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The role of information technology in STEM education

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Abstract

The ubiquity of IT (Information technology) for teaching at large is a reality that can be observed, including STEM education, which is the field of study of this research. In view of this situation, this work is intended to determine the role of IT in STEM (Science, Technology, Engineering, Mathematics) education. It was decided to conduct a systematic review based on PRISMA model and adding information obtained from the analysis of fugitive literature. The literature review was carried out on a total of 16 articles. The main inclusion criteria were a temporal selection from 2015 to March 2023, the inclusion of the terms IT and STEM in the title, abstract or keywords of the articles. The main results show an increasing tendency of this topic, especially in English research. Most relevant conclusions of the systematic review evidence a positive relationship between IT and STEM education, although some negative aspects are also highlighted as there is still a lack of resources and teacher training, leading to ineffective application of IT in STEM classes. The research results have important practical implications, it motivates teachers to research, propose and implement measures to enhance the role of IT in STEM education, while minimizing the limitations that have been identified.

Keywords: Digital devices, Information technology, Key competencies, Negative, Positive, STEM education, STEM.

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Contents

Contribution of this paper to the literature
The research systematically shows the roles of IT in STEM education, directions for applying IT in STEM education, positive and negative aspects when applying IT in STEM education.

1. Introduction

STEM education focuses on teaching STEM subjects (science, technology, engineering, and mathematics) in an interdisciplinary approach, integrated with practice to form and develop students' qualities and competencies. On the other hand, information technology (IT) has an important position in the field of education, including STEM education. Therefore, it is necessary to clarify the role of IT in STEM education to promote faster and more effective implementation of STEM education. This issue leads to the following research questions: How does IT support teaching and learning in STEM education? To what extent do teachers use IT in STEM education? What type of digital technology is used by teachers in STEM education? What is the impact of using IT in STEM education? Are they useful to apply? If helpful, what is an empirical demonstration of using IT in STEM education? To answer these questions, the research method of this paper is to conduct a systematic review of the literature to determine the role of IT in STEM education, this systematic review is consistent with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses approach (PRISMA (Moher, Liberati, Tetzlaff, Altman, & Group*, 2009)). STEM education is a new trend that has rapidly developed and been widely applied in recent years both globally and in Vietnam. Similarly, IT has become an indispensable element in all fields, including education. Researching and determining the role of IT in STEM education is a meaningful task.

1.1. STEM Education

STEM education is an interdisciplinary teaching approach where lesson content is contextualized in the real world, encouraging students to apply knowledge and skills in science, technology, engineering, and mathematics to solve specific problems in their communities (Hoang, 2023). The main purpose of STEM education is not solely to train scientists, mathematicians, and engineers, but to inspire learning, help students recognize the interconnectedness of knowledge, understand the impact of STEM on the world and society's future, and apply knowledge to address real-world challenges and create innovative products. Additionally, STEM education emphasizes nurturing soft skills which are essential for future career success, such as collaboration, teamwork, problem-solving, creative thinking, and critical thinking (Kelley & Knowles, 2016; Sanders, Kwon, Park, & Lee, 2011). The levels of application of STEM education in high schools are as follows (Ministry of Education and Training, 2020):

1.1.1. Teaching Subjects According to the STEM Educational Method

This is the main form of STEM education organization in high schools. Teachers design STEM lessons to deploy in the process of teaching subjects in the general education program according to an integrated intra-subject or interdisciplinary approach.

1.1.2. Organizing Experiential Activities in the STEM Education Program

STEM experience activities are organized through clubs or practical experience activities; They are organized and implemented according to the interests, talents and choices of students voluntarily. Schools can organize STEM experience spaces in schools; Introducing a library of digital learning materials, virtual experiments, simulations, and learning software for students to learn, explore experiments, and apply science and technology in real life.

1.1.3. Organizing Scientific and Technical Research Activities

STEM education can be implemented through scientific research activities and science and technology innovation competitions. This activity is not for the masses, but for students who have abilities, and are interested in scientific and technical research and discovery activities to solve practical problems. Joining the STEM club and doing scientific and technical research is an opportunity for students to see the fit of their abilities, interests, and values with careers in the STEM field.

1.2. IT in STEM Education

In the current trend, IT is constantly developing, increasingly widely used in all areas of social life. When it comes to its integration in education, IT has expanded the possibilities of education as they have created the possibility of distance learning, e-learning and blended learning. It also provides personalized learning platforms and a variety of online activities to reinforce and expand students' knowledge, which can contribute to autonomy, self-directed learning, and creativity. Furthermore, IT can serve as a tool to promote a student-centered approach as it leads to engagement and promotes active learning in which students feel themselves as protagonists in the learning process (Gámiz-Sánchez, 2017). Thus, IT enhances students' interaction and collaborative work.

