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RESEARCH ARTICLE

THE EFFECT OF CABRI 3D (C3D) ON SHS STUDENTS' UNDERSTANDING OF THREE-DIMENSIONAL GEOMETRY CONCEPTS

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ABSTRACT

This study investigates the impact of Cabri 3D (C3D) simulations, a virtual reality-based dynamic geometry software, on Senior High students' academic performance in 3D geometry concepts. The research addresses the persistent challenges students face in understanding abstract spatial relationships and geometric principles through traditional teaching methods. Grounded in constructivist theory, the study posits that immersive, interactive learning environments can enhance conceptual understanding, spatial visualization skills, and problem-solving abilities. A quasi-experimental design was employed, involving 122 SHS2 students from a public Senior High School in Ghana, divided into an experimental group (n=69) taught using C3D simulations and a control group (n=53) instructed via conventional methods. Pre-test and post-test assessments measured students' performance before and after the intervention. Descriptive and inferential statistics (independent sample t-tests) were used to analyse the data. The results revealed a statistically significant improvement in the experimental group's post-test scores (M=53.12, SD=5.635) compared to the control group (M=39.30, SD=4.432) with a p-value of 0.002 ($p<0.005$). This finding supports the hypothesis that C3D simulations enhance students' comprehension of 3D geometry by fostering engagement, motivation, and spatial visualization skills. The study aligns with prior research, highlighting the efficacy of technology-integrated learning in mathematics education. The study recommends the adoption of Cabri 3D and similar dynamic geometry tools in SHS curricula to address learning gaps in abstract mathematical concepts. Schools are encouraged to equip ICT labs with relevant resources and train educators to leverage these technologies effectively. Future research could explore long-term retention and scalability of such interventions across diverse educational contexts.

KEYWORDS

Cabri 3D, virtual reality, 3D geometry, spatial visualization, constructivist learning, mathematics education, senior high school.

1. INTRODUCTION

1.1 Background to the Study

Researcher defined five mathematics process, including problem solving, reasoning and proof, linkages, communications, and representations (Sbaih, 2022). These processes are essential for developing a comprehensive understanding of mathematical concepts and skills. By integrating these elements into instruction, educators can foster a more engaging and effective learning environments for students. One of these processes is mathematical problem solving. Spatial skills are among the abilities that have been linked to mathematical learning and success (Tarte, 2020). There is a connection between mathematical accomplishments and spatial visualisation abilities, according to research studies such as (Reid et al., 2000). Furthermore, according to the study, practices and training can help learners improve their spatial visualisation abilities (Alam, 2009). Technology integration in education has revolutionised conventional teaching approaches and provided creative means of improving students' understanding of challenging material. Among these technologies, C3D has become a potent tool for immersive learning experiences as a virtual reality simulation (Dalgarno and Lee, 2012). Students sometimes have trouble comprehending spatial relationships and abstract notions in the context of mathematics, especially 3-dimensional geometry (Hoffler and Leutner, 2007). With the use of virtual reality simulations, students can interact with 3D objects and possibly enhance their completion of geometric concepts (Al Bulushi, 2017). Using Cabri 3D to learn and practice three-dimensional geometry as part of a dynamic geometry software (DGS)-based learning programme may be crucial for improving students' problem-solving abilities. Motivation, conceptual comprehension, and problem-solving techniques are considered significant in how well students acquire dynamic geometry software-based lessons (Denbel, 2023). Students in senior high schools, who are at a crucial juncture in their cognitive development, stand to gain much from these technology interventions. By integrating DGS into the curriculum, educators can create engaging and interactive learning experiences that cater for diverse learning styles. This approach not only enhances students' understanding of geometric concepts but also fosters a collaborative environment where they can share ideas and strategies with peers. However, more research is still needed to determine how much C3D's use as virtual reality simulation affects students understanding of 3D geometry (Psotka and Chen, 2019). By investigating how Cabri 3D, a virtual simulation tool, affects SHS students' comprehension of 3D geometry topics, this study aims to close this knowledge gap.

