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A systematic literature review of computational thinking study in physics learning

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ABSTRACT

This systematic review aims to summarize the technological resources for teaching and learning about computational thinking (CT) in physics and provide suggestions to conduct new studies in future research. A total of 22 academic articles on CT in physical learning were reviewed from 2012 to 2022. The number of research participants was 3,269, with details of 2,752 college students, 439 high school students, 32 junior high school students, 20 elementary students, 21 teachers, and five librarians. This study confirmed that research on CT in physical learning has been dominated by two countries, the United States and Indonesia. Over the past 10 years, there has been an increase in physics courses focusing on topics in kinematics, force and motion, and electricity. The common method practices are quantitative and qualitative, with some developing learning. The implications of this research can inform education experts, educators, and technologists interested in the CT environment and technological development in physics learning. Computational skills in physics have the potential to improve cognitive, affective, and psychomotor outcomes, including students' thinking abilities. Students can benefit from their experience learning physics using the concept of CT because they can solve technology-based problems and develop various competencies needed in learning physics.

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1. INTRODUCTION

Computational thinking (CT) is now essential for students in the 21st century and the digital age. High school and college educators promote CT to all students through curriculum integration [1]. CT becomes a thinking model for students interested in computer science, mathematics, and other disciplines [2]. There are essential principles in CT, namely solving problems, understanding complex systems, human behavior [3], and information management [4]. In addition, implementing CT can build essential literacy skills and encourage engineering design principles and early exploration of sequencing and causality [5].

CT is a skill or thought process needed in computer science, but this skill can also be integrated into education in any field [6]. CT is also seen as an activity that promotes the development of CT [7]. According to Wing [1], CT is a thought process involved in formulating a problem and expressing the solution so that a computer, human, or machine can do it effectively. CT describes students' knowledge to design computational solutions to a problem, coding, and algorithmic thinking to develop student qualities such as abstract thinking, pattern recognition, problem-solving and logical reasoning [8]. CT is the primary way someone understands problems and designs problem solutions [9]. CT affects everyone along with the development of science, technology, and society and becomes a challenge in education.

CT is a problem-solving strategy, but it is not required to use of a computer [10]. CT includes logical thinking, algorithmic thinking, problem-solving, decomposition, abstraction, modeling, and evaluation [11]. CT builds the structural thinking, creativity, and critical power needed by society to increase digital literacy and many strategies for learning it [12]. Activities based on CT are the primary goals for improving cognitive skills and supporting teaching and learning processes [13]. On the other hand, there are advantages to implementing CT, and some challenges are faced by educators, such as the low level of teacher knowledge and CT skills of teachers and students' acceptance of CT [6].

CT is being recognized as a critical component of student success today. Many opinions and research integrate CT into the core curriculum as an appropriate method for developing students' CT. Sung and Black [14] conducted learning mathematics by embedding CT to support thinking-doing. Furthermore, Peel *et al.* [15] studied biology on the topic of natural selection through CT with an emphasis on algorithmic explanations. Chongo *et al.* [16] applied a CT module to see its effectiveness on students' chemistry achievement. Furthermore, Fayanto *et al.* [17] analyzed comparative of physics CT skill in experiment laboratory. The application of CT has been made in the field of science. The application of CT has been made in the field of science. However, there is yet to be a consensus on the conceptualization of CT to facilitate this integration. There are still few attempts to critically analyze and synthesize research on CT integration [18].

One effort can be made to conduct a literature review on CT. Currently, several researchers have conducted literature studies on CT, such as in the field of mathematics [19], in the field of science and STEM education [20]. However, no CT literature review has focused on the field of physics. This study needs to be carried out to facilitate CT in physics. Even, computation has shifted from being merely a helpful aid in scientific research to becoming absolutely essential to what it means to conduct science [21]. The novelty of this analysis allows the finding that applying a CT environment can be the primary choice in learning physics, which influences various skills and student learning outcomes. Teachers and students familiar with coding activities in physics learning will develop other increasingly convincing activities in this technological era.