Various digital tools coexist in most schools today. For example, learning management system (LMS), a digital platform for incorporating other digital elements for educational institutions (Yazid, 2021). Similarly, several studies have looked at the use of mobile technology, virtual reality in the classroom, which has also led to other emerging approaches (Boonbrahm, Kaewrat, & Boonbrahm, 2015; Martin, 2021). However, in terms of popularity, software elements are increasingly becoming an important aid in classrooms. The next part of the article will analyze the role of IT for other subjects in STEM education.

For Science: In STEM classrooms, it's easy to see the integration of IT in the science classroom. For example, robotics is a prime example of applying technology to science. With advancements in 3D, 4D or virtual reality (VR) imaging technology, students can easily visualize a finished product. From there, it is possible to design products with high applicability.

For Technology: Instead of letting students access to technology through playing video games or spending too much time on social networks (TikTok, Facebook, YouTube...) students can be exposed to research activities and apply technology to life. Students can experience and create products in the field of technology, which not only trains

their thinking but is also an important factor in promoting students' interest in learning. On the other hand, when applying IT, it is possible to create computer software that can be assigned to computers to help solve part or even all the problems that the technology field poses.

For Engineering: Engineering not only helps students familiarize themselves with devices such as electrical circuit structure, model assembly, etc. In the STEM model, students can apply IT in engineering such as: developing software that can control the operation of devices such as automatically turning lights on and off when detecting people passing by, setting up automatic modes for electrical circuits, etc.

For Mathematics: Mathematics is a basic academic subject with many abstract concepts. In fact, more and more classrooms are equipped with touch screens and educational software for more effective learning. For example, learning spatial geometry is easy, intuitive, and dynamic with touch screens and math software like GeoGebra.

Thus, IT is widely applied in the field of education. In the field of STEM education, IT helps students access to technology in many fields, develop creative thinking and apply technology to life. Moreover, as a foundational technology, IT plays a central role in connecting other subjects, promoting STEM education, and fostering students' creativity to create high-quality digital products.

1.3. IT and STEM Education in High Schools

The implementation and application of IT in high schools has seen many changes. Teachers have actively applied IT in teaching, regularly exploited the effective uses of electronic learning materials, and actively applied IT in professional activities and self-study and self-improvement to meet the 2018 general education program (Trinh & Vo, 2023). Most teachers are proficient in using PowerPoint software in teaching presentations; using iSpring, and Adobe Presenter to compose e-learning lectures. Skills in using simulation software, virtual experiments, and teaching software to innovate content and teaching methods in the classroom are always concerned and implemented regularly. Using Smart TV (Television) is well exploited by teachers. Although both course content and skills in using digital devices and software have improved, a few errors are being noted including connection problems, software incompatibilities, and teacher supervision is necessary (Kumar, 2004).

The implementation of STEM education in high schools still faces many difficulties (Lâm & Nam, 2022). STEM education for high school students today is mainly in the form of participating in clubs led by high school teachers and university lecturers to guide students in implementing learning projects such as sensors and data, smart agriculture, nanotechnology, self-operated robots, etc. These learning projects often involve topics that are new, interesting, and challenging but not too difficult, thereby helping students understand the applied meaning of knowledge.

Integrating IT in STEM education can be beneficial in reducing anxiety, promoting motivation, and engagement. This is because IT can provide deeper explanations through visual means (Fontecha, 2012). In addition, many high schools organize STEM festivals to encourage students to be creative and develop their own abilities in researching, discovering, and creating many applied products.

1.4. IT and STEM Education from a Teacher's Perspective

Teachers almost all agree that IT has an important role in education, and STEM education is no exception. IT provides the tools, and brings a wave of favorable learning material design (Ta, 2023). However, teachers have acknowledged that it is a time-consuming task, it requires teachers to invest a lot of effort to learn and practice creating teaching products, if teachers do not manage the classroom well, it can distract students' attention (Mouaziz, El Byad, El Biadi, & Moumni, 2021).

Teachers who are knowledgeable about STEM education consider that the most basic core point of STEM education is to learn by doing, and practice making specific products, thereby enhancing the passion and love for the subject. Informatics is a highly practical subject with tight scientific integration, suitable to promote and enhance STEM education. For example, the Scratch programming language is intuitive, it is easy to create products, programs, software, or simply a game (Tuấn, Lê Diễm, Huy, & Tuấn, 2019). Therefore, teachers' IT competence favors the integration of IT in STEM education so that students can learn their knowledge and digital skills.

