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Research Analysis on STEAM Education with Digital Technology in Korea to Prepare for Post-Corona Era Education

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This is an excellent paper selected from the papers presented at ICCC 2019.

Abstract: *Problem solving in real life is a core competency commonly adopted in several subjects recently. The real-world problems were rarely resolved with only one domain of knowledge. Thus, convergence education is becoming a trend in many countries. As on-line education is revitalized because of COVID-19, the need for changes to STEAM education is emerging. In December 2019, the on-line education systems quickly settled in schools because of COVID-19. During the first semester of 2020, most school education was conducted as virtual/distance learning classes. It is necessary to analyze how much technology has been used in the STEAM classes in Korea. This paper analyzes the research papers related to the STEAM education in Korea conducted in the last 10 years. By doing this, we analyze what kind of edutechs we were interested in, what kind of STEAM education actually occurred, and to whom it was conducted. The previous research papers analyzed in this paper are the papers in the Korea Citation Index accredited journals and candidate journals. Finally, this paper proposes educational changing factors to be considered for future technology-based STEAM education.*

Keywords: STEAM education; technology-based education; association rule analysis; edutech; keyword-based analysis

1. Introduction

STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has been considered important in the field of Korean education. STEAM education is needed to improve understanding of modern science and creative problem-solving ability based on interdisciplinary convergence [1]. The STEAM education in Korea enhances students' interest and understanding of science and technology and to develop science-based convergent thinking skills and real-life problem-solving skills [2]. Recently, technology has rapidly infiltrated our daily lives and has been making many changes. Education is no exception. The role of technology in STEAM education has also been increasing as STEAM education content development and the introduction of artificial intelligence (AI) have coincided with the era of the fourth industrial revolution [3, 4]. Many researchers predict that technology will play a big role in education in post-corona era. However, it is questionable if STEAM education with digital technology is ready to be applied in classes. Based on the existing research papers on STEAM education, it is necessary to analyze how much researchers are interested in digital technology.

On the other hand, the global education system is changing due to the impact of COVID-19 in December 2019. According to a survey published by UNESCO, the new semester Corona 19 Pandemic, 1.6 percent of the world's students, 1.6 billion, remained at home without attending school [5]. As most of the classes suddenly turned into non-face-to-face online education, voices of difficulties emerged in the fields of various schools during the spring semester of 2020. Unlike the fact that various kinds of ICT (Information & Communication

Technology) have been limited to a few majors and have received attention, the necessity for classes based on ICT has started to emerge in all majors. However, there are still few clear studies on how to apply technology to classes, how to use technology and how to teach students.

According to one report, current online learning was highly dissatisfied with low learning effects (56.3% of all respondents), and edutech such as AI, augmented/virtual reality (AR/VR), games, etc. was the most popular for effective distance learning in the future [6]. Edutech is a compound word of education and technology. The importance of edutech for distance learning is being emphasized with the opening of online school [6].

In fact, in 2018, the U.S. department of education's office of educational technology set out 9 dimensions to support the success of technology-based STEM (Science, Technology, Engineering, and Mathematics) education [7]. Through this, they are pursuing STEM education based on technology. While technology poses the problem of addiction, it presents a variety of approaches to learning content and how to interact with others [8]. In other words, students can easily and accurately understand the learning contents using visual/audio information, and learn how to communicate with students through collaboration. If technology is combined with STEAM education, it can extend the experience of learning activities [9]. In particular, one study encouraged teachers to provide skills use education by acting as STEAM experts, as teachers' attitudes toward positive skills [10].

Accordingly, in this paper, after adopting 855 papers with the keyword 'STEAM education' among Korea Citation Index (KCI) accredited journal papers and candidate journal papers, we look into what areas have been studied based on the keywords of the papers. Through this analysis, we would like to analyze what kind of edutechs we were interested in, what kind of STEAM education actually happened, and to whom it was conducted. And then, we count the papers to examine how many papers have been published for the 9 dimensions of the US department of education's office of educational technology [7]. Next, in order to be successful in STEAM education, teachers' role is very important. Thus, we analyze how many research works have been performed for teachers' perception for STEAM education with technology. Finally, this study aims to analyze the current status of STEAM education in Korea by analyzing the relationship between keywords included in a paper. The review of the past research trends is very important in that it can serve as a reference point for exploring and pioneering new fields in the future [11].