1.2 Statement of the Problem

One of the standards for the mathematical process is problem-solving. The main abilities for resolving issues in both the real world and mathematics

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are mathematical problem-solving abilities. Prior research has shown that effective teaching strategies can significantly enhance student engagement and learning outcomes (Lowrie et at., 2021). Their findings suggest that incorporating interactive elements into lessons fosters a deeper understanding of the material. They further indicated that spatial visualisation abilities could be enhanced via practice and that there was a correlation between mathematics achievement and spatial visualization abilities (Lowrie et al., 2021). The challenge is how to successfully improve mathematical problem-solving abilities while also cultivating and improving spatial vision abilities. Learning and practicing three-dimensional geometry using both dynamic geometry software and conventional tools can help develop and improve spatial visualisation skills (Aziz and Supriyadi, 2022). Because 3D geometry is abstract, many SHS students still struggle to understand it, even with the advances in educational technologies (Mathematics, 2007). The dynamic visualisation needed for deeper comprehension is frequently lacking in traditional teaching techniques like static models and textbook diagrams (Wu and Shah, 2007). Although virtual reality simulations are a viable substitute, there is little empirical data regarding their efficacy in this setting. Several studies demonstrate the connection between mathematical success and spatial visualising abilities (Psotka and Chen, 2019). The relationship between spatial skills and mathematical achievement has been the subject of extensive research. However, the role that learning and practicing three-dimensional geometry with Cabri 3D plays in developing spatial visualisation and problem-solving abilities has not been sufficiently examined, nor has the mediation relationship between the development of mathematical problem-solving abilities and learning three-dimensional geometry with Cabri 3D spatial visualisation abilities been examined. In contrast to traditional teaching techniques, the purpose of this study is to determine whether virtual reality simulations may improve SHS students' comprehension of 3D geometry concepts. The study aims to explore the effectiveness of these simulations in enhancing students' understanding by providing an interactive and immersive learning environment. By comparing the outcomes of students using Cabri 3D with those who engage in conventional learning methods, the research will offer insights into how technology can transform mathematical education.

1.3 Objective of the Study

To assess the effect of C3D simulations on SHS students' academic performance in 3D geometry concepts

1.4 Research Question

What is the effect of C3D simulations on SHS students' performance in 3D geometry concepts?

1.5 Research hypothesis

H_0: There is no significant difference in the academic performance of students taught using Cabri 3D and those taught using the conventional instructions.

H_1: There is significant difference in the academic performance of students taught using Cabri 3D and those taught using the conventional instructions.

2. Literature Review

2.1 Theoretical Framework

The constructivist theory serves as the foundation for the investigation into how C3D simulations affects SHS students' comprehension of 3D geometry. According to constructivism, which was put forth by Piaget in 1950 and Vygotsky in 1978, students actively interact with their surroundings to create knowledge. By offering an immersive, interactive environment where may manipulate 3D objects, virtual reality simulations support this notion by encouraging deeper knowledge through experiential learning (Dalgarno and Lee, 2012). Constructivism is an educational theory that holds that humans learn best via experience. To put it another way, humans create their meaning through experience. Constructivism is a way of thinking that holds that knowledge and meaning are created by people interacting with their thoughts and experiences. It has influenced several disciplines, including psychology, sociology, education, and scientific history (Suhendi 2018). The development of the SHS students' spatial visualisation skills falls under the fourth stage of the Piaget paradigm, known as the Formal Operational Stage. Students' understanding of geometrical concepts, especially those pertaining to Euclidean geometry, grows during this phase within the complex formal framework. The constructivism ideology places a strong emphasis on meaning of a learning process. According to the constructivism theory, students are motivated and assisted in comprehending the main idea through discovery learning (Suhendi 2018).