Currently, CT has been widely adopted by several disciplines. CT comes from the thinking of computer scientists. CT is one of the skills needed in computer science [6]. Although there has been much debate about integrating CT in disciplines other than computer science, CT has benefits in other disciplines. In addition, this type of thinking is still recognized as a form of thinking to solve problems for anyone and helps deal with life's problems. Thus, the integration of CT is mainly carried out in disciplines other than computer science, one of which is education. CT is part of updating the integration of the educational curriculum for 21st-century skills, especially in empowering digital literacy [22].

CT has been recognized as essential for student success in the digital age [18]. The essence of CT involves breaking a complex problem into manageable and more familiar subproblems (problem decomposition), using a sequence of steps to solve a problem (algorithmic thinking), examining how the solution can be transferred to similar problems (abstract) and specifying a computer can help solve these problems more efficiently (automation) [23]. The most substantial reason for integrating CT in the education system is to depart from the problem. One of the learning processes is that students can solve problems about learning, science, and problems faced in their lives.

Some researchers are beginning to integrate CT into education because it has benefits in enhancing other skills. According to Saidin *et al.* [6], CT can improve critical and analytical thinking skills, pedagogy, and curriculum. Furthermore, the activities of CT usually require students to practice their skills in problem decomposition, abstraction, algorithm design, debugging, iteration, and generalization [24]. In addition, applying CT helps develop individual thinking skills, such as being more creative and thinking critically in problem-solving [25].

According to Beecher [11], the concept of CT is as: i) Logical thinking is being able to distinguish between right and wrong arguments; ii) Algorithmic thinking can sequence clear steps start-end point correctly; iii) Problem-solving can define the characteristics of the problem and the goals to be achieved; iv) Decomposition, namely being able to break down large and complex problems into small and simple problems; v) Abstraction is a way of expressing ideas in a particular context while at the same time suppressing details that are irrelevant in that context; (modeling is a type of abstraction that represents ideas or solutions; and iv) Evaluation (evaluation) is to re-analyze whether the solution provided is exemplary. According to the various demands of 21st-century skills and the benefits of integrating CT in learning, this is a new concept in the education system. In addition to skills and experience in integrating CT, enlightenment of ideas and ideas is also needed to optimize curriculum integration. This literature review can provide insight into the integration of CT in the learning process, especially in the review of physics learning.

This research aims to synthesize the best available evidence on the application of CT. Three potential research problems are formulated as: i) analyzing the impact of a CT environment in learning; ii) examining the technology used in implementing a CT environment; and iii) investigating what variables influence the application of CT in physics learning. The main contribution of this research is to provide ideas that show the level of effectiveness, factors, and challenges faced in learning CT during physics learning. It will enable proper and efficient monitoring and development of learning strategies and future research.

2. METHOD

In this study, the method used is qualitative research with a systematic literature review (SLR) design. A systematic review is a research synthesis to systematically seeks, assesses, and synthesizes research evidence, following guidelines in studies and using strategies to limit bias [26]. Systematic reviews can present findings to policies and policymakers, such as illuminating policy issues, challenging, or developing policy assumptions, offering impacts, or implementing policy options and considering the diversity of contexts [27]. The literature review aims to find textual information, take its collective strengths and weaknesses, find patterns of relating different items together, and summarize what was done or not said and what it means for our research readers [26]. The purpose of this systematic review of research is to provide a reputation for the modern literature on CT in physics learning. The systematic review of this study follows the steps of Haseski *et al.* [28], which consists of a search strategy, setting inclusion-exclusion criteria, and analytical procedures. The systematic review procedure of this study follows that of Erten and Köseoğlu [29], which can be seen in Figure 1.