This paper is organized as follows. Section 2 describes the 9 dimensions of the U.S. department of education's office of educational technology and the edutechs related with STEAM. Section 3 analyzes the direction of the previous research on STEAM education, and describes the various kinds of statistics that can explain the previous research works. In Section 4, we find out the top 10 keywords used in the 855 papers, and then we analyze the keyword relationship among the concurrent keywords for the top 10 keywords. By performing these, we point out the problem of the current education and suggest the direction of future STEAM education with digital technology. Finally, we conclude this paper in Section 5.

2. Backgrounds

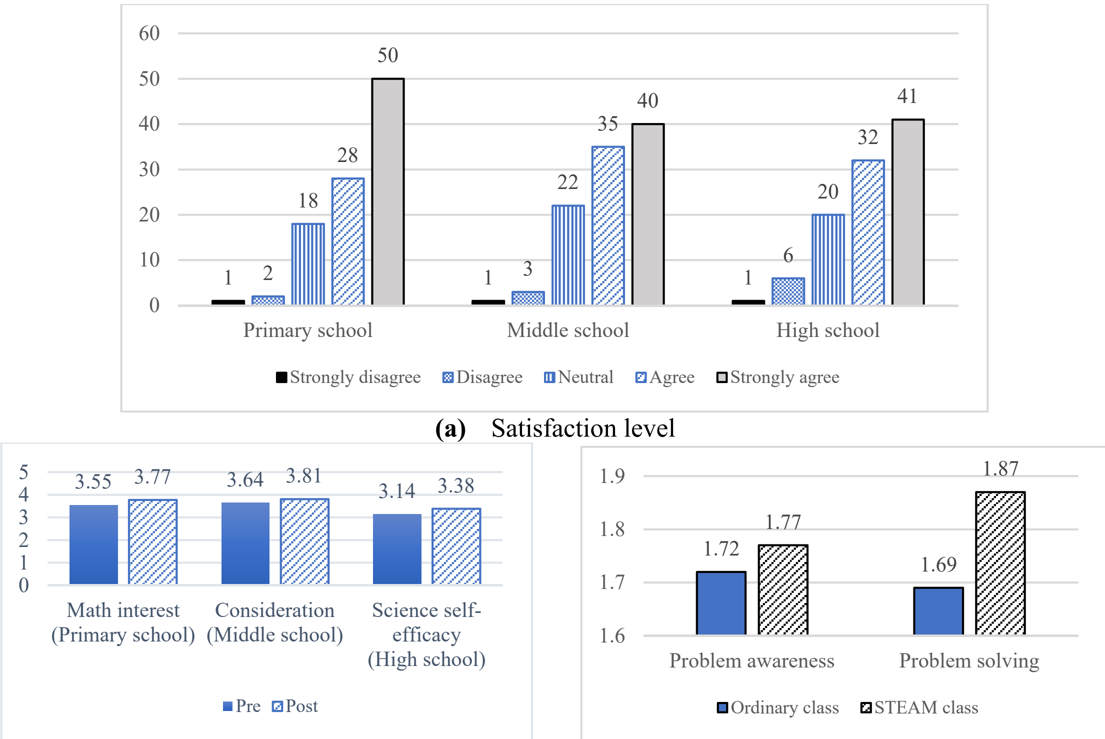
2.1 The 9 Dimensions of the U.S. Department of Education's Office of Educational Technology

In 2019, the department of education of Korea reported that STEAM classes' satisfactory level has increased and the mathematics interest, consideration, and science self-efficacy of students also have improved as shown in Figure 1 [12]. The directions of the existing research about STEAM are community-based and activity-based. For example, in a H. Jho et al.'s research, it is crucial that teachers cooperate with their peer teachers and to develop interdisciplinary (open-ended and creative) instructions on their own for STEAM education [13].

