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Computational Thinking in Mathematics Education : A Systematic Literature Review on its Implementation and Impact on Students' Learning

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Abstract: This study aims to analyze the impact of mathematics learning using Computational Thinking (CT) integration and to enlighten educators, researchers, and policy makers on the tactics, benefits, and challenges involved in incorporating CT into mathematics education by synthesizing existing research and educational initiatives. Using the systematic literature review (SLR) method with a qualitative approach, the results of this research were in the form of descriptive analysis. The database used was Scopus to filter relevant material about CT and mathematics education. Based on the search, nine publications from 2019 – 2023 were selected systematically based on the PRISMA protocol. This study's results indicated a relationship between CT and several students' mathematical abilities, such as problem-solving and improving problem-solving skills. Not only can it improve the cognitive side of students, but CT can also improve students' affective side, such as increasing creativity, confidence, and involvement in the learning process. The impact felt is not only in the micro scope (in the classroom), but can also be macro. CT can improve the quality of higher learning, so CT research can be used to determine a country's curriculum.

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Introduction

Within the early 19th century, the term "computational considering" developed in association with the utilization of subjective examination in science and came afterward in association with the emphasis on thinking within the instructing of number juggling (Childs, 2015). As we enter the mid-21st century essential computational considering aptitudes are basic for people of all ages (Kalelioğlu et al., 2016; Wing, 2014). Computational considering is utilized as one of the approaches to create problem-solving aptitudes (Afifah & Kusuma, 2021). Computational considering alludes to a joining of problem-solving stages comprising of thoughts, openings, and challenges confronted to create an arrangement that will be chosen (Fajri et al., 2019).

Arithmetic is closely related to computational considering since it includes designs, issue structures, and factors that can be utilized with diverse values. Computational considering abilities have four fundamental components, specifically decay, design acknowledgment, deliberation, and calculations (F. K. Cansu & Cansu, 2019; Kidd, T., R & Morris, 2017). Computational consideration is basic within the learning handle. This is often to bolster high-level tackling abilities (Tim Penyusun Materi ITB, 2020). Instructing computational thinking can be deciphered as an educator instructing understudies to think and fathom issues like a computer. In expansion, CT is additionally related to inventiveness and development (Mishra & Yadav, 2013; Repenning et al., 2015). A few nations have actualized computational considering in their educational modules, for case in Indonesia computational considering has been actualized since 2018. In Permendikbud number 37, the government made computational considering one of the aptitudes that must be had by students at the basic and auxiliary school levels. CT integration in learning has been exhausted in a few nations, such as Australia (Falkner et al., 2014), United Kingdom (Brown et al., 2014), Finland (Mannila et al., 2014), Sweden (Kilhamn & Bråting, 2019), and the United States (Fisher, 2016).

With increasing nations' coordination computational consideration into their educational program, there's a developing number of investigations on this issue. Numerous analysts raise this issue because computational thinking could be an unused thing within the world of investigation and the pointers in computational considering are curious to ponder. The subject of computational considering is related to a few aptitudes such as algorithmic considering, agreeable considering, inventiveness, basic considering, and issue fathoming. One of the articles that examines the relationship of the over points with CT is the article of Doleck et al., (2017).

This study intends to enlighten educators, researchers, and policy makers on the tactics, benefits, and challenges of incorporating CT into mathematics education by synthesizing existing research and educational initiatives. The novelty of this study is that the data used is from Scopus, so the research collected is of good quality and well analyzed. This study's findings will help clarify the direction of future research on this CT and show how earlier studies have developed.

Research Method

This study used the systematic literature review method with a qualitative approach. The systematic literature review method emphasises classifying, selecting, assessing, or counting critically significant investigations and collecting and examining information from the findings for review (Aliyu et al., 2021). The stages of this SLR usage for the most part include three fundamental components: results, improvement, and arranging. Each stage's specifics are shown in Figure 1.