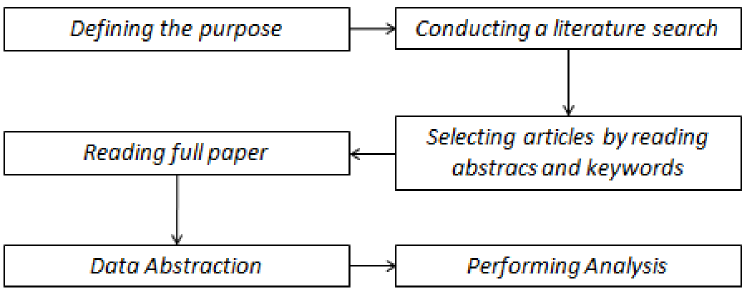

Figure 1. Resource procedure

A comprehensive search was performed on an electronic database with keywords defined based on study objectives and accessing publications about CT. The keywords used were "computational thinking in physics learning". The search process is carried out in two stages. First, the search process as the primary source is carried out in electronic databases, such as ScienceDirect, Scopus, Clarivate analytics Web of Science (WoS), and Sage Publications. Furthermore, the search process is carried out on electronic databases such as Google Scholar and Mendeley Search. These two stages aim to obtain a broader target article about CT in physics learning. The target articles accessed were published for the last ten years, from 2012 to 2022. The article search was carried out by alternating the year of publication and starting in 2022. For each article that examines CT during the last ten years, it is collected in a database: name of article and author, journal name, year of publication, research question, research method (data collection method, type of data, and sample), a technology used, physics topic and research results. Finally, the overall results are categorized based on the synthesis of the articles presented to understand how CT is in learning physics.

The purpose of the first criterion is for evidence-based synthesis and primary research sources [30] and the target of higher quality and relevant articles [31]. The purpose of the second criterion is to limit CT to physics only, and CT in other subject areas is excluded from the analysis. Another purpose of this criterion is also to analyze related physics topics applied. The third criterion aims to access quality and internationally indexed publications. The purpose of the fourth criterion is to include studies that have been undertaken in a broader time frame and are recent. The fifth criterion's purpose is to ease access and understanding of the target article. In this study, the inclusion-exclusion criteria were determined as: i) the article is primary research, not a literature review; ii) the article is about CT in physics learning; iii) published by Scopus or WoS; iv) the article was a publication in 2012-2022; and v) articles in English.

Manual content analysis was carried out on several aspects, such as the type and author of the study (location, year of publication, and name of the journal), the method used, the topic of physics and technology applied, and the research results. The results of the article synthesis are categorized based on the research questions. Finally, we explain the importance of this systematic review for further research, the limitations of the research, and offer options for policymakers. The authors report that there is no conflict of interest in the reporting of this research and that no human participants were used in this study. Data will be made available by submitting an individual request to the first author.

3. RESULTS AND DISCUSSION

There were 22 scientific papers on CT in physics learning from 2012 to 2022, as shown in Table 1. Each study identifies more specific knowledge about CT in physics learning to answer the stated SLR objectives. A total of 3,269 participants on that paper consisted of 2,752 college students, 439 high school students, 32 junior high school students, 20 elementary students, 21 teachers, and five library staff.

This systematic review aims to determine what, where, by whom, how, when, and what is found regarding applying CT in physics learning. Through this technique, the authors can analyze research results from various studies, such as how and what are the challenges of implementing CT in physics learning. The results of this analysis can help to plan future research. This systematic review focuses on several research questions which include: i) the research focused on the country; ii) the interest of researchers who investigate CT in physics learning; iii) the most systematic and practical methods used; and iv) objective studies focus on the impact of applying CT in learning physics.

3.1. Geographic scope

There are four countries that dominate research on CT skills in physics. Most of the research papers that examine CT skills in physics learning come from the United States (68%) and Indonesia (23%), as seen in Table 1. A small number of countries are studying CT in physics learning such as Albania (5%) and the Netherlands (5%). Of the 63% of authors studying CT in physics at the time of publication, these authors were affiliated with universities located in the United States. Other author affiliations at the time of publication are Indonesia (25%), Albania (1%), Netherlands (5%), Kuwait (2%), Finland (1%), Egypt (1%), and Latvia (1%). There are 54 different authors affiliated with institutions or colleges in the United States, with five authors conducting three studies and four authors conducting two studies. Regarding Indonesia, there is one author who conducted two different studies. Five writers are affiliated with the Netherlands, one from Albania, Finland, Egypt, Latvia, and Norway, and two from Kuwait.