However, the U.S. department of education's office of educational technology suggested the 9 dimensions for successful STEM learning with technology. STEM education is not a separate learning of science, technology, engineering, and mathematics, but is a method of educating students with application by mixing at an interdisciplinary level [7]. They are as following:

- *Dynamic Representation (DR)* – Students interact with tools dynamically such as simulations while learning.
- *Cooperative Reasoning (CR)* – The students use collaboration tools that enable equal participation and help other students.

- *Immediate and Personalized Feedback (IPF)* – Digital tools provide immediate and personal feedback to students.
- *Science Argumentation Skills (SAS)* – Tools support scientific debates and test students' hypothesis for students' argumentation skills.
- *Engineering Design Process (EDP)* – Students solve problems by using engineering design process.
- *Computational Thinking (CT)* – Students use technology while solving problems with algorithms and data.
- *Project-Based Interdisciplinary Learning (PBIL)* – Students use technology that is required in project-based learning activities that merge multiple subjects.
- *Embedded Assessments (EA)* – Digital assessments are included in STEM education.
- *Evidence-Based Model (EBM)* – Students can use digital tools to set up data-driven models.



(a) Satisfaction level

(b) Math interest, consideration, and science self-efficacy **(c)** Problem awareness and problem solving

Figure 1. A report about STEAM education in 2019: **(a)** Satisfaction level; **(b)** Math interest, consideration, and science self-efficacy; **(c)** Problem awareness and problem solving

Analyzing the 9 dimensions, in terms of learning method, STEAM education using process-oriented problem-solving learning, cooperative learning, individualized learning, and discussion learning is emphasized. In terms of technology use, data-based, immediate interaction such as simulation, or immediate feedback are emphasized. Finally, computational thinking is required not only in computer science education, but also in STEAM education [14]. Therefore, technology must support these learning methods, and students must have abstraction and automation skills to solve problems based on technology.

2.2 Edutech Related to STEAM Education

The ministry of science, ICT and communication of Korea has laid out a national strategy to move beyond the IT (Information Technology) powerhouse to the AI powerhouse [15]. Educational contents, instructional methods, and instructional materials are all changing. AI, IoT, cloud, big data, and mobile technologies are being merged into education. Edutech is expected to be the primary means of education in the near future [5, 6, 16]. In addition, edutech's necessity is undeniable in the change from teacher-oriented education to student-oriented education. In the case of students' self-directed learning, edutech can become the main educational tool and even a customized educational tool [16].

One report that contained the results of a survey on future online learning for 187 experienced online learners and 209 parents in Korea also stated that the response to inducing entertainment and improving learning effects by applying edutech is the highest [6]. In addition, it reported that the response that real-time communication and discussion should be possible is also high [6]. These results are highly related to CR and SAS among the above 9 dimensions.

On the other hand, Lee Dong-jun's Java lab (http://javalab.org) is specifically designed to experiment with physics more than other websites. The experiment provided here has a close relationship with DR because the results can be checked quickly and easily. In a paper containing a mobile STEAM content for scientific experiments in middle schools, an application created using VR technology allowed students to interact with the application itself and experiment in the virtual world to provide instant feedback [9]. Some dimensions have already attracted the attention of researchers, but others are still unfamiliar. Therefore, it is necessary to analyze how interested the current research papers are about the above 9 dimensions, and it is necessary to set the research direction to lead successful STEAM education with technology based on the results.

In the 2015 revised curriculum of Korea, 'creativity', 'communication', and 'collaboration' were added as core competencies required for students. Edutech has emerged as a methodology to implement these more effectively. You can experience what you cannot do with memorizing textbooks using AR/VR devices. According to edutech industry officials, AI can provide customized education by level for one student [17, 18].

