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Effectiveness of Python-based Mathematical Animation in Learning Trigonometric Function

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ABSTRACT

The abstract nature of trigonometric functions often presents a cognitive barrier for high school students, necessitating visual media capable of representing these concepts with mathematical precision. This study aims to evaluate high school students' perceptions of the effectiveness of Python-based mathematical animations as an interactive learning medium for trigonometric functions. A quantitative descriptive design was employed involving 91 students. The research instrument was a Likert-scale questionnaire measuring four dimensions: understanding, engagement, interest, and motivation. To ensure analytical accuracy, ordinal data were transformed into interval data using a z-distribution weighting procedure (Method of Successive Interval). The findings indicate that the media is highly effective across all dimensions. Specifically, the animation significantly clarified the connection between the unit circle and function graphs (understanding score: 3.5064), maintained high student focus through precise transitions (engagement score: 3.4888), and increased learning enthusiasm (motivation score: 3.4904) by making abstract content more captivating (interest score: 3.2339). The integration of programming-based visualization, with an overall effectiveness score of 3.4299, has proven to enhance students' cognitive and affective experiences. This study provides an empirical basis for using mathematically accurate animations as an innovative instrument to bridge abstraction and improve the quality of trigonometry education at the high school level.

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1. INTRODUCTION

Trigonometry is a core component of advanced secondary mathematics and serves as a crucial foundation for further study in Science, Technology, Engineering, and Mathematics (STEM) (Bekene Bedada & Machaba, 2022; Hsu et al., 2021; Owusu et al., 2025). Conceptually, trigonometry is unique because it simultaneously integrates algebraic manipulation, geometric reasoning, and graphical interpretation (Canonigo, 2025; Mukuka & Tatira, 2025). However, despite its central role, trigonometry is consistently reported as one of the most difficult mathematics topics for students, often characterized by fragmented understanding and an over-reliance on formula memorization (Adolphus & Nweke, 2025; Serpe & Frassia, 2021).

A major obstacle to this learning lies in students' inability to coordinate multiple representations (Nordlander, 2022; Owusu, 2023). The curriculum transition from static right triangle ratios to dynamic trigonometric functions on the unit circle often fails. Consequently, students find it difficult to connect symbols, geometry, and graphs in a way that makes sense, which leads to the false belief that trigonometric functions are just separate steps instead of whole mathematical relationships (Bornstein, 2017; Kamber & Takaci, 2018).

Mathematical animations have emerged as a promising instructional medium to address this representational challenge (Scheiter et al., 2010; Taylor et al., 2007). Unlike static images in textbooks, animations can visualize the transformation of mathematical objects in real time, helping students build complex mental models (Dyrvold & Bergvall, 2023; Ploetzner et al., 2020). In this context, the use of the Python programming language (through libraries like Manim) offers the advantage of high computational precision (Koupritzioti & Xinogalos, 2020). This precision is crucial because even small errors in the visualization of angles or coordinates can lead to conceptual distortions (Hamzah et al., 2021). Python enables the accurate integration of geometric and graphical aspects, which is now increasingly accessible through open platforms (Papagiannakis et al., 2023; Pradal et al., 2009).

While Python's technical potential for creating sophisticated mathematical visualizations is well-recognized, a significant research gap remains. Most previous research has focused on software development or the effectiveness of general visualization tools (Karnalim & Ayub, 2017; Lavanya et al., 2023; Mladenović et al., 2021). Limited empirical studies specifically evaluate students' perceptions of the effectiveness of Python-based animations, which are characterized by high precision across comprehensive psychological and cognitive dimensions.

This study aims to fill this gap by investigating how students evaluate the use of Python animations across four dimensions of effectiveness: conceptual understanding, engagement, interest in the topic, and learning motivation. From the perspective of high school students, this study aims to provide empirical evidence regarding whether the sophistication of code-based visuals is indeed correlated with improved classroom learning experiences.

2. METHOD

This study employed a quantitative descriptive design to evaluate the primary construction, namely the perceived effectiveness of the learning media. Effectiveness was operationalized through four measurement dimensions: (1) understanding of trigonometric functions, (2) engagement during the animation, (3) interest in the topic, and (4) sustained motivation to learn trigonometry. Each dimension was measured using a validated Likert-scale questionnaire.