In the United States region, a survey with an international scope has been conducted to investigate the introduction of disciplines that focus on teaching how computing systems work. However, the results of this survey are impossible due to the homogeneous comparison between countries because the education system is very different. Other aspects of digital technology that are important in education include basic digital literacy, the ability to use computers and the internet (professionally), and the ability to apply technology to support scientific disciplines or other fields [32].

CT has been adopted into the curriculum of many states in the United States. Several attempts have been made to overcome the weaknesses of CT. Future efforts are planned to focus on the dispositions and attitudes of CT. It can help learn CT skills and reveal potential misconceptions in acquiring CT competencies [33]. Finally, more assessments need to address the perspective of CT and examine its relationship to learning outcomes and potential gender differences within the United States.

In Indonesia, studies on CT refer to future research plans looking at CT in several subjects. It is necessary to review whether the concept of CT will be included in the school curriculum in Indonesia [34]. Indonesian students' CT skills need to be improved. Where aspects that Indonesian students must improve are not only cognitive aspects but also affective aspects because these two aspects influence each other to achieve success in CT [35]. Education in CT has yet to be widely implemented in Indonesia. The national curriculum issued by the Ministry currently does not contain computer education courses. However, schools can conduct their computer-related education as part of the curriculum or as an additional activity. Recognizing this condition as a problem for computer education, several computer practitioners at universities in Indonesia decided to hold a CT program. This project aims to measure students' CT skills and promote the concept of CT in Indonesia. This project has been running since 2016 and has been designated an annual event [36]. CT is related to taxonomic bloom, where the learning base in Indonesia also applies taxonomic bloom. It shows that the development of CT in Indonesia does follow the applicable curriculum. CT can be facilitated by using robotics. So that in Indonesia, future research will focus more on testing robotics to support CT skills [36]. Table 1 shows the number of countries and researchers by affiliation.

Table 1. The number of countries and researchers

Country	Study location		Author's affiliation	
	N	%	N	%
United States	15	0.68	54	66
Indonesia	5	0.23	22	22
Albania	1	0.05	1	1
Dutch	1	0.05	5	5
Kuwait	-	-	2	2
Finland	-	-	1	1
Egypt	-	-	1	1
Latvia	-	-	1	1
Norway	-	-	1	2
	22		89	

3.2. Scope by year

There are 22 research articles reviewed using the SLR method, as presented commutatively in Figure 1. Overall, the average number of research articles published every year for the last 10 years is two (2) articles. This review of articles from 2012 to 2022 is divided into two equal periods of 5 years each to classify trends in the number of publications that have been published. From 2012 to 2016, papers were published only partially absent, or the average number of publications was 0.6 per year. However, there has been a significant increase in the publication of CT in physics classes from the first period (2012 to 2016) of three publications to the second period (2017 to 2022) of 19 publications or an average number of publications of 3.8 per year. That is the equivalent of six times the number of research papers published five years ago. Overall, of the total research articles reviewed, 13.6% of the research was published in the first period (2012-2016). Then there was a very large increase in the second period, where 86.4% were published in the second period (2017-2022). Figure 2 shows the frequency of research paper examining CT in physics.