2. Materials and Methods

Considering the topic "The role of IT in STEM education" is an issue that needs clarification. To solve this problem, it is first necessary to carry out a *review* process, in which documents on the topic are searched and then systematically sorted and classified. From there, synthesize and evaluate the research results. This work aims to find "research gaps", which are the basis for making research questions and choosing new research directions. We use the Preferred Reporting Items for Systematic Reviews and Meta-Analyses approach (PRISMA (Moher et al., 2009)). This approach represents a scientific method in overview research and has the important advantage of being able to help find answers to posed research questions.

2.1. Research Questions and Objectives

Many studies have mentioned the role of IT in STEM education to promote faster and more effective implementation of STEM education. From there, our research question is: What is the role of IT in STEM education?

To answer this question, we analyze the implementation of IT in two aspects: IT as a component in STEM education and IT in supporting the components of STEM when teaching STEM to students. To achieve this goal, this work has some research questions and objectives.

Table 1 presents research questions and objectives.

Table 1. Research questions and objectives.

Research problem	Research questions	Research objectives
What is the role of IT in STEM education?	How does IT support teaching and learning in STEM education?	To identify key studies around IT and STEM education over the past 8 years (2015 to 2023), by type and object of study.
	To what extent do teachers use IT in STEM education?	
	What types of digital technology are used by teachers in STEM education?	To analyze the type of technology implemented in STEM education.
	What is the impact of using IT in STEM education? Are they useful to apply? If helpful, what is an empirical demonstration of using IT in STEM education?	To analyze the role of IT integration in STEM education. To determine how IT affects STEM education.

2.2. Information Sources

The research was conducted in the databases Scopus and WOS (Web of Science) in March 2023. The keywords used were *IT* and *STEM education* in English. These terms are searched in the "title, abstract, keywords" of each article using the Boolean operator "and". As this work also aimed to consider other sources of information that might be important but omitted in the PRISMA approach, interim documents were included to mitigate this problem. In addition, as the research in the above direction has resulted in most documents in English, the addition of other documents also aims to expand the sample of results in Vietnamese. These documents are not included in the journals belonging to Scopus and WOS, to achieve this effect, research was conducted using Vietnamese search keywords in the "title, abstract, keywords" of the articles and using the Boolean operator "and".

2.3. Criteria for Collecting and Searching Information

The method of collecting and searching the documents mentioned above is not enough to accurately indicate the scope and characteristics of the documents related to the research problem. To overcome this, document search crawling should be defined according to the following criteria.

2.3.1. Selection Criteria

Type of publication: Scientific publications are articles from scientific journals and book chapters;

Time: To ensure the update as well as limit the research that is too old, the time of the publications will be selected from 2015 to February 2023;

Search terms: Include IT, and STEM education terms in the title, abstract or keywords;

Search scope: Articles are cited correctly, without redundancy; The role of IT, and STEM education is the main topic in the content;

Research object: The collected documents are related to students, teachers, and lecturers;

Access: Articles are available under open access.

2.3.2. Exclusion Criteria

- Articles are not related to IT and STEM education.
- Articles are not available under open access.

2.4. Stages and Procedures

As we have described, the first stage was the search for the Scopus and WOS databases in March 2023. There were 39 results found in these databases according to the search method identified. Results are available in English. To expand the search results, 6 results were also found in Vietnamese in other journals. So, at the first stage, a total of 45 results were found (according to the stated collection and search methods and criteria).

In the second stage, articles are analyzed by title, abstract and keywords. This work resulted in the removal of 25 articles that were not relevant to the research problem (the role of IT in STEM education). Some articles only focus on discussing STEM education, or some articles only mention the role of IT in education in general, not emphasizing STEM education.

In the third stage, the resulting sample of 20 articles was fully examined and 4 articles did not match the inclusion criteria, but it was not possible to determine this fact in the second stage by only examining the title, abstract and keywords. These articles did not focus on discussing the relationship between IT and STEM education. Specifically, an article that did not show the relationship between IT topics and STEM education would be excluded. In summary, after the third stage, the source material directly related to the research problem includes 16 publications. From a statistical perspective, according to the PRISMA approach, this can be considered as a sample (representing the totality of documents related to the research problem). Figure 1 summarizes the process of carrying out the three stages of document collection according to the stated method and criteria (based on the PRISMA approach).

3. Result

A total of 16 articles were included in the synthesis that followed the PRISMA guidelines for systematic review. The factor analysis results related to date, language, level and object research, and type. *Regarding date*, articles are analyzed by publication date. Articles are limited from 2015 to February 2023. *As for language*, the articles focus on languages, specifically English and Vietnamese languages, in which focus on research in English. In terms *of level and object* research, the articles were analyzed by educational stage (secondary education, higher education) and research object (students, teachers). When it comes to *the type*, the articles can be divided into three categories: *Empirical*, *Revision* and *Educational proposal*. Empirical studies refer to experiential learning about the use of IT in STEM education. Revision studies evaluate the use of IT in STEM education. Educational proposal studies investigate to identify needs and propose solutions for applying IT in STEM education. According to these categories, the sample of 16 studies is classified as shown in Table 2.