2.2 Cabri 3D (C3D) Geometric Software

Cabri 3D is a dynamic geometry software designed to facilitate the study of three-dimensional shapes. Unlike traditional tools, it allows students animate and explore geometric figures, enhancing spatial visualisation and conceptual understanding (Accascina and Rogora, 2006). Studies suggest that such interactive features improve engagement and retention of geometric concepts (Denbel, 2023).

2.3 Effect of C3D simulations on SHS students' academic performance in 3D geometry concepts

Studies have examined how SHS students perform when learning 3D geometry concepts, and the results typically support the beneficial effects of C3D simulations.

a. Improved Conceptual Understanding and Spatial Visualisation

Students' ability to visualise intricate 3D geometric concepts through C3D simulations enhances their spatial thinking and problem-solving abilities. According to studies, interactive 3D technologies improve comprehension by giving abstract ideas a concrete form (Hoffler and Leutner, 2007). This shows that using dynamic 3D graphic software like Cabri 3D can greatly help students who struggle with spatial awareness.

b. Improved Application and Retention

Compared to traditional techniques, research shows that students who use 3D simulations retain geometric concepts longer and use them more successfully in problem-solving (Gooden, 2020).

c. Enhanced Motivation and Retention

Because they offer immersive and interactive learning experiences, dynamic 3D simulations also help students become more engaged in their studies. According to the study, this results in increased motivation and improved performance on geometry task (Dalgarno and Lee, 2012; Al Bulushi, 2017). Thus, by establishing immersive and dynamic learning environments, virtual reality can greatly increase student engagement. It further suggests that virtual reality settings increase motivation and engagement more than conventional teaching techniques (Al Bulushi, 2017). Similarly, by offering motivation and joyful learning experiences, technology can increase students' intrinsic motivation and interest in the subject, as demonstrated by (Makransky and Lillelolt, 2018).

d. Decrease in Mental Stress

By dividing difficult 3D geometry issues into interactive, visual parts, C3D tools reduce cognitive overload (Ginns and Leppink, 2019).

3. Methodology

3.1 Research Paradigm

According to the study, this study follows the positivist research paradigm, which prioritize objectivity, quantifiable results, and the testing of hypotheses by quantitative means (Weyant, 2022). The positivist paradigm is suitable for this study since it uses empirical data and statistical analysis to investigate how Cabri 3D simulations affects SHS students' comprehension of geometry concepts.

3.2 Research Approach

This study uses a quantitative research methodology to critically examine the connection between students' comprehension of 3D geometry and C3D simulations. Numerical data can be gathered using this method, and patterns and correlations can be found through analysis (Bryman, 2016). Students' performance is evaluated both before and after they are exposed to C3D simulations using pre-test and post-test assessments.

3.3 Research Design

Using a quasi-experimental non-equivalent methodology, the study compares the performance of students exposed to C3D simulations with those taught using traditional methods. The approach includes a pre-test and a post-test to measure changes in comprehension (Ayu Swati Pramitha Yuliandari et al., 2023).

Two groups; the experimental group, which received tuition based on C3D simulations, and the control group, which received conventional instructions; were used to assess how well the technology integration improved conceptual understanding.

3.4 Population and Sampling techniques

The study's target population was SHS 2 students in the Lawra Municipality of the Upper West Region. The sample size consisted of one hundred and twenty-two (122) form two students from two intact classes (class X and class Y) at one of the Municipality's high schools. Purposive sampling was employed to choose the classes because of the capacity of the school's ICT laboratory which served as the experimental group's classroom during the period of the study. Class X with a student population of sixty-nine (69) was the experimental group whilst class Y with a population of fifty-three (53) was the control group. The distribution of students who participated in the study is shown in the table below. The experimental group consisted of forty-five (45) boys and twenty-four (24) girls, while the control group was made of twenty-eight (28) boys and twenty-five (25) girls.