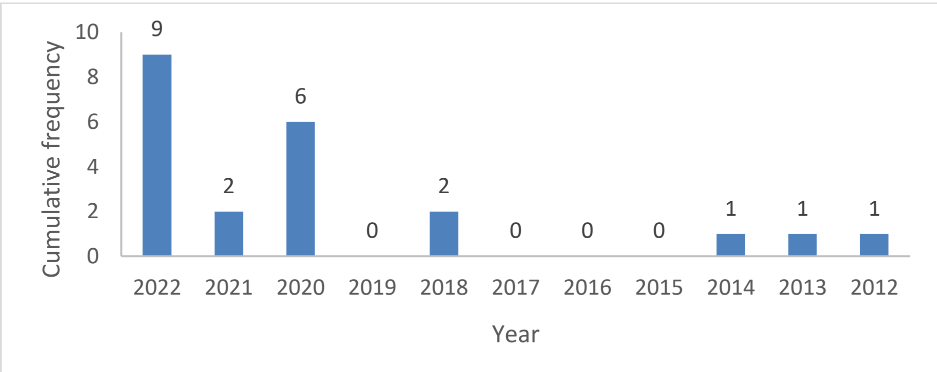

Figure 2. Cumulative frequency of research paper examining by year

3.3. Scope by field

Increasing the attention to CT in physics learning has been studied in 14 different journals and conference series with various fields, as seen in Table 2. It involves academic journals on the topics of kinematics (36%), force and motion (23%), electricity and magnetism (18%), and 4.5% each on the topics of computational physics, material physics, Kepler's law, wave motion and not mentioned. The Journal of Science Education and Technology, with five research papers, is dominated by journals assessing CT in physics learning.

Kinematics studies the motion of objects without regard to what causes these objects to move appropriately. Regarding CT for the three kinematics units (velocity, graph, and distance), the time spent on resource domains decreases. Kinematics questions test students' understanding of the relationship between distance, speed, and acceleration associated with indicators of critical thinking ability. In each unit, new concepts are included that build on the concepts presented in the previous unit. Therefore, the read time is reduced, but not significantly [37]. Studies that can be connected between CT and kinematics are: i) 1D ground transportation involving constant acceleration and deceleration; ii) 2D constant velocity motion for transportation across rivers; and iii) 2D accelerated motion (with a factor of gravity) for shipping objects, in remote areas using flying drones [17].

For the concepts of force and motion, the questions given still have to use indicators of CT and their previous experience and questions about content such as calculating force and acceleration [37]. There are several examples of how the researchers have presented integrating the concept of CT with the topic of force and motion. For example, to formulate an algorithm such as positioning a falling object, students conceptually need to understand the definition of acceleration. Next, they describe how to represent the concept as a conceptual (diagram); algorithmic (mathematical); code (encoded); and virtual simulation (visualization) that can help them understand physics concepts, especially force and motion [38]. Table 2 shows the field of CT in physics.

Table 2. The field of CT in physics

Field	Journal/conference series	No. of paper
Kinematics	Journal of Science Education and Technology	2
	Physical Review Physics Education Research	1
	Communications in Computer and Information Science	1
	Proceedings of International Conference of the Learning Sciences, ICLS	1
	ACM International Conference Proceeding Series	1
	Computer-Supported Collaborative Learning Conference	1
	International Conference on Computers in Education, Main Conference Proceedings	1
Force and motion	Journal of Science Education and Technology	1
	International Journal of Emerging Technologies in Learning	1
	Proceedings of International Conference of the Learning Sciences, ICLS	1
	AIP Conference Proceedings	2
Electricity and magnetism	Journal of Science Education and Technology	2
	Educational Technology Research and Development	1
	Annual Conference and Exposition, Conference Proceedings	1
Computational physics	Education and Information Technologies	1
Material physics	Journal of Physics: Conference Series	1
Kepler's law	Journal of Physics: Conference Series	1
Wave motion	ACM International Conference Proceeding Series	1
No mention	Jurnal Pendidikan IPA Indonesia	1

3.4. Investigation research method and sample size

Various methods have examined CT in physics learning, as shown in Table 3. Most of the researchers conducted quantitative and qualitative research (32%) rather than R&D (23%) and mixed method (14%) research. The most used method is the test (45%) in the form of essay and multiple-choice tests. Other methods are interviews (14%), documentation (32%), and surveys (9%). Six types of samples were selected in 22 peer-reviewed research papers with a total of 3269 samples. The most chosen sample is college students (84%). Other samples chosen were senior high school (13%), library staff (0.2%), and 1%, respectively, from junior high school, junior high school, and elementary school. Table 3 shows the research method and sample used.

In particular, the advantages of the quantitative method allow structured, large-scale, and rapid administration of tests to be applied directly to students. Quantitative research has the advantages of higher accuracy and integrity, greater attention, and credibility. With the development and use of data analysis technology, complete and large-scale sample data can further increase the credibility of research conclusions, which are more widely accepted and recognized by experts [39], including in CT studies.