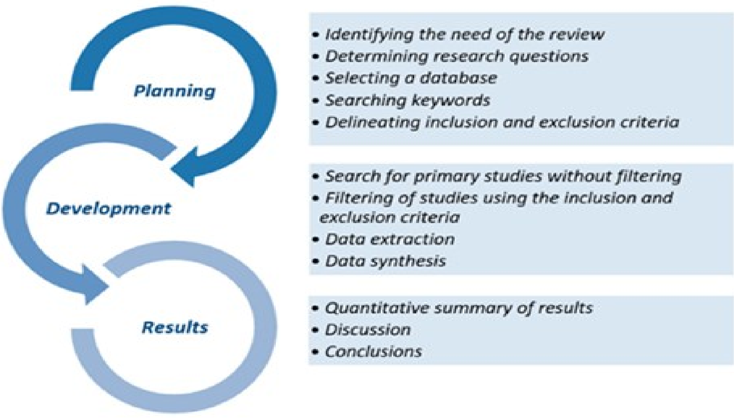

Figure 1. Phase diagram of SLR (Pahmi et al., 2023)

Planning

The primary arrangement in this consideration was arranging. An audit method was created that served as a direct for looking into and deciding the goals, strategies, and key results of intrigued for the SLR. In this stage, catchphrases, and inclusion-exclusion criteria of the inquiry about questions (RQ) were decided. The watchwords were utilized to look at the Scopus database. The article found 42 articles based on the watchwords: "computational

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thinking" AND "mathematics" OR "mathematics education" OR "learning mathematics". Inclusion-exclusion criteria were set to rearrange the method of selecting suitable writing.

Table 1. Inclusion-Exclusion Criteria

Criteria	Inclusion	Exclusion
Article title and content	an appropriate title that complied with the study's requirements	did not match the requirements of the study and had an irrelevant title
Year of publication	publications from 2019 to 2023	publications outside the range specified
Type of publication	solely for journal articles	reviews, editorials, and non-empirical studies
Language	English	others
Field of article study	mathematics education	others than mathematics education
Accessibility	full-text articles or open access	preview articles and required a payment

These criteria will later determine the literature that answers the RQ. RQ is the cornerstone of SLR research. It guides the process of searching and extracting literature. Data analysis and synthesis are obtained from the SLR results, which answer the RQ that we have determined. The RQ formula is presented in Table 3.

Development

The arrangement utilized after arranging is the improvement arrangement. The advancement could be an arrangement that involves the execution of an SLR. We allude to the Favored Detailing Things for Efficient Surveys and Meta-Analyses (PRISMA) at this arrangement. PRISMA makes a uniform peer survey strategy that uses a list of best hones to assist in standardizing the quality and reproducibility of the amendment process (Conde et al., 2020). (Conde et al., 2020). Distinguishing proof, screening, qualification, and consideration are the essential components of PRISMA. The stream of this PRISMA convention is appeared in Figure 2.

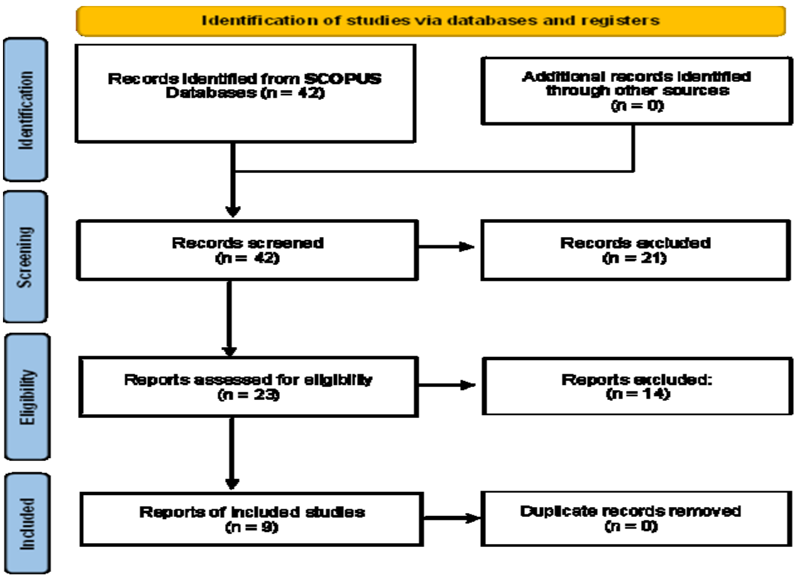

Figure 2. PRISMA Protocol Flow Picture

Results

The ultimate organizes of this SLR inquire about includes methodological examination and talk of the detailed results based on the RQ raised, driving to an SLR conclusion. The SLR investigation moreover gives data on encouraging examination related