Table 1: Study participants

Sex	Experimental group	Control group	Total
Male	45	28	73
Female	24	25	49
Total	**69**	**53**	**122**

Source: Field Data, 2025

3.5 Data Collection Procedure

i.Pre-test

The researcher developed a list of questions centred on three-dimensional geometric ideas and administered them to both the experimental and control groups. The pre-test consisted of twelve (12) questions, with a total score of 60. The pre-test was designed to assess the students' comprehension and application of three-dimensional geometry concepts. The duration of the pre-test was one hour.

Interventions

a. Control group

The researcher used the traditional approach of instructor-led instructions and educational materials to teach the control group. This includes hand-drawn representations of 3D figures and explanations of geometry concepts. A variety of 3D shapes, such as cubes, cuboids, cylinders, and prisms, were also presented to the students. Additionally, the researcher walked the students through the process of calculating the volumes and total surface areas of these shapes. After that, students were divided into groups and given a class task that involved identifying forms and figuring out the volumes and areas of three-dimensional shapes. An hour was allocated for the lesson.

b. Experimental group

In the school's computer lab, the experimental group was instructed through 3D geometry lessons utilizing C3D simulations. Every student got access to a computer with Cabri 3D software pre-installed. The C3D interface, including the toolbar, workspace, and navigation, was introduced at the start of the class. To design shapes, the students were instructed to start by choosing simple 3D shapes, such as the cube, from the workplace toolbar.

Additionally, they received instructions on how to altar shapes' dimensions using the selection tool and how doing so impacts volumes and surface areas. Learners were led to open shapes into their nets using the selection tool to visualize the cross-sections of 3D solids. This made it simple for them to determine the total surface areas. Additionally, they learned how to measure the lengths, distances, and angles of shapes using the menu tool. They were able to compute the volumes and areas of solids after these exercises. Throughout the class, they had time to build various three-dimensional solids, like cuboids, prisms, cylinders, and other composite structures, such as pyramids. They were able to identify the nets and determine each shape's area and volume.

ii. Post-test

To measure the degree of gain following treatments, the researcher administered a second test a week after the treatments, with assistance from a mathematics teacher at the school where the study took place. There were twelve test items on this test, and the total score was 60. With the help of a research professional, the researcher created the test items, which included questions about fundamental understanding and applications of geometric principles.

3.6 Validity

Validity, according to the study, is the degree to which study results faithfully capture the social processes being studied (Creswell, 2003). The validity of an instrument is determined by how well it accomplishes its stated purpose (Lee, 2022). It distinguishes between internal and external validity in the social sciences (Streefkerk, 2019). He goes on to say that the extent to which research findings can be extrapolated(generalized) to other individuals, situations, or occurrences is known as external validity. The degree of assurance that the casual relationship under study real and unaffected by outside influences is known as internal validity. To ensure internal validity, the instruments were given to research professionals who regularly evaluate, check, and validate the validity of the research instruments.

3.7 Reliability

The degree to which an instrument consistently measures the traits it is meant to assess is known as its reliability (Lee, 2022). It defines reliability as the extent to which a research tool yields consistent results when applied to the same subjects and circumstances (Creswell, 2003). A pilot study was carried out utilizing a test-retest process on students from a class that was not participating in the study to assess the reliability of the research instrument. This was done to see if respondents' replies were consistent throughout a predefined period. The Cronbach's Alpha coefficient was used to evaluate the survey items' internal consistency. With an alpha value of 0.8, which is greater than the dependable coefficient of at least 0.7, the items were considered satisfactory.

4. Results and Analysis

To compare group performance, the quantitative test data was analysed using both inferential and descriptive statistics as suggested by (Ahmad et al., 2020).