Table 3. Research method and sample

Type	Category	N	%
Detail of the methods	Test	10	45
	Documentation	7	32
	Interview	3	14
	Survey/questionnaire	2	9
Data	Quantitative	7	32
	Qualitative	7	32
	R&D	5	23
	Mix method	3	14
Sample	College students	2752	84
	Senior high school	439	13
	Junior high school	32	1
	Elementary school	20	1
	Teacher	21	1
	Library staff	5	0.2

Not only quantitative methods have advantages. The advantage of the qualitative method is that it uses open questions, allowing participants to answer freely and not forcing them to choose from multiple choices, as in the quantitative method. Open-ended questions can elicit explanations in a rich natural context with the researcher's meaningful, influential, and unexpected answers [40]. To benefit from qualitative methods can be done by using the required code tracking questions, reducing selection bias, and focusing on measuring how well students learn the material, univalent (having one correct answer), and providing construct-responses [41].

3.5. Technological practices

Some technologies have been used to examine CT in physics. Most researchers used visual technology, such as Python (22%) and Arduino (9%). One of the 22 papers chose to use two technologies: Makey Makeys (4%) and Arduino. Other technologies (4%) used NetsBlox, Electronic textile circuits (e-textiles), Cubic spline interpolation, Unity3D visual studio, Pyret interface, STEPP, Scratch, MATLAB, CODAP, Snap, Camtasia™ screen-capture software, and ViMAP. Three research papers do not mention the technology used. Table 4 shows the technology used in the 22 research papers.

Table 4. The technology used

Technology	Website	N	%
Visual Phyton	https://vpython.org/	5	22
Arduino	https://www.arduino.cc/	2	9
NetsBlox	https://physics.c2stem.org/	1	4
Electronic textile circuits (e-textiles)	https://learn.sparkfun.com/tutorials/e-textile-basics	1	4
Cubic spline interpolation	https://www.geeksforgeeks.org/cubic-spline-interpolation/	1	4
Unity3D visual studio	https://docs.unity3d.com/Manual/VisualStudioIntegration.html	1	4
Pyret interface	https://www.pyret.org/docs/latest/runtime.html	1	4
Makey Makeys	https://makeymakey.com/	1	4
STEPP	https://stepp.utdallas.edu/	1	4
Scracth	https://scratch.mit.edu/	1	4
MATLAB	https://www.mathworks.com/products/matlab.html	1	4
CODAP	https://codap.concord.org/	1	4
Snap	https://www.snaplearning.net/	1	4
Camtasia™ screen-capture software	https://www.techsmith.com/video-editor.html	1	4
ViMAP	https://play.google.com/store/apps/details?id=vn.vimap.map&hl=id&gl=US	1	4
No mention	-	3	13

There are some benefits to using technology in CT during physics learning. Python is an efficient and flexible high-level programming language with many applications in artificial intelligence and data mining. This application's advantages are that programming is simple, easy to understand, open source and valuable, and can be combined with other programs [42]. Other advantages of using Python language are: i) Python is available to enhance noncomputer major programming applications and ii) Python training can effectively train and develop CT in daily life [43]. Python can be used for several tasks: i) as a calculator; ii) calculate variables automatically; iii) evaluate data, read data from text files, and write data to text files; iv) visualize results with graphs and plots; v) save graphics as high-quality images in formats, such as png, pdf, and jpeg; vi) analyze data and perform linear regression; and vii) display the results of data analysis as well-formatted tables in Markdown or HTML [44]. Communication classes for sending and receiving messages are also provided by the Python interface [45]. Python is therefore a great choice for learning through CT. Figure 3 shows the Python application interface.