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to patterns, considering inadequacies, and recommendations. This arrangement will, too, precisely assess the significance of each stage that appears in Figure 1 and highlight the methodological limitations that are inalienable within the SLR.

Thematic analysis is the data analysis approach used in this research. Thematic analysis, according to Fereday & Muir-Cochrane, is a useful method for thoroughly reviewing qualitative data to identify interconnected patterns in events and be able to describe the extent to which a phenomenon occurs from the researcher's perspective (Naeem et al., 2023). Thematic analysis, as proposed by Holoway & Todres, is essential in the analysis of qualitative research (Vaismoradi et al., 2013).

Result and Discussion

Due to applying the inclusion criteria, all the articles were met, so the number of articles remained at 42. After reviewing the 'title, keywords, abstract, and content', 23 articles were published as they met the requirements within the scope of 'mathematics education'. Finally, 9 articles that met the RQ criteria were selected and will be further analyzed and reviewed. The following articles were used to analyze the information in Table 2.

Table 2. Author, Article Tittle and Year of Publication

Author (Year of Publication)	Article Tittle
Maharani et al., (2019)	Problem Solving in The Context of Computational Thinking
Reichert et al., (2020)	Computational thinking in K-12: An analysis with mathematics teachers
Soboleva et al., (2021)	Formation of Computational Thinking Skills Using Computer Games in Teaching Mathematics
Bråting & Kilhamn, (2021)	Exploring the intersection of algebraic and computational thinking
Tan et al., (2021)	Exploring the Effectiveness of STEAM Integrated Approach via Scratch on Computational Thinking
Rich et al., (2022)	Computational thinking practices as tools for creating high cognitive demand mathematics instruction
Ng et al., (2023)	Exploring computational thinking as a boundary object between mathematics and computer programming for STEM teaching and learning
Looi et al., (2023)	Exploring Computational Thinking in the Context of Mathematics Learning in Secondary Schools: Dispositions, Engagement and Learning Performance
Sala-Sebastià et al., (2023)	Didactic–Mathematical–Computational Knowledge of Future Teachers When Solving and Designing Robotics Problems

Based on the PRISMA arrangement, all articles (n = 9) will be analyzed to assemble the data required to reply to this investigation address so that the targets in this SLR inquiry can be accomplished based on the discoveries and realities. The discourse in this consideration will be categorized into 5 concurring with this address inquiry. Table 3 below gives the answers to the inquiry questions posed and the inspiration behind the investigative questions.

Table 3. Research Questions

Code	RQ	Motivation
RQ1	How has CT progressed in math learning by year and demographic?	Knowing the year and socioeconomics will give a diagram of the improvement of CT considers that have been conducted and utilized as prescient fabric and those that will be conducted.
RQ2	What research approach was used in the	This research will provide an overview of the

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Code	RQ	Motivation
	CT study?	types of research that have been conducted related to CT
RQ3	Who are the research subjects in CT research?	This research provides an overview of the CT research subjects that have been conducted
RQ4	What is the CT research focus of the study?	Provide insight into the focus of CT research studies and serve as a basis for further research
RQ5	What is the impact of learning mathematics integrated with CT?	Provides insight and knowledge on the impact of CT learning integrated in mathematics learning.