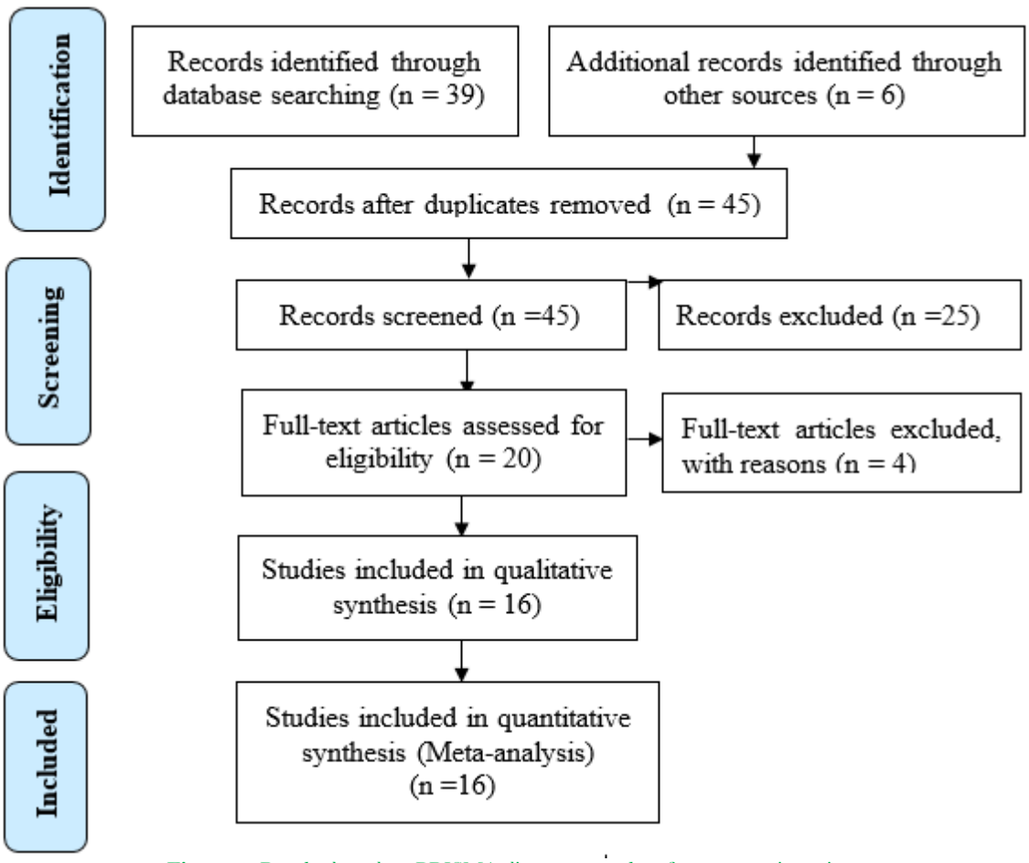

Figure 1. Results based on PRISMA diagram template for systematic review.

Table 2. Describes the studies.

Study	Date	Language	Level and object of study	Type
Hidiroglu and Karakas (2022)	2022	English	Students	Revision
Mangahas, Tate, and Harris (2022)	2022	English	Students	Educational proposal
Atman Uslu, Yavuz, and Koçak Usluel (2022)	2022	English	Students	Educational proposal
Xu and Ouyang (2022)	2021	English	Students	Revision
Lukychova, Osypova, and Yuzbasheva (2022)	2021	English	Students	Empirical
Hrynevych, Morze, Vember, and Boiko (2021)	2021	English	Students	Empirical
Birzina and Pigozne (2020)	2020	English	Teachers, students	Empirical
Yang and Baldwin (2020)	2020	English	Students	Educational proposal
Khaokhajorn, Thongsri, Panjaburee, and Srisawasdi (2020)	2020	English	Teachers, students	Revision
Istrate, Mironov, and Popovici (2019)	2019	English	Teachers	Empirical
Barakabitze et al. (2019)	2019	English	Teachers, students	Educational proposal
El Mawas et al. (2019)	2019	English	Students	Educational proposal
Terzieva, Pavlov, Todorova, and Kademova-Katzarova (2019)	2018	English	Teachers, students	Empirical
Manosuttirit (2019)	2018	English	Students	Educational proposal
Wu and Anderson (2015)	2015	English	Students	Revision
Chacko, Appelbaum, Kim, Zhao, and Montclare (2015)	2015	English	Students	Educational proposal

The 16 articles were the result of the process of implementing the collection, search and filtering method based on the PRISMA approach as presented in section 2. Articles were classified into the following five categories: Date; Language; Level and object of study; Type of research; Type of technology.