The study subjects consisted of 91 high school students who had taken trigonometric functions in the regular mathematics curriculum. The learning material used was a high-precision animated video developed using the Python library and uploaded to the "VisMath" YouTube channel, titled "Visualization of Trigonometric Functions." This video dynamically integrates representations of the unit circle and function graphs.

Data were collected through a perception questionnaire with four response categories: Strongly Agree (S), Agree (S), Disagree (S), and Strongly Disagree (STS). The use of these four scales aimed to eliminate the tendency for respondents to choose an ambiguous middle (neutral) value. The data collection procedure was carried out in three systematic stages:

- Orientation: The teacher explained the learning objectives and instructed students to watch the animated video in a controlled classroom environment.
- Implementation: Students carefully watched the animated video using the provided devices.
- Evaluation: Immediately after the viewing session, students independently completed a questionnaire to objectively record their cognitive and affective impressions.

Given the ordinal nature of the data generated from the Likert scale, this study applied a z-distribution weighting procedure based on the Method of Successive Intervals (MSI) approach as formulated by Sappaile (2007). The transformation steps included:

- Determining the frequency distribution (f) for each response category.
- Calculating the cumulative proportion (cp) and converting it into a z-score using the standard normal distribution.
- Transforming the z-score into interval weights for each category.

These interval weights were then applied to the students' raw responses to produce weighted scores for each subscale (understanding, engagement, interest, and motivation) and an overall effectiveness score. This analysis ensured that the processed data had a higher level of statistical precision for descriptive interpretation.

3. RESULTS AND DISCUSSION

Results

To establish the basis for weighted score calculation, the z-distribution for each response category was determined separately for each dimension. All 91 participating students completed the questionnaire in full. Table 1 presents the category weight for each dimension based on Z-distribution, and Table 2 presents the frequency distribution of raw responses before weighted transformation.

Table 1. Category Weight for Each Dimension Based on Z-Distribution

Dimension	SD	D	A	SA
Understanding	1.0000	2.1172	3.1476	4.2978
Engagement	1.0000	1.8931	2.7327	3.9993
Interest	1.0000	1.6405	2.5723	3.8088
Motivation	1.0000	1.8369	2.8602	4.0932

Note: SD = Strongly Disagree; D = Disagree; A = Agree; SA = Strongly Agree.

The results of data transformation using the z-distribution procedure, Table 1, present the interval weight values for each response category (SD, D, A, SA) across the four dimensions of effectiveness. This process yielded several technical findings, as follows:

- The resulting weight values indicate that student perception data has been successfully converted from an ordinal scale to a more precise interval scale. For example, in the Understanding dimension, the distance between the Strongly Disagree (1.0000) and Disagree (2.1172) categories is not identical to the distance from Agree (3.1476) to Strongly Agree (4.2978). This demonstrates that the intensity of students' perceptions on each dimension has unique distribution characteristics.
- There is variation in the weight values for the positive response categories (Agree and Strongly Agree) across all dimensions. Understanding has the highest Strongly Agree weight (4.2978). This indicates that respondents who rated the understanding dimension highest contributed most significantly to the total effectiveness score. Motivation follows with an SA weight of 4.0932, indicating that Python animations provide a strong learning motivation for students who respond positively. Interest has a relatively lower positive category weight compared to other dimensions (A = 2.5723; SA = 3.8088). This factor reflects the more concentrated frequency distribution of student responses in the interest dimension, resulting in closer interval values.
- All dimensions have a uniform baseline value for the Strongly Disagree category (1.0000). This baseline value serves as a statistical anchor, allowing researchers to objectively compare the growth of effectiveness scores across dimensions after weighting.

Overall, these weighting results indicate that the Understanding and Motivation dimensions are the most sensitive factors in measuring the effectiveness of Python animations. This interval data will then be used to calculate each respondent's final score to comprehensively determine the media effectiveness category.