Based on the Scopus database distributed between 2019 - 2023 related to CT in arithmetic instruction. Figure 3 shows the dispersion of articles analyzed based on the year of distribution based on the researcher's discoveries; CT inquiries about arithmetic instruction have changed based on the Scopus database. It was famous that in 2019 and 2020, 1 article was distributed. In 2021, alongside the improvement of CT in science instruction, this investigation has expanded, specifically 3 articles. Be that as it may, in 2022 it diminished, to be specific as it were 1 article. In 2023, it expanded once more, specifically by 3 articles. The advancement of CT investigations in arithmetic instruction has varied since the consideration given to the productivity of programming learning plans that utilize CT is still missing (Grover & Pea, 2017; Lye & Koh, 2014). Polat et al., (2021) recommend that further research on CT in arithmetic instruction ought to be conducted within the future to compare the real effect of CT on math problem-solving aptitudes. Combining information and innovation will be the arrangement to the issue (Voskoglou & Buckley, 2012). In this manner, the improvement of CT investigates and the arrangement to illuminate the issue is to actualize the integration between CT and educational modules (Bower et al., 2017; Geary et al., 2000; Voogt et al., 2015; Weintrop et al., 2016) as has been drained Asian nations, Hong Kong, Taiwan, and China (Subramaniam et al., 2022).

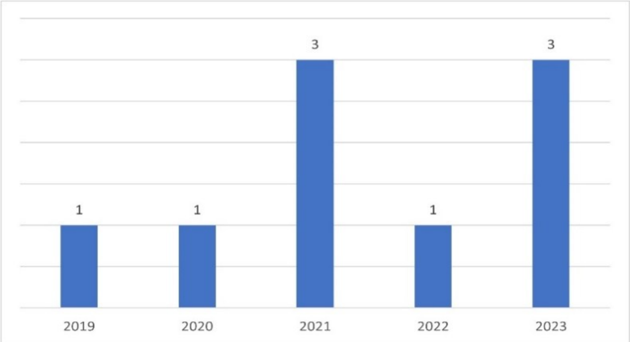

Figure 3. Distribution of Articles Based on Year of Publication

CT will continue to develop in mathematics education, including in the scope of education. The development of CT is important in education because CT and mathematical habits of mind can be linked to instruction (Pei et al., 2018; Weintrop et al., 2016). Good CT skills are one of the things to support higher-order skills (Tim Penyusun Materi ITB, 2020). The fluctuating development of CT in the 2019-2023 timeframe is due to several things. One of the causes of fluctuations is that in the 2019-2022 period, the world was experiencing a COVID-19 pandemic. Hence, the tendency of researchers at that time was technology-based research, such as Augmented Reality (AR) research, which is widely carried out (Eldokhny & Drwish, 2021). Regarding the distribution of CT studies by country, Figure 4 shows the publications of selected studies based on the country in which they were conducted.

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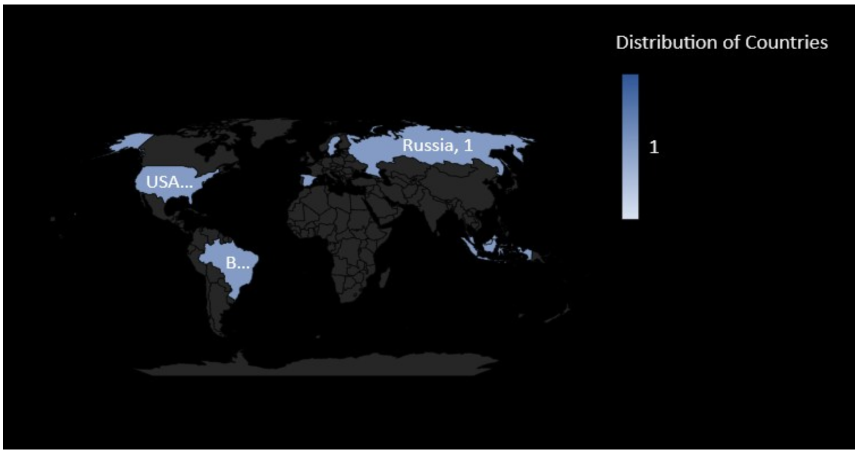

Figure 4: Distribution of Countries by Research Site

Based on the data, it was found that there were 9 studies with 9 different research sites. The 9 countries are Indonesia, Brazil, Russia, Sweden, Malaysia, the United States, Hong Kong, Singapore, and Spain with each having 1 article. These countries illustrate that CT research has developed in these 9 countries.