2019 is a meaningful year that edutech began to spread to Korean elementary school classrooms. Software compulsory education was fully implemented in elementary schools, and digital textbooks using personal devices were introduced in all grades (except in grades 1 and 2). Buksam elementary school also purchases 60 tablet PCs and uses them to view digital textbooks. The wireless communication network, which is the infrastructure required to utilize various devices, has also been built since 2019 [19]. In addition, due to Corona 19, the edutech industry and the clouding service industry are facing each other to switch to a future education system [19]. The core technologies of edutech [20] are shown in Table 1.

Table 1. Core technologies of edutech

Edutech	Apps/Tools/Organizations
VR [21]	Anne Frank House VR (History and Literature), Anatomyou VR, InMind VR2 (Biology and Anatomy), National Geographic Explore VR, Ocean Rift (Geography), Titans of Space (Astronomy), The VR Museum of Fine Arts (Arts), Learn Language VR (Language)
AR [22]	3DBear, Catchy Words AR, CoSpaces Edu, Froggipedia, JigSpace, MERGE Cube, Metaverse, Moatboat, Orb, VowldBrush
MR [23]	HoloLens (Microsoft)
AI [24]	Century, kidaptive, Osmo, blippAR
Robot [25]	Tello EDU, Tyche, Bell educational robotics kit, mBot-STEM, Dash and Dot, Thymio2, Ozobot, Lego Mindstorms,
Cloud [26]	Microsoft Azure, Amazon Web Service (AWS), salesforce.com, IBM, Google Drive, Polaris office, Goorm
Collaboration Tool	Slack (Jandi), Teams (Microsoft), Webex (Cisco), Zoom (Zoom Video Comunications)

Edutech are also quite related to cognitivism, constructivism, and social constructivism. In terms of cognitivism, technology can challenge the thoughts of learners, whereas teachers can use technology to confirm that learner's work is properly assigned in terms of constructivism. In terms of social constructivism, technology can make students test their problem-solving, communication, and collaboration abilities [27].

All of the items in Table 1 come together to further the teaching and learning process. An interactive discussion forum would allow the learner to ask the educator questions. The classes' learning management system (LMS) would allow the learner to take quizzes and exams and to turn in homework [27]. The management system would allow the outside educator as well as the educators at the learner's home school to see progress and to give instant feedback and assessment of the learner's progress.

3. Previous Research Works Review

3.1 Direction of the Previous Research on STEAM Education

The previous research analysis through keywords can clarify what kind of research has been conducted a lot, what research direction is attracting attention, and what research fields are relatively underdeveloped [15].

Recently, as the transformation of our society into a technology-based society has accelerated, fostering creative convergent talents according to the convergence phenomenon between academic fields such as knowledge, technology, and industry continues to attract attention [28].

Kim and Ko (2018) analyzed the research trend of 55 journal papers and theses registered in KCI published in 2013-2018 [29]. In their research, a lot of quantitative studies, mainly in program development and effect analysis, were conducted, but qualitative studies and mixed studies were found to be insufficient [29].

Kim (2020) analyzed the research trend of STEAM education research for young children by activity type, composition content, and evaluation content. According to the results of the paper, the linked-type activities centered on the artistic field were performed the most. The evaluation of educational content and creative thinking in the technical field was done the most [30].

Kang et al. (2016) analyzed the trend of STEAM education centered on technology targeting five engineering journals. According to the research results, literature analysis was done the most, and research on education trends analysis, program development, and effects were conducted in STEAM education research. Research on STEAM education program development occupied the largest portion. It was investigated that there is insufficient research on the analysis frame of the evaluation tool that can actually evaluate the effectiveness of STEAM education [31].

Lee et al. (2017) analyzed the research trend of physical computing to verify the educational effect of it. They found that educational research using physical computing has gradually increased from 2013. For elementary school students, physical computing using Arduino was mostly used. The programming language for physical computing education was Scratch the most [32].

