - Observed vs Expected Responses (n=33)

Hypothesis 4 (H4): Level of improvement in their Understanding and Learning

The participants were asked (Question 13) to evaluate how the Trimble XR10 HoloLens influenced their understanding or learning. In the question if the Trimble XR10 HoloLens enhanced their understanding or learning. Based on the Alternative Hypothesis 1 (Ha_4), the Null Hypothesis 4 (H_{04}) for the statistical test was derived as follows:

- Null Hypothesis 4 (H_{04}): High school students who used AR showed an average level of improvement in their understanding and learning.

Twenty-seven percent (27%) of participants reported a significant enhancement, while thirty percent (30%) noted a moderate improvement (Figure 5). Thirty-four percent (34%) of participants experienced slight enhancement, and nine percent (9%) stated that the device did not enhance their learning. This distribution shows a generally positive impact on learning, with most respondents reporting at least some level of improvement. Nevertheless, a chi-square test yielded a chi-square value of 4.6970, with three degrees of freedom, resulting in a p-value of 0.19538. Since the p-value exceeds 0.05, the null hypothesis (H_04) cannot be rejected. This implies that the alternative hypothesis (Ha4) is rejected, indicating no statistically significant evidence that students who used AR devices feel that it significantly improved their understanding and learning. The findings do not align with the literature and need further investigation. Results from other research suggest that the activity improved students' conceptual understanding of dimensional analysis (Estapa & Nadolny, 2015).

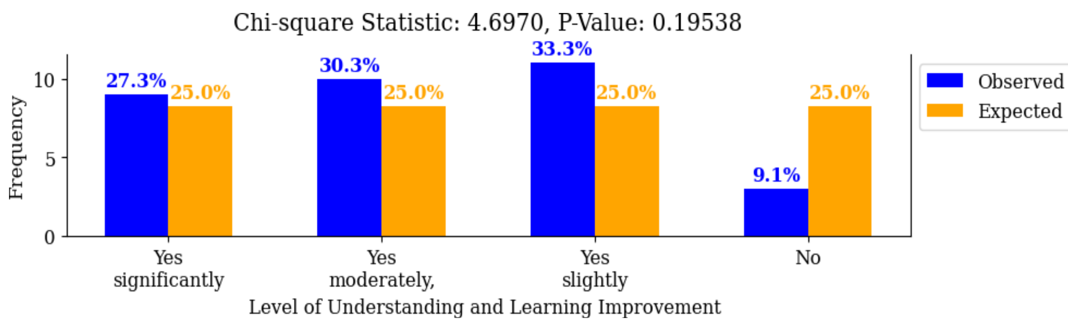

Figure 5. Level of Understanding and Learning Improvement - Observed vs Expected Responses (n=33)

Discussion and Practical Implications

This study provides valuable insights into high school students' familiarity, proficiency, and interaction with AR devices, as well as their potential to enhance learning. The data indicated that 61% of respondents had prior familiarity with AR devices. However, this result was not statistically significant ($p = 0.18242$), which means that although most students reported familiarity with AR technology, the finding is not strong enough to confirm that most students are indeed familiar with it. This aligns with results from another study, which suggested that high school students may have limited knowledge of AR (Qasrawi et al., 2024)

Participants reported varying proficiency levels, with most students identifying as having "Basic" to "Intermediate" knowledge. The result was not statistically significant (p-value of 0.34538). In other words, although most student responses suggest proficiency with AR technology, this finding is not statistically significant enough to confirm that most students are indeed proficient with AR. However, the results do not show statistically significant evidence that using AR leads to improved learning and understanding, which contradicts some previous studies (Cao & Yu, 2023; Mohamad & Husnin, 2023).

Regarding satisfaction with AR use, results suggest that most users had at least an average or better experience with the device, though a small percentage encountered significant challenges. These findings are consistent with previous studies that highlight AR's potential to create engaging and interactive learning environments (Estapa & Nadolny, 2015).

The study found that while most students reported some improvement in their understanding and learning (91%), the results (P=0.19538) indicated no statistically significant evidence that use of AR devices significantly enhanced their understanding and learning. However, results from other research suggest that the activity improved students' conceptual understanding of dimensional analysis (Alvarez-Marin & Velázquez-Iturbide, 2022; Estapa & Nadolny, 2015).

The results of this study highlight AR's potential as a transformative educational tool, especially in STEM education. However, challenges regarding familiarity, proficiency, and content integration need to be addressed to fully harness AR's benefits.

Conclusions

Given concerns about student learning skills in mathematics and science, and the potential for augmented reality (AR) to improve these skills, this research investigated US high school students' familiarity, proficiency, satisfaction, and learning potential with AR technology. The research used a non-experimental research methodology with data collected through a cross-sectional online survey. The survey population was high school students participating in two optional summer camps. Most participants (44% of respondents) were 15 years old, followed by those who were 14 years old (25% of respondents). Additionally, most participants identified as male (58%).

Although AR can potentially enhance learning, the findings suggest significant room for improvement in existing AR implementations. The study found that although many high school students reported familiarity with Augmented Reality (AR), the data do not provide statistically significant evidence to confirm that most students truly possess this familiarity. Furthermore, the participants indicated that they had more than minimal proficiency with AR. However, the study also found no statistically significant evidence that using AR devices significantly improved students' understanding or learning.

The conclusion of this study provides actionable insights and recommendations to further advance the integration of AR technology in education. Introducing foundational AR modules in the curriculum can gradually increase students' familiarity and proficiency with AR, creating a stronger basis for using AR in more complex learning tasks. Additionally, prioritizing investments in resources, training, and infrastructure is crucial to ensure equitable access to AR technology in schools. Policymakers should focus on developing training programs for educators and ensuring that schools are equipped with the necessary tools to integrate AR effectively.

The intellectual merit of this work lies in its contribution to understanding the readiness of high school students to engage with advanced AR technology in educational settings. The broad impact of this work extends to advancing the integration of AR technology in education, particularly in Science and Mathematics, as it shows that high school students are more familiar with AR than previously thought and underscores the technology's ability to enhance learning. This insight supports the development of future educational tools that utilize AR.

Limitations and future research

One of the limitations of the research was the small number of participants, which may limit the broader applicability of the findings. In addition, the assessment focused on students' initial experiences with AR devices. This may not accurately reflect long-term effects on learning outcomes or satisfaction. Additionally, most of the data relied on self-assessments from students, which can introduce bias. Such self-reporting can lead to overestimations or underestimations of proficiency and satisfaction, potentially not aligning with actual skill levels or learning impacts. It would be beneficial to explore alternative statistical analyses that could provide deeper insights beyond the chi-square analysis presented.

Future research may focus on the long-term impact of AR on learning outcomes in diverse student populations, considering factors like age and prior technology exposure. Experimental designs with control groups can help establish causal links between AR use and educational gains. Additionally, examining teacher training and curriculum integration may offer valuable insights for optimizing AR in education.

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