CT Research Approaches

CT research analyzed in this study has varied research approaches. The differences in research approaches used are due to differences in research objectives carried out by researchers. Figure 5 shows the type of research used.

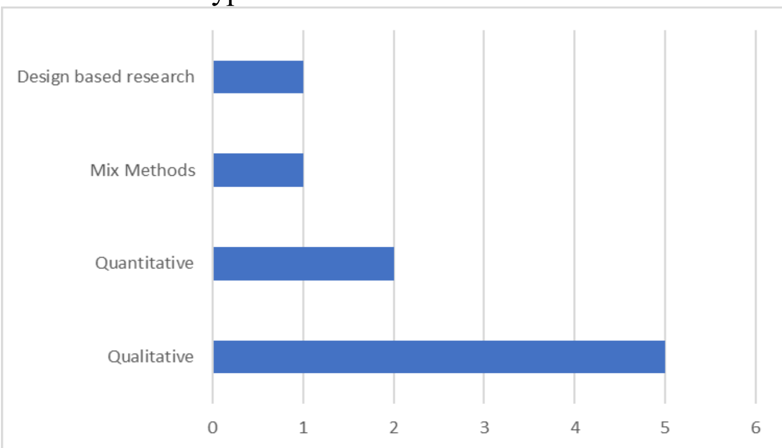

Figure 5: Types of CT Research

Based on Figure 5, qualitative research is the most common type of CT research in mathematics education, with 5 articles. CT research with a qualitative approach is widely carried out because CT research allows researchers to conduct descriptive analysis based on CT indicators (for example: Helsa et al., 2023; Safitri et al., 2023). The research that uses this type of research is research Bråting & Kilhamn, (2021); Maharani et al., (2019); Reichert et al., (2020); Rich et al., (2022); dan Sala-Sebastià et al., (2023).

Then, CT research with a strong quantitative approach, as many as two articles. Researchers may use this research approach to see the implementation of school mathematics programming that currently interacts with thinking and learning algebra (Bråting & Kilhamn, 2021), and look at the exploration of relationships between teachers in schools to integrate computational thinking (CT) practices (Rich et al., 2022). Finally, CT research that uses design-based research and mixed methods approaches has 1 article each. Research that uses design-based research is research by Ng et al., (2023), while mix .methods are research Looi et al., (2023). The variety of research approaches indicates that CT studies are fascinating.

Research Subject

CT investigate the employment of a few distinctive inquiries about subjects custom-made to the targets of each ponder. In this paper, the investigated subjects are understudies, understudies, and K-12 arithmetic instructors. Inquire about employment understudy inquires about the subjects of Maharani et al., (2019), and Soboleva et al., (2021). Not as it were understudies, understudies are utilized to investigate subjects related to CT. Understudies analyzed in CT investigate comprise of understudies from review 1 to review 9. CT must be studied in students since it could be an essential capacity of understudies in instruction related to perusing, composing and checking (Hu, 2011; Zhong et al., 2016). Utilizing CT in learning can assist understudies to memorize to think dynamically, algorithmically, and consistently and be prepared to fathom complex and open-ended problems (Maharani et al., 2019). The procedure that can be utilized is activity-based learning to assist adolescents' cognitive development and offer assistance to their learning viably through genuine control (Cho & Lee, 2017).

Finally, research related to CT used K-12 mathematics teachers as the research subjects. The only research that uses K-12 teachers as research subjects is the study of Reichert et al., (2020). The application of CT ideas and programmatic teaching in K-12 schools can be found in national and international programs and initiatives (Barr & Stephenson, 2011; Guzdial, 2008; Haseski et al., 2018; Kong et al., 2022) thus, the selection of K-12 mathematics teachers as research subjects was feasible. Sanford & Naidu, (2016) revealed that thinking about CT does not come naturally and requires guidance and training, so qualified teachers are needed to build CT in the future. Therefore, future research needs to be conducted to build CT skills in teachers, especially K-12 teachers.