4.1 Pre-test results

Prior to the intervention, the pre-test was administered to both groups to see if the geometry proficiency of students in the two classrooms was equivalent. The students' pre-test score ranged from zero (0) to five (5), with 5 representing correct answer and 0 representing inaccurate answers. The total score was 60. Table 2 presents the results of the pre-test. The control group's average scores (M=1.40, SD=0.492) and the experimental group's scores (M=1.43; SD=0.498) were remarkably similar.

Table 2: Pre-test descriptive statistics

Statistics	Experimental group	Control group
N	69	53
Mean	1.43	1.40
Standard Deviation	0.498	0.492
Minimum	3	3
Maximum	**12**	**11**
Range	**9**	**8**

Source: Field Data, 2025

The results also show that the mean scores were nearly equal and that the range of scores was quite close, with the experimental group's range being 9 and the control group's range being 8. The standard deviation of the experimental group's scores was 0.498, whereas that of the control group was 0.492. This suggests that the two group's standard deviations were quite comparable. An independent sample was used to ascertain whether the pre-test scores differed significantly.

Table 3: Pre-test scores for the experimental and control groups using an independent sample t-test.

Group	N M SD	t-value Df p-value
Control Experimental	53 1.40 0.492 69 1.43 0.498	0.214 120 0.002
Source: Field Data, 2025		

As recommended by Ahmad et al. (2020), an independent sample t-test was employed to ascertain whether there was a significant difference in the pre-test scores. The control group's performance (M=1.40; SD=0.492; t (120) =0.214, p=0.002) was not statistically and substantially superior to that of the experimental group (M=1.43, SD=0.498). Any variations in the students' performance in three-dimensional geometry on the post-test can be attributed to the intervention because the pre-results showed that the geometric ability of the students in both groups was identical before the intervention.

4.2 Post-test results

A post-test questionnaire was given to both groups after they had been taught three-dimensional geometric ideas utilizing the Cabri 3D geometric software and the conventional lesson delivery, respectively. The purpose of the twelve (12) question test, which had a total score of 60, was to gauge the two group's comprehension and retention levels following the treatments. The post-test descriptive statistics in table 4 showed that the experimental group's average score (M=53.12; SD=5.635) was higher than the control group's average score (M=39.30; SD=4.432). The mean scores of the two groups differ by 13.82 points. This shows that, on average, learners in the experimental group outperformed those in the control group by 13.82 points. Students in the experimental group received the highest score of 54, while those in the control group received the highest score of 35.

Table 4: Post-test score descriptive statistics

Statistics	**Experimental group**	**Control group**
N	69	53
Mean	53.12	39.30
Standard Deviation	5.635	4.432
Minimum	31	20
Maximum	**54**	**35**
Range	**23**	**10**
Skewness	**-0.235**	**-0.117**

Source: Field Data, 2025

The experimental group's score range was wider than that of the control group. The difference between the top and lowest scores of the experimental group was 23 points, while the control group's score was 10 points. The control group's mean score 39.30, whereas the experimental group was 53.12. This suggests that the experimental group's mean score spread was marginally larger than the control group.

4.3 Research Hypothesis

The research hypothesis's significance level was established at $p < 0.05$, (2-tailed). The post-test data were analysed using an independent sample t-test to see if the average performance of the experimental group and the control group differed significantly. The preliminary study's findings demonstrated that the t-presumptions test was functioning properly. This suggest that the post-test scores were based on a normal distribution, the variance was uniform, the measuring scale was an interval scale, and the scores for the two groups were unrelated to one another.

Table 5: Post-test results for the experimental and control groups using independent sample t-test.

Group	**N M SD**	**t-value Df p-value**
Control Experimental	53 39.30 4.432 69 53.12 5.635	2. 523 120 0.002
Source: Field Data, 2025		

The experimental group's post-test performance (M=53.12; SD=5.635) was significantly better than the control group's performance [M=39.30; SD=4.432; p=0.002 and t (120) =2.523], as indicated in Table 5. The t-test results corroborated studies by Hoffler and Leutner (2007) since the p-value of 0.002, which is less than 0.05, showed a significant difference between students who learnt 3D geometry concepts through C3D teaching approach and those who received traditional teaching mode. Consequently, the null hypothesis was rejected. The results of the t-test demonstrated that these students' average performance was noticeably higher than that of students who did not receive instruction using C3D teaching methodology.