Articles were classified into technology categories and were analyzed in the following aspects: hardware (technological devices and peripherals), software (programs and applications), others (digital tools, web pages, multimedia documents). Therefore, the analysis of the results was carried out as follows:

3.1. Date

Focusing on publication date, it could be seen that publications on the role of IT in STEM education have been interesting since early, in 2015 there were 2 articles (Chacko et al., 2015; Wu & Anderson, 2015). In 2016 and 2017, no research results related to this topic were found. However, in 2018, two related studies Terzieva et al. (2019) and Manosuttirit (2019) were found. From 2019 to 2022, there were 3 research results each year (Barakabitze et al., 2019; Birzina & Pigozne, 2020; El Mawas et al., 2019; Hidiroglu & Karakas, 2022; Hrynevych et al., 2021; Istrate et al., 2019; Khaokhajorn et al., 2020; Lukychova et al., 2022; Mangahas et al., 2022; Xu & Ouyang, 2022; Yang & Baldwin, 2020). It could be said that considering the role of IT in STEM education is an important issue, gaining more and more research attention, this trend will continue throughout 2023 and the ensuing years (see Figure 2).

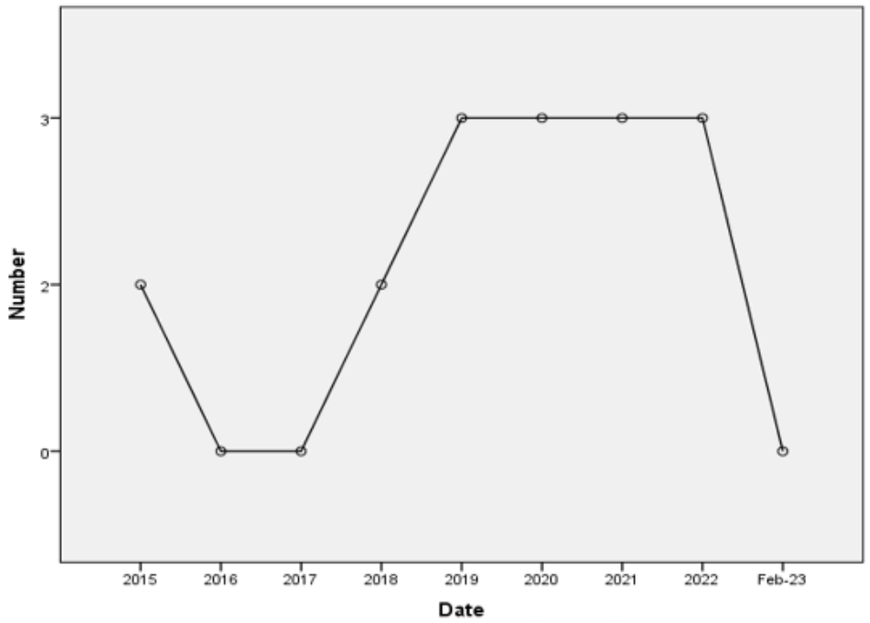

Figure 2. Number of results according to date.

3.2. Language

The research results are presented in English. According to the presented search strategy, no articles on the role of IT in STEM education were found written in Vietnamese.

3.3. Level and Object of Study

In terms of education stage and research object, out of 16 results, there were 11 results (Chacko et al., 2015; El Mawas et al., 2019; Hidiroglu & Karakas, 2022; Hrynevych et al., 2021; Lukychova et al., 2022; Mangahas et al., 2022; Manosuttirit, 2019; Wu & Anderson, 2015; Xu & Ouyang, 2022; Yang & Baldwin, 2020) in relation to the implementation of IT applications in STEM education with the audience being students. There was 1 result Istrate et al. (2019) presenting the experiences of teachers in implementing IT applications in STEM education. The remaining 4 results (Barakabitze et al., 2019; Birzina & Pigozne, 2020; Khaokhajorn et al., 2020; Terzieva et al., 2019) refer to perspectives, experiences, and solutions related to this topic of teachers and students (see Figure 3).