CT Research Focus

In this section, the author reviews the research focus based on the research approach used. Investigate Maharani et al., (2019) utilized a subjective investigative approach by uncovering the relationship between issue tackling and respondents' computational consideration when fathoming issues. His research states a relationship between issue-solving and computational considering. When characterizing issues within the context of issue fathoming, respondents undergo the deterioration and reflection stages within the setting of computational considering. It is imperative to raise this subject since scientific consideration is critical in CT(Gadanidis, 2017; Rambally, 2017; Son & Lee, 2016) numerical issue tackling is basically a development prepare (Benakli et al., 2017; Junsay, 2016; Lockwood et al., 2016).

In spite of the fact that utilizing the same approach as investigate Maharani et al., (2019) investigate Reichert et al., (2020) raised diverse themes, specifically the introductory recognition of computational considering in a gather of K-12 science instructors, assessing the commitment of proceeding instruction courses in science subjects, and examining conceivable changes in educating strategies. CT inquiries in K-12 are significant to consider since the educational programs being created now emphasize CT, as in the case of Brazil. More particularly, at the basic school organize, the term CT is related to the particular competencies and topical unit "Variable based math" in mathematics, which states that learning variable based math, number, geometry, and likelihood and statistics can contribute to the advancement of students' computational considering (BRAZIL, 2018).

Inquire about Bråting & Kilhamn, (2021) moreover employments a qualitative approach by raising the subject of examining how the current usage of school science programming interatomic with logarithmic considering and learning. The examination utilized is based on Duval's semiotic representation hypothesis, which, to be specific, implies that the language structure and semantics of the programming dialect are harmonized by comparing arithmetical imagery. It has been uncovered that even though the semiotic representation of programming dialects is comparative to logarithmic documentation, the meaning of diverse concepts in these two spaces is diverse, so from a learning viewpoint, these contrasts must be considered. It emphasizes that utilizing computers as a apparatus to instruct variable based math is supportive. However, it can lead to errors if programming presents other implications of language structure (Qian & Lehman, 2017), and this could have an effect on learning algebra.

Investigate Rich et al., (2022) utilized a qualitative approach as the investigate approach utilized by raising the subject of investigating the relationship between the endeavors of two basic school instructors to coordinated computational considering (CT) abstraction, debugging, and decomposition into science educating and the advancement of their high-level tasks. It is critical to raise this subject since the integration of computational consideration at the essential school level in mathematics teaching is one of the strategies that can be utilized to present primary school understudies to computer science thoughts (Gadanidis et al., 2017; Israel et al., 2015; Rich & Yadav, 2020). At long last, CT inquire about those employments a subjective approach is that of Sala-Sebastià et al., (2023) with the subject of characterizing the highlights of didactic-mathematical and computational information of imminent kindergarten instructors displayed when fathoming and posturing mechanical autonomy issues. Mechanical technology issues are utilized to familiarize understudies with algorithmic considerations to improve students' CT abilities.

Subjects raised utilizing this sort of quantitative approach are moreover curiously to think about in inquire about related to computational considering, for illustration investigate by Soboleva et (al., 2021) raised a point related to instructive computer recreations as an action in student arithmetic, and this may move forward the quality of arithmetic educating in advanced schools in supporting the improvement of students' computational considering aptitudes. What is curiously about this subject is that instructive amusement spaces ought to be utilized as openings to spur Era Z learning, empower cognitive exercises and create students' systemic and critical considering (Ilomäki & Lakkala, 2018).