5. Conclusion and Recommendations

This study suggests that learning and practicing three-dimensional geometry with Cabri 3D can enhance one's capacity for spatial visualization. This implies that Cabri 3D can have a direct effect on spatial vision abilities. Furthermore, there is direct link between the ability to visualise space and the ability to solve mathematical problems. On average, students who received instruction utilizing Cabri 3D method performed better than those that received instructions using the conventional method. The performance of the treatment group differed noticeably. Additionally, this current confirmed the findings of Hoffler and Leutner (2207) by demonstrating a substantial association between students' spatial vision skills and their ability to solve mathematical problems. According to Al Bulushi (2017), virtual reality environment boost motivation and engagement more than traditional teaching methods. This claim is further supported by the current study's conclusion. The findings of the study have several implications for mathematics instructions in senior high schools. The use of Cabri 3D or other technology that may express mathematical concepts should be promoted among SHS mathematics teachers. In addition to improving their performance in the subject, this will increase students' interest and positive attitudes towards learning the subjects and mathematics in general. The dynamic mathematics software Cabri 3D is recommended for senior high school mathematics students to use in their schoolwork to improve their understanding of the numerous geometry principles they are studying. The heads of senior high schools in Ghana should evaluate the various mathematics courses' content and make suggestions for implementing appropriate technological tools to teach mathematics in areas where students struggle. To facilitate the teaching and understanding of abstract mathematical concepts, the ICT labs in the various senior high schools should be equipped with the required personnel and materials.

References

Accascina, G., and Rogora, E., 2006. Using Cabri3D Diagrams for Teaching Geometry. The International Journal for Technology in Mathematics Education, 13(1).

Ahmad, Z., Saleem, Z., and Rehman, K., 2020. Impact of Teacher Effectiveness and Student Attitude on Students Academic Achievement in Science Subjects in the Secondary Schools of Dera Ismail Khan (Pakistan). Global Social Sciences Review, V(I). https://doi.org/10.31703/gssr.2020(v-i).25

Al Bulushi, Z., 2017. Book Review: Virtual Literacies: Interactive Spaces for Children and Young People, edited by Guy Merchant et al, London: Routledge, 2014. International Journal of Literacy, Culture, and Language Education, 5. https://doi.org/10.14434/ijlcle.v5i0.26945

Ayu Swati Pramitha Yuliandari, K., Ratminingsih, N. M., and Budasi, I. G., 2023. An Experimental Study on The Impact of Digital Multilingual Thematic Dictionary for The Sixth Grade Students' Literacy Skill. Acitya: Journal of Teaching and Education, 5(2). https://doi.org/10.30650/ajte.v5i2.3667

Aziz, A., and Supriyadi, E., 2022. Upaya Memberikan Infomasi Kepada Siswa Tehadap Bimbingan Dan Konseling Melalui Layanan Bimbingan Klasikal Bagi Seluruh Siswa Smp Islam Nurul Yaqin. Papanda Journal of Mathematics and Science Research, 1(1). https://doi.org/10.56916/pjmsr.v1i1.127

Bryman, A., 2016. Social Research Methods - Alan Bryman - Oxford University Press. In Oxford University Press.

Clements, D. H., Sarama, J., Yelland, N. J., and Glass, B., 2008. Learning and Teaching Geometry With Computers in the Elementary and Middle School. Research on Technology and the Teaching and Learning of Mathematics: Vol. 1. Research Syntheses, November.