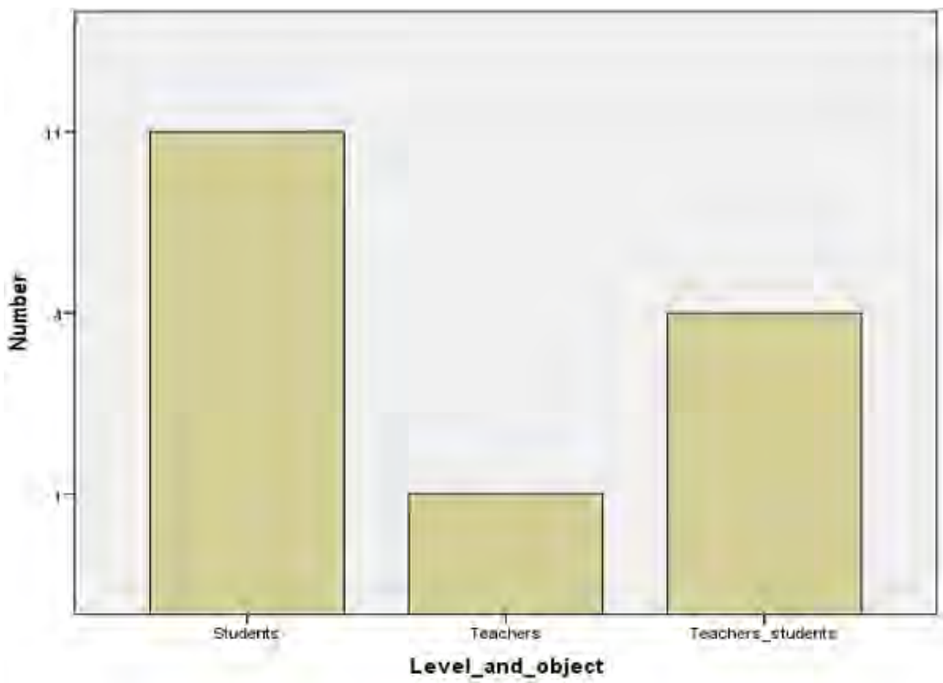

Figure 3. Number of results according to level and object of study.

3.4. Type of Study

Studies related to proposing IT application solutions in STEM education dominate (7 out of 16) (Barakabitze et al., 2019; Chacko et al., 2015; El Mawas et al., 2019; Mangahas et al., 2022; Manosuttirit, 2019; Yang & Baldwin, 2020) accounting for 44%. In parallel, empirical studies and overview studies in this field have also been interesting, specifically, there are 5 studies Lukychova et al. (2022); Hrynevych et al. (2021); Birzina and Pigozne (2020); Istrate et al. (2019) and Terzieva et al. (2019) related to the experiment and 4 studies Hidiroglu and Karakas (2022); Xu and Ouyang (2022); Khaokhajorn et al. (2020) and Wu and Anderson (2015) related to the literature review, accounting for 31% and 25%, respectively, (see Figure 4).

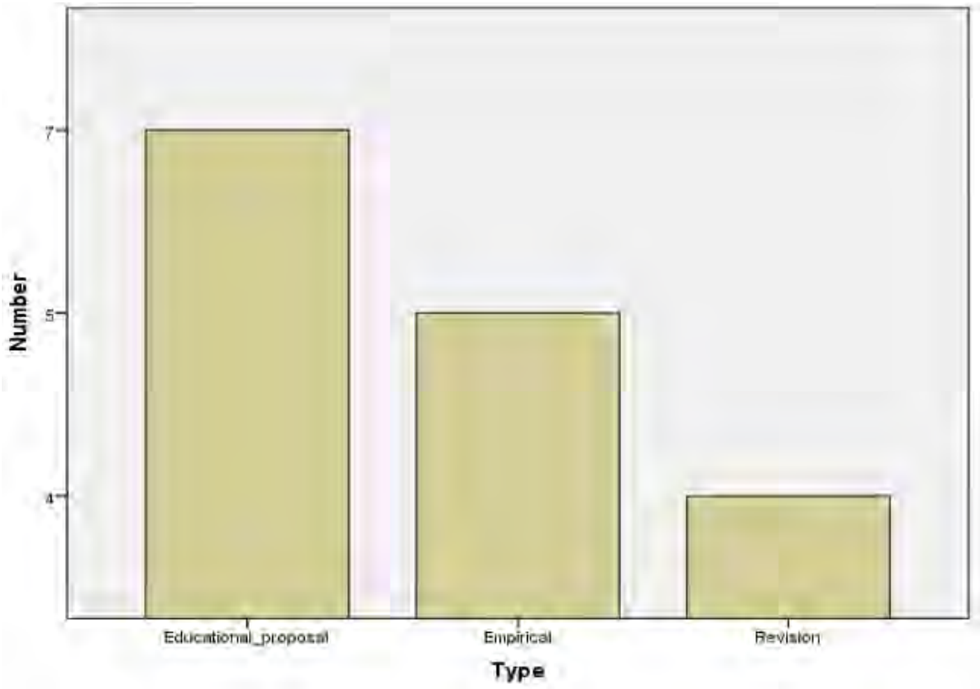

Figure 4. Number of results by type of study.