Another application used in testing CT in physics is Arduino. The advantage of Arduino lies in its flexibility, unlimited possibilities for its use, and allowing students to use it according to their needs [46]. Many benefits of Arduino family boards such as: i) there are many options available with out-of-the-box, most suitable controllers having a wide range of variable parameters; ii) there are expansion boards to increase functionality and perform specific technical tasks without the need to design additional peripherals yourself; iii) completely user-adapted programming environment suitable for all Arduino kits and clones, including software for programming controllers; iv) free license for device and software; and v) there is an Arduino language translation designed to overcome the language barrier [47]. Students' response to using Arduino to create a circuit was also overwhelmingly favorable [48]. Therefore, Arduino is very suitable for learning physics based on CT. Figure 4 shows the Arduino application interface.

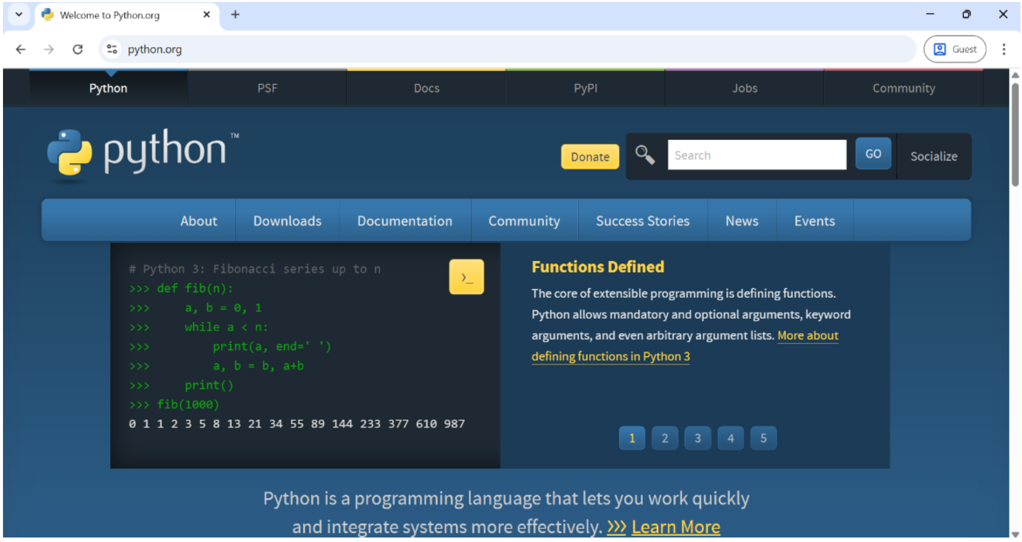

Figure 3. Python

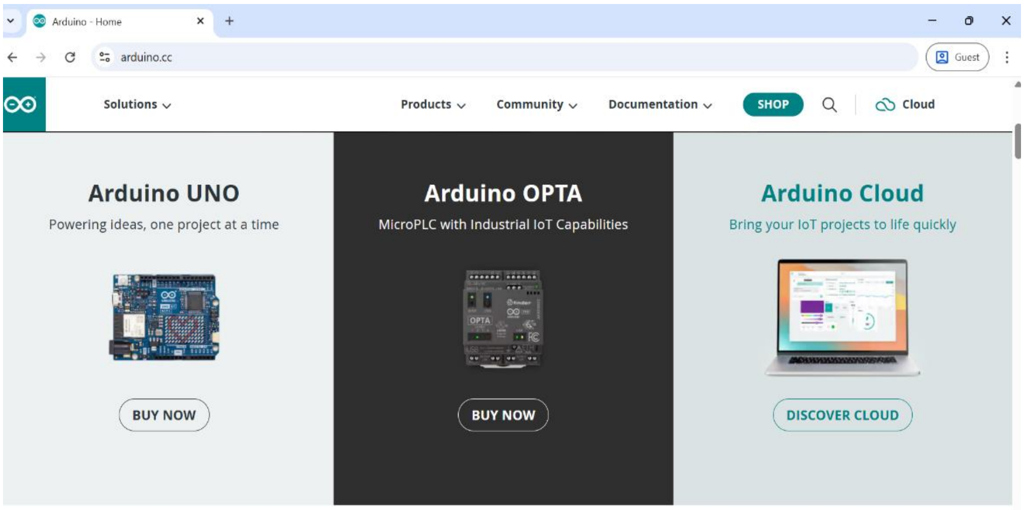

Figure 4. Arduino

3.6. The overall result of the research question

From 22 papers reviewed in this study, 32 research questions were identified. A total of 7 research questions examines the development of CT activities, including Collaborative Computational STEM (C2STEM), computational modeling activities, STEPP learning, student worksheets with project-based learning models to improve CT, and CT-based student worksheets. A total of 11 research questions examines the cause and effect between independent and dependent variables in terms of CT activities on problem-solving abilities, knowledge of physics, and motivation to learn physics. Furthermore, thinking of computing as the dependent variable, research questions examine the influence of self-confidence, Arduino activities, maker activities, problem-based learning, research-based-learning, and computational modeling on CT. A total of two research questions examined teachers' and students' perceptions of CT. A total of four research questions examined assessment to measure CT skills in terms of formative assessment, psychometric assessment characteristics, and synergistic assessment. A total of eight research questions examined classroom applications such as teacher pedagogical content knowledge (PCK) in CT integration, how CT improves physics learning, CT practice, and CT design exploration in class. Table 5 shows the relation of CR with other variables.

Many researchers develop CT learning in physics learning. The results of this development show a positive impact on students. One of them is Hutchins *et al.