3.2 Basic Statistical Data for the 855 Research Works

In this paper, we selected 855 research papers belonged to the KCI accredited journals and candidate journals. We searched the papers with the keyword, 'STEAM education'. Figure 2 shows the numbers of papers from 2011 to 2020.

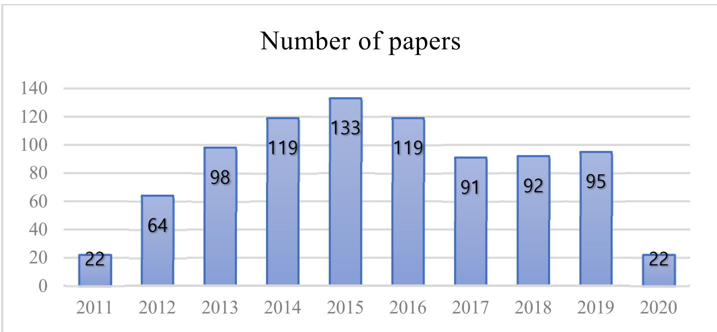


Figure 2. The number of papers from 2011 to 2020.

As shown in Figure 3, the top 10 keywords are science (252), primary school (229), creativity (164), teacher (160), fine arts (72), mathematics (72), design (69), technology and industry (69), arts (67), and curriculum (66) among 1,715 distinct keywords. The number in parentheses means the number of the research papers of this study.

The schools that were subject to study by school age were elementary school (229), middle school (82), and universities for liberal arts subjects (12). In the case of the papers specifically mentioning students, gifted students (63) and special school students (9) were included. There were many studies on teachers, and there were 10 studies on pre-service teachers in addition to regular teachers.

The subjects reported in the STEAM education-related papers covered in this study included science (252), fine arts (72), mathematics (69), technique and industry (69), engineering (40), environment (34), music (29), practical course (23), energy (23), software (23), programming (14), computer (7), chemistry (5), and moral (2).

In case of edutech used in the papers were robot (33), 3D (16), maker (14), AR (10), VR (10), physical computing (8), gamification (7), AI (3), hologram (2), and on-line (2). The teaching and learning method being dealt with in the paper were project-based learning (24), invention (19), field study (16), and flipped learning (8).

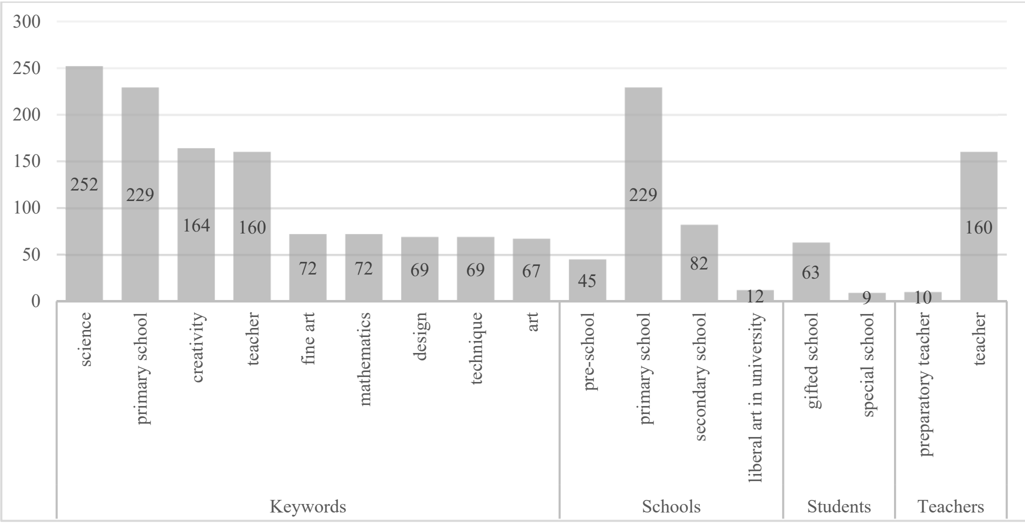


Figure 3. The number of papers in the top 10 keywords, schools, students, and teachers

For the 9 dimensions mentioned in [7], since we could not find exactly the same words as the 9 dimensions, we used the following words instead as shown in Table 2. Since the 9 dimensions are not about the content of education, but focus on how to apply technology while teaching, the number of target papers was not large. This phenomenon can be said that currently domestic research papers are mainly analyzing STEAM education from the perspective of educational content rather than educational methods. Of the total 855 papers, only four research papers on technology-based STEAM education were published, and only one paper had the keyword, edutech.