Table 2. Frequency distribution of student responses (N=91)

Dimension	SD	D	A	SA	Total
Understanding	1	12	37	41	91
Engagement	1	5	26	59	91
Interest	2	5	29	55	91
Motivation	1	6	31	53	91

The data in Table 2 presents the distribution of responses from 91 students to the four dimensions of the effectiveness of Python-based math animations. Overall, the trend of the data indicates a very positive response across all dimensions measured. Most of the students answered "Agree" (A) or "Strongly Agree" (SA) on all the questions. For the Engagement dimension, 59 students (64.8%) stated "Strongly Agree," the highest score compared to other dimensions. This indicates that the visual appeal and dynamics of Python animations are highly effective in maintaining student attention throughout the learning process. The Interest and Motivation dimensions also showed strong scores, with 55 and 53 students, respectively, selecting "Strongly Agree."

Although the Understanding dimension remained dominated by positive responses (37 respondents agreed and 41 respondents strongly agreed), it recorded the highest frequency of Disagree (D) categories, with 12 students. This suggests variation in the level of cognitive assimilation among students; although animations facilitate visualization, a small number of students may still require additional verbal explanations to connect the visualizations to formal calculation procedures. Furthermore, rejection of the media's effectiveness (Strongly Disagree category) was at a very marginal level, with only 1 to 2 students in each dimension. The low frequency of this negative scale confirms that Python-based animations were well-received as a learning medium and did not pose significant obstacles or confusion for most study subjects.

Cumulatively, more than 85% of students fell within the positive response spectrum (A + SA) for all dimensions. This raw frequency data provides initial validity, indicating that the developed animation medium has a high level of acceptance before being converted to interval data through a weighted z-distribution in Table 1 for more in-depth statistical analysis.

Using the z-distribution weights presented in Table 1 and frequency distribution shown in Table 2, weighted scores were calculated for each student across all dimensions. These interval-transformed scores were then aggregated to produce mean scores for each effectiveness dimension as well as an overall effectiveness score. Table 3 summarizes the descriptive statistics of the weighted interval scores, including categorical classifications that represent the level of effectiveness.

Table 3. Descriptive statistics of effectiveness scores

Dimension	Mean	Category
Understanding	3.5064	Positive
Engagement	3.4888	Positive
Interest	3.2339	Positive
Motivation	3.4904	Positive
Overall Effectiveness	3.4299	Effective

Table 3 presents descriptive statistics of the effectiveness scores that have gone through an interval weighting process. This data provides a comprehensive overview of students' perceptions of the use of Python-based mathematical animations. Based on the analysis results, the four measured dimensions showed high average values (means), which were consistently in the "Positive" category. The Understanding Dimension recorded the highest average score of 3.5064. This indicates that Python animations significantly helped students construct a better conceptual understanding of trigonometry material. The Motivation and Engagement Dimension: These two dimensions showed very competitive scores, at 3.4904 (Motivation) and 3.4888 (Engagement), respectively. These figures indicate that the media not only functions as a cognitive aid but is also effective in stimulating the affective aspect and active participation of students in class. Furthermore, the Interest Dimension: Although it had the lowest average score compared to other dimensions (3.2339), this score remains in the positive category, reflecting a positive reception of the aesthetics and relevance of the video content.

The most crucial indicator in this table is the overall effectiveness score, which reached 3.4299. Based on the established assessment criteria, this score places the "VisMath" animated video learning media in the "Effective" category. These results confirm that the integration of Python-based visualization technology can meet students' needs in understanding abstract and complex material. The consistent average score above 3.20 for all dimensions indicates that this media has high reliability in improving the quality of the learning experience. The main advantage of this media lies in its ability to balance clear conceptual explanations (understanding) with visual appeal that can stimulate learning enthusiasm (motivation and engagement).

Discussion

This study evaluated high school students' perceptions of the effectiveness of a trigonometry animation video developed using Python. Using Sappaile's (2007) z-distribution weighting method, the results showed that this media was positively perceived across all dimensions of effectiveness. These findings provide strong empirical evidence that precise animated visualizations can bridge the gap between abstract concepts and students' cognitive understanding of trigonometric functions (Orhani, 2024; Singh et al., 2024).