3.5. Type of Technology

Regarding the type of technology implemented in the studies, we can determine that many studies tend to introduce hardware elements in STEM education classrooms, especially whiteboards and computers or similar devices (Birzina & Pigozne, 2020; Hrynevych et al., 2021; Lukychova et al., 2022; Mangahas et al., 2022). Then, another percentage of studies Xu and Ouyang (2022); Lukychova et al. (2022); Birzina and Pigozne (2020); Terzieva et al. (2019) and Chacko et al. (2015) used software to create content such as designing, programming robots, for example, students can use Scratch programming language to organize programs, illustrate results, thereby supporting learning activities and deeper understanding of learning content.

Several studies Mangahas et al. (2022) and Barakabitze et al. (2019) have indicated that the Internet provides online query and collaboration platforms that support the use of extensive use of online resources including audio, video, and web pages. Most of these documents are highly linked for interactive and collaborative purposes. Furthermore, there has been the introduction of communication technologies, interactive and immersive technologies (Birzina & Pigozne, 2020; El Mawas et al., 2019; Istrate et al., 2019; Wu & Anderson, 2015; Xu & Ouyang, 2022) e.g., simulations, games, expanding learning possibilities through computer technology, providing opportunities for students to conduct experiments or investigate phenomenon beyond physical limits. Similarly, the trend of using web-based software elements, especially LMS such as Google Classroom, Microsoft Teams (Khaokhajorn et al., 2020; Manosuttirit, 2019) and other digital tools to respond different purposes in the growing STEM classroom (Barakabitze et al., 2019; Chacko et al., 2015; El Mawas et al., 2019; Hidiroglu & Karakas, 2022; Istrate et al., 2019; Terzieva et al., 2019) (see Figure 5).

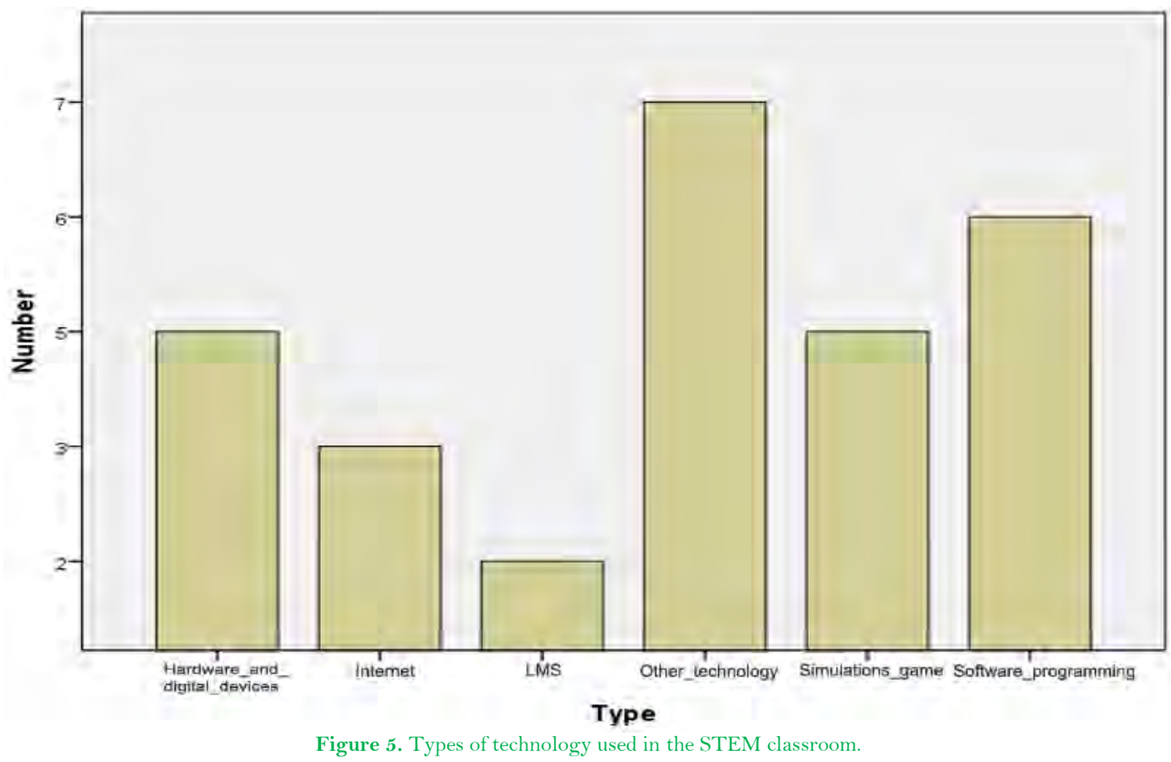

Figure 5. Types of technology used in the STEM classroom.