Table 2. Core technologies of edutech

Dimension	Related Keywords	No. of Papers
DR	Simulation	1
CR	Collaboration	4
IPF	Feedback	0
SAS	Communication	8
EDP	Design process	3
CT	Computational thinking	11
PBIL	Project-based	24
EA	Academic achievement	9
EBM	Big data, data mining, data science	7

Besides, from a teacher's perspective, awareness (42), training (20), competency (attitude, skill, knowledge) (20), collaboration (1), and communication (1) were the important research topics to study, whereas from a student's perspective, creativity (62), career management (30), design thinking (20), self-directed (8), communication (7), convergence thinking (7), logical thinking (3), and critical thinking (3) were the important topics. In the subject area related to pedagogy, curriculum (66), educational effectiveness (16), teaching and learning methods (11), and educational policy (10) were the main research topics. The research on learners' attitudes was also active. In the attitude field (55), scientific (25), learning (8), STEAM (4), mathematical (2), technical (2), and engineering (1) attitudes were included.

4. Association Rule Analysis among the Keywords Used Together for the Top 10 Keywords

In this paper, we selected 855 research papers belonged to the KCI accredited journals and candidate journals. And, we found out the top 10 keywords used in the 855 papers. In this Section, we analyze the keyword association among the concurrent keywords for the top 10 keywords. As shown in Table 3, we selected 7 concurrent keywords for the top 10 keywords.

Table 3. Core technologies of edutech

Keyword	Top 7 Concurrent Keywords						
Science	Primary school (19)	Convergence (15)	Teacher (11)	Creativity (10)	Technology and Industry (9)	Fine Arts (7)	AR (6)
Primary school	Teacher (46)	Creativity (33)	Science (19)	Awareness (16)	Design (13)	Mathematics (14)	Robot (11)
Creativity	Primary school (33)	Problem solving (19)	Education (19)	Convergence (12)	Design (10)	Personality (9)	Competency (6)
Teacher	Awareness (41)	Primary school (30)	Education (21)	Kids (17)	Training (12)	Competency (11)	Science (11)
Fine Arts	Primary school (8)	Convergence (7)	Science (7)	Creativity (6)	Curriculum (6)	Design (5)	Teacher (4)
Mathematics	Primary school (14)	Gifted (6)	Problem solving (6)	Curriculum (5)	Creativity (5)	Self-efficacy (3)	Design (2)
Design	Thinking (13)	Primary school (13)	Education (10)	Creativity (10)	Technology and Industry (9)	Convergence (8)	Fine Arts (5)
Arts	Convergence (7)	Education (5)	Fine Arts (4)	Teacher (4)	Science (4)	Creativity (4)	Kids (3)
Technology and Industry	Middle school (10)	Design (9)	Primary school (9)	Science (9)	Thinking (4)	Creativity (4)	Engineering (4)
Curriculum	STEAM (13)	Primary school (11)	Fine Arts (9)	2009 revised (8)	Convergence (8)	2015 revised (6)	Mathematics (6)

Next, the *Apriori* algorithm [33] was used to analyze the association rule analysis among keywords of the research papers related to STEAM education. Association rule analysis is an algorithm that creates a set of rules that tells which two sets of items occur at times. The indicators that reveal the effectiveness of the rule are largely support, confidence, and lift. Let A → B a rule. Then, the support of the rule A → B, *support (A→B)*, refers to the number of transactions in which an item A and an item B are simultaneously included in the total number of transactions [33]. Each transaction consists of multiple items selected together. The reliability of the rule A→B, *reliability (A→B),* refers to the proportion of transactions containing item B among transactions containing item A [33]. In this paper, we use 0.4 as support value and 0.2 as reliability. In item A, when items B and C with the same reliability exist, the degree of improvement is used to determine which item should be recommended more. The degree of improvement is a value obtained by dividing the share of items A and B traded simultaneously by the share of items A and B traded simultaneously when they are independent events. If the degree of improvement is 1, A and B are independent, and if it is greater than 1, there is a positive correlation [33].