The understanding dimension had the highest average score, which was 3.5064. This indicates that students considered the animation highly effective in clarifying complex trigonometric function concepts. This finding aligns with previous literature suggesting that mathematical animations support conceptual understanding by making abstract relationships more tangible (Çilingir Altiner, 2024; Nabani & Narpila, 2025; Nurdin et al., 2019; Pires et al., 2022; Schneider et al., 2025). The sequential integration of the unit circle and graphs in the "VisMath" video facilitated students' mastery of connecting various mathematical representations coherently.

Student engagement showed a significant score of 3.4888, reflecting a high level of attention, with 64.8% of students stating "Strongly Agree" that this media increased their engagement. According to Mayer's (2024) theory, dynamic and visually rich instructional media retain students' attention better than static presentations. Smooth animation transitions and coordinated color use in Python technology have been shown to maintain student focus throughout the learning process.

The interest and motivation dimensions scored 3.2339 and 3.4904, respectively. This is a crucial finding, given that trigonometry is often perceived as a boring and difficult topic to understand. The success of animation in increasing interest demonstrates that well-designed visualizations can make challenging mathematical content more engaging. The aesthetic appeal and novelty of the animated video format helped shift students' perceptions of the material's relevance. Furthermore, the high motivation score reflects students' willingness to continue learning trigonometry through similar resources in the future. By transparently visualizing functions, this media reduced learning anxiety and increased students' confidence in mastering advanced mathematical topics.

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Cumulatively, the overall effectiveness score of 3.4299 places this media in the "Effective" category. These results confirm that the use of programming tools such as Python to create mathematically precise visualizations is not just a technical innovation but a valid pedagogical solution to improve the quality of mathematics learning at the secondary school level.

This research makes significant theoretical and practical contributions to mathematics education, particularly in the integration of programming technology for learning visualization. This research shows clear evidence that using code-based animation (Python) helps students better understand difficult abstract trigonometric concepts. The z-distribution weighting procedure (Method of Successive Interval) helps in analyzing students' views by changing data from an ordinal to an interval scale, which leads to more accurate and precise statistical results. This study shows that using libraries like Manim in Python can clearly show the changing relationship between the unit circle and the function graph, which is hard to do with regular static images. In addition, the findings of this study contribute to strategies for improving students' affective aspects, where aesthetic and precise visualizations are proven to be able to significantly increase students' interest, motivation, and engagement in learning topics that are traditionally considered difficult. Furthermore, the results of this study can be a reference for education practitioners and curriculum developers to adopt the use of programming-based visual media as an innovative solution to improve the quality of mathematics learning at the secondary school level.

4. CONCLUSION

The findings of this study conclude that the use of Python-based mathematical animations is effective in improving the quality of trigonometric function learning in high school students. The study demonstrates this effectiveness in four key areas: (1) Conceptual Understanding: The use of Python-based animations enables students to comprehend the connections between the unit circle and function graphs, resulting in an average score of 3.5064. (2) Engagement and Attention: This media can maintain student focus throughout the learning process with a score of 3.4888, driven by dynamic and precise visual transitions. (3) Motivation and Interest: The use of this technology increases students' enthusiasm for learning (score 3.4904) and makes previously considered abstract material more captivating (score 3.2339). Overall, the effectiveness score of 3.4299 confirms that the integration of programming in learning media has a positive impact on students' cognitive and affective experiences. This evaluation confirms that mathematically accurate visualization is an important instrument in bridging abstraction in mathematics education.

As a suggestion, mathematics teachers are advised to start integrating precision-based visual media, such as Python animations, to minimize misconceptions on other abstract topics besides trigonometry. Further development of animations can add interactive features where students can manipulate variables directly through a code-based interface or web platform to increase deeper engagement. Future research should use an experimental design (control and experimental classes) to test the direct impact of using Python animations on student learning outcomes (test scores), beyond just perceived effectiveness. In addition, further studies are needed to see the effectiveness of this media at different educational levels or with groups of students with diverse mathematical abilities to ensure the inclusivity of this technology-based learning medium.

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