4. Discussion

IT is an integral part of the STEM field. IT can contribute to the design and implementation of STEM activities in many ways. However, two models emerge when analyzing the literature on the use of IT for STEM education: 1) direct integration and embedding of IT into STEM activities; and 2) use of IT as a tool or facilitator for STEM enrichment.

IT can be implemented in single STEM fields, or computer programming environments can be used in supporting model-based learning. It also has a role as a serious use of games in STEM education (Wu & Anderson, 2015).

The role of IT can be to provide real models of interaction for educators and parents; connect educators with a community of fellow learners; provide ready access to learning resources (Birzina & Pigozne, 2020; Xu & Ouyang, 2022).

The results drawn from the study's experiments (Xu & Ouyang, 2022) show that most students held positive attitudes towards the use of IT in STEM education. Moreover, the applications of IT also contributed to the development of students' higher-order thinking, computational thinking, and problem-solving ability.

Empirical data in studies Terzieva et al. (2019); Istrate et al. (2019); Lukychova et al. (2022) and Hrynevych et al. (2021) show that IT tools are increasingly encountered in learning situations in STEM education.

Study Chacko et al. (2015) also show that, by integrating IT in STEM education, helping students to understand the problem better, presenting the problem more clearly, 100% of students improve high understanding of the learning topic, 80% of students maintain high attention in learning, the percentage of students who think science is not for them decreases from 13% to 0% after one cycle.

However, the application of IT in STEM education is a time-consuming activity. It requires teachers to spend more time when organizing teaching activities (Birzina & Pigozne, 2020).

In addition, studies show that there is still a lack of resources in terms of teaching equipment and teacher training, many educational institutions have not met the requirements in terms of facilities, and teachers have not been properly trained in STEM education (Hidiroglu & Karakas, 2022) or the limited digital capacity of teachers, leading to the ineffective use of IT applications in STEM classrooms. Figure 6 presents a summary of the positive and negative aspects of IT application in STEM education.

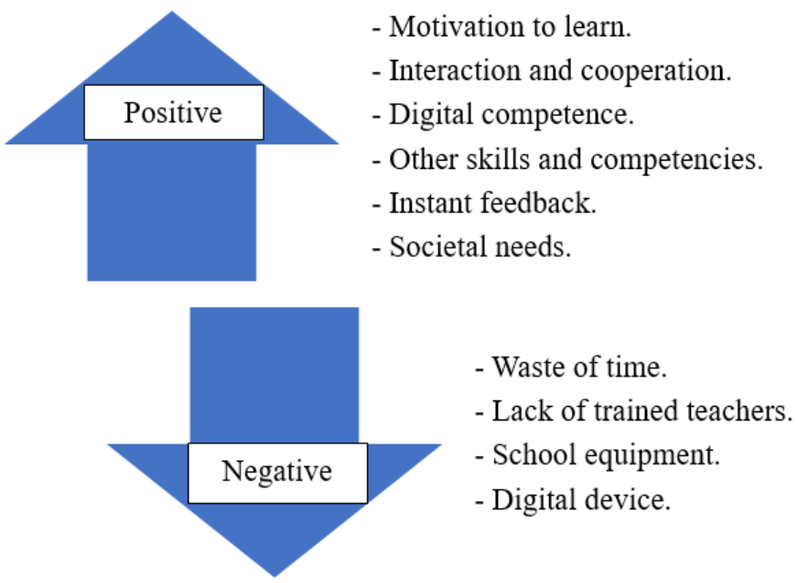

Figure 6. Summary of the positive and negative aspects of IT integration in STEM education.

5. Conclusions

The article thoroughly explores the role of IT in STEM education and presents positive associations between the two. The main objective of the study has been successfully addressed through the analysis of existing research.

For the first objective, we can conclude that there have been relevant studies related to teachers and students, the limitation of only finding research conducted in English and the absence of Vietnamese studies on this topic need to be acknowledged.

The second objective's conclusion emphasizes a shift from individual hardware device use to a more integrated approach, where IT is seen not only as a tool but also as an essential component in various stages of the STEM classroom. For instance, students use visual programming languages to create products that exemplify this integration.

Another significant conclusion that answers our third objective is that the findings highlight positive aspects of including IT in the STEM classroom, such as increasing student motivation, enhancing learning experiences, and accelerating learning. These digital tools aid in teaching STEM subjects and encourage students to explore scientific concepts in innovative ways. However, the study also identifies limitations, such as the cost of implementation in terms of time, equipment, and teachers' capacity not meeting the requirements.

In conclusion, the study highlights that IT plays a vital role in producing positive outcomes in STEM education. Nonetheless, further research is required due to the relatively new nature of this field and the limited existing research. Future studies could focus on reviewing the implementation process and proposing measures to address the identified limitations, which have not been the object of the present research. This would contribute to better understanding and successful integration of IT in STEM education.

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