Subjects raised by Soboleva et (al., 2021) are distinctive from those raised by Tan et al. (2021) even though both utilize a quantitative approach. Inquire about Tan et al. (2021) centres more on things related to the adequacy of the STEAM (Science, Technology, Engineering, Art, Mathematics) coordinates approach through Stracth on five subconstructs of computational considering (CT), including algorithmic considering, participation, imagination, basic considering, and problem-solving abilities. The integration of CT in STEAM interdisciplinary instruction may be a modern point (Li, 2018; Li et al., 2020). Combining the five disciplines into one subject without compromising the quality and learning targets of the lesson may be a challenge (Conde et al., 2019). In this manner, this investigative topic is exceptionally curious to be considered within the following CT-related investigation.

There are also computational considerations that utilize design-based research as the chosen approach; for illustration, the ponder of Ng et al., (2023) raised the subject of a student's work inspected and, at that point, analyzed. In contrast, it locks in numerical issue understanding in a programming environment, taking CT as a boundary protest implanted in a block-based programming environment stretch. The discoveries in his think about open a unused measurement that explores CT as a boundary question in an coordinates STEM (Science, Technology, Engineering, Mathematics) instructional method. At long last, research Looi et al., (2023) utilized blended methods as the chosen approach. Their investigate raised

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topics related to creating CT-integrated science learning that combines issue fathoming and CT-focused modeling in arithmetic instruction investigate.

Impact Of CT-Integrated Mathematics Learning

Within this investigation audit's past segment, a few subjects that can be raised in CT-themed inquiries were revealed. In this area, we will examine the effect of joining CT in arithmetic learning. The execution of CT-integrated science learning benefits understudies to be commonplace with computer science thoughts (Gadanidis et al., 2017; Israel et al., 2015; Rich & Yadav, 2020) since CT can be presented since elementary school. CT advancement only comes sometimes and ought to be created early.

Joining CT in learning can be through instructive diversions as done by Soboleva et (al., 2021). The benefits that understudies can feel include spurring Era Z learning, empowering cognitive exercises and creating students' systemic and basic thinking (Ilomäki & Lakkala, 2018). In this manner, planning and creating extended instructive diversions is vital since they will learn how to utilize computers to illuminate math issues, connect errands, and make educated choices utilizing computerized assets.

At that point, CT capacity moreover affects issue fathoming capacity, particularly when characterizing issues within the setting of issue fathoming; respondents do the decomposition and deliberation stages within the setting of computational thinking. It happens because a person's CT consideration is related to the student's problem-solving capacity (Maharani et al., 2019). Not as it were, the impact felt by understudies through the STEAM approach through the electrical concept diversion plan moreover includes a noteworthy impact on expanding CT within the five understudies CT subconstructs (Tan et al., 2021) such as algorithmic considering, participation, inventiveness, basic considering, and problem-solving abilities. The effect of CT can be seen from an educational module's point of view, where CT can be utilized as a learning introduction to back instructors in arranging high-quality science instruction (Rich et al., 2022). CT acts as a curriculum-stage methodology (Rich et al., 2022). In this case, CT acts as a curriculum-stage methodology (Taylor, 2016). CT introduction utilized in learning can make learning significant.

Moreover, CT has an impact as a considering apparatus in defining issues so that their arrangements can be spoken to as computational steps and calculations (Sala-Sebastià et al., 2023). Finding the correct computational show is imperative to this preparation (Aho, 2012). At long last, the impact of coordination CT within the mathematics learning preparation is that CT miens can increase students' engagement in a roundabout way, such as expanding self-confidence to an exceptional level by making them more able to work difficult and pay more consideration so that their engagement in expanding will to increment (Looi et al., 2023).

Conclusion

The systematic literature review results show a relationship between CT and several students' mathematical abilities, such as problem-solving ability and improvement of problem-solving skills. Not only can it improve the cognitive side of students, but CT can also improve their affective side by increasing creativity, confidence, and student involvement in the learning process. The impact felt is not only in the micro scope (in the classroom), but can also be macro. CT can improve the quality of higher learning, so CT research can be used to determine a country's curriculum.

Recommendation

Recommendations for further research to examine other abilities, further research is expected to make a study that focuses more on CT on modules or teaching materials in learning mathematics. Furthermore, research is recommended to focus on CT at the elementary to secondary school level.

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