* [49], who developed the C2STEM learning environment in physics. Students who study with C2STEM can develop a better understanding of concepts, physics practices, and CT skills than students who study through the traditional curriculum. Students also demonstrate the ability to transfer concepts and expand and enhance problem-solving skills in new problem-solving situations. Students seemed more motivated and worked harder on their physics assignments, even when they had difficulties. In addition, the development of learning based on CT in physics can improve the ability of this skill, especially in aspects of abstraction from complex problems, algorithm automation, data collection, representation, and analysis [50]. In addition, this systematic review has found that several variables can be improved through CT, including problem-solving skills, motivation, teacher perceptions, self-confidence, computational modeling, and physics concepts. Thus, CT-based learning in physics learning positively impacts learning.

Table 5. Relation of CR with other variables

Category of research question	N	%
Development of CT activities	7	0.22
Cause effect		
CT-problem solving and motivation	1	0.03
CT-physics knowledge	1	0.03
Self-confidence-CT	3	0.09
Arduino activities -CT	1	0.03
Maker activities-CT	1	0.03
Problem based learning-CT	1	0.03
Research based learning-CT	1	0.03
Computational modelling-CT	2	0.06
Perception	2	0.06
Assessment to measure CT	4	0.13
Application of CT in the classroom	8	0.25

4. CONCLUSION

A systematic review has presented research results on applying or integrating CT in physics. This study found that research on this topic has been dominated by two countries with large territories, namely the United States and Indonesia. Over the past ten years, there has been an increase in physics courses focusing on topics in kinematics, force and motion, and electricity. Python (22%) is the most popular platform to use in applications to engage CT in the visualization of physics learning. The common method used in the reviewed studies is dominated by quantitative and qualitative research methods, with some developing learning. The development of CT in physics significantly contributed significantly to learning.

There are several important aspects of CT in physics in practice for learning applications. These aspects cover extracting computational insights, building computational models, and data practice starting from data collection, analysis, and inference. Additionally, there are aspects of debugging, demonstrating changes to computation, and working in groups on computational models, as well as self-practice. Many contextual factors, including activity format, computing platform, and group composition, affect CT abilities. The application of CT, which is different for each implementation, is influenced by the role and perceptions of the teacher. The more teachers are involved, the easier it will be to identify examples of CT to produce optimal learning quality. Different pedagogical choices also influence the frequency and occurrence of practice. Therefore, developing a CT environment in physics learning must be continued in the future.

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Supahar	✓			✓	✓		✓			✓		✓	✓	
Riki Perdana		✓	✓	✓	✓	✓		✓	✓		✓			✓
Jumadi	✓				✓		✓			✓		✓		
Soeharto		✓	✓			✓		✓	✓		✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author [R], upon reasonable request.

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