Creswell, J. W., 2003. Chapter One, A Framework for Design. Research Design Qualitative Quantitative and Mixed Methods Approaches. https://doi.org/10.3109/08941939.2012.723954

Dalgarno, B., and Lee, M. J. W., 2012. Exploring the relationship between afforded learning tasks and learning benefits in 3D virtual learning environments. ASCILITE 2012 - Annual Conference of the Australian Society for Computers in Tertiary Education. https://doi.org/10.14742/apubs.2012.1581

Denbel, D. G., 2023. History of mathematics (HM) in secondary school mathematics textbook. Cogent Education, 10(2). https://doi.org/10.1080/2331186X.2023.2228988

Ginns, P., and Leppink, J., 2019. Special Issue on Cognitive Load Theory: Editorial. In Educational Psychology Review (Vol. 31, Issue 2). https://doi.org/10.1007/s10648-019-09474-4

Gooden, L. A., 2020. Enhance Faculty Experience and Skills Using Maple in the 21st Century Classroom. Communications in Computer and Information Science, 1125 CCIS. https://doi.org/10.1007/978-3-030-41258-6_18

Höffler, T. N., and Leutner, D., 2007. Instructional animation versus static pictures: A meta-analysis. Learning and Instruction, 17(6). https://doi.org/10.1016/j.learninstruc.2007.09.013

Lee, D., 2022. Chapter 3. Research design and methodology. In Public Space in Transition. https://doi.org/10.1515/9783839462324-007

Lowrie, T., Harris, D., Logan, T., and Hegarty, M., 2021. The Impact of a Spatial Intervention Program on Students' Spatial Reasoning and Mathematics Performance. Journal of Experimental Education, 89(2). https://doi.org/10.1080/00220973.2019.1684869

Makransky, G., and Lilleholt, L., 2018. A structural equation modeling investigation of the emotional value of immersive virtual reality in education. Educational Technology Research and Development, 66(5). https://doi.org/10.1007/s11423-018-9581-2

Mathematics, N. C. of T. of., 2007. The Learning of Mathematics: 69th NCTM Yearbook [2007 NCTM Yearbook (69th)]. In National Council of Teachers of Mathematics.

Psotka, J., and Chen, N. S., 2019. The new potentials for Intelligent Tutoring with learning analytics approaches. In Interactive Learning Environments (Vol. 27, Issues 5–6). https://doi.org/10.1080/10494820.2019.1612888

Reid, M. E., Christian, S. B., and Brien, D. L., 2000. Gravitational stability of three-dimensional stratovolcano edifices. Journal of Geophysical Research: Solid Earth, 105(B3). https://doi.org/10.1029/1999jb900310

Sbaih, A. D., 2022. Analysis of Mathematical Operations Content for Grades (4th, 5th, and 7th Grades) Books in Jordan According to the Standards of Mathematics NCTM (2000). Journal of Educational and Social Research, 12(2). https://doi.org/10.36941/jesr-2022-0046

Streefkerk, R., 2019. APA Manual 7th Edition: The 17 Most Notable Changes. Scribbr.

Suhendi, A., and . P., 2018. Constructivist Learning Theory: The Contribution to Foreign Language Learning and Teaching. KnE Social Sciences, 3(4). https://doi.org/10.18502/kss.v3i4.1921

Tartre, L. A., 2020. Spatial Orientation Skill and Mathematical Problem Solving. Journal for Research in Mathematics Education, 21(3). https://doi.org/10.5951/jresematheduc.21.3.0216

Taylor, M., Pountney, D., and Malabar, I., 2007. Animation as an aid for the teaching of mathematical concepts. Journal of Further and Higher Education, 31(3). https://doi.org/10.1080/03098770701424975

Weyant, E., 2022. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 5th Edition. Journal of Electronic Resources in Medical Libraries. https://doi.org/10.1080/15424065.2022.2046231

Wu, H. K., and Shah, P., 2004. Exploring visuospatial thinking in chemistry learning. In Science Education (Vol. 88, Issue 3). https://doi.org/10.1002/sce.10126