We selected keywords that belong to the top 10 among the keywords. After that, 7 keywords with high relevance for each keyword were selected. And then, we analyzed the association relationship among them. Table 4 shows the results of the association relationship among keywords used concurrently. Table 4 shows the frequent items sets for the 10 keywords.

Table 4. Frequent itemsets and their support for each keyword

Keyword	Support	Itemsets
Science	0.45	(primary school, science)
Primary school	0.52	(teacher, awareness, primary school)
Creativity	0.89	(education, creativity)
Creativity	0.42	(primary school, creativity)
Creativity	0.41	(primary school, education, creative)
Teacher	0.82	(training, teacher)
Teacher	0.47	(awareness, teacher)
Fine 1	0.45	(primary school, education, fine arts)
Mathematics	0.85	(primary school, education, mathematics)
Design	0.88	(education, design)
Design	0.40	(thinking, design)
Arts	0.44	(STEAM, arts)

Arts	0.90	(education, arts)
Technology & industry	0.63	(design, education, thinking, technology & industry)
Curriculum	0.64	(education, curriculum)

In summary, papers with science as a keyword have association rules related to elementary school education. In case of primary school, teachers' awareness about STEAM education has a meaningful support. Beside the keyword science, creativity, fine arts, and mathematics have meaningful support with primary school. In other words, many STEAM studies have been conducted for elementary school students. In the case of teachers, teachers' awareness of STEAM and teacher training had high support. In the case of design and technology & industry, a set of frequent items was formed along with design thinking.

Next, we searched for associated rules about keywords that are in the top 10. As shown in Table 5, science education (lift=1.18), creativity education (lift=1.07), and fine arts education (lift=1.38) positively associated with primary school.

Table 5. Frequent itemsets and their support for each keyword

Keyword	Antecedents Consequents	Antecedent	Lift	Leverage Support
Science	(education, science) → (primary school)	0.80	1.18	0.07
Primary school	(teacher) → (primary school)	0.52	1.0	0.0
Creativity	(creativity, education) → (primary school)	0.89	1.07	0.03
	(primary school) → (creativity, education)	0.42	1.07	0.03
Teacher	(teacher) → (education)	1.00	1.0	0.0
	(teacher) → (awareness)	1.00	1.0	0.0
Fine arts	(education, fine arts) → (primary school)	0.73	1.38	0.12
	(education) → (primary school, fine arts)	0.73	1.38	0.12
Mathematics	(education, mathematics) → (primary school)	1.00	1.0	0.0
	(mathematics) → (primary school, education)	1.00	1.0	0.0
Design	(education) → (design)	0.88	1.0	0.0
	(thinking) → (design)	0.40	1.0	0.0

Through keyword analysis of research papers, the characteristics of existing research are summarized as follows. First, there have been attempts at convergence in several subjects, but there are few papers on Korean, English, and social studies. mainly science and mathematics education has been covered. In the arts-related subjects, the attempt to converge music and fine arts is also worth noting. Until now, science-centered fusion-type programs have been studied the most, but in the future, more researches on real-life-oriented fusion-type and integrated programs should be conducted.

Second, the research subjects were mainly focused on elementary school students. However, the STEAM curriculum in middle and high schools seems more necessary for convergent thinking. In Ahn and Yoo (2015), middle school students had an important period corresponding to the stages of multidisciplinary. For this, cooperation among multiple academic subjects and multiple teachers is key in middle school STEAM education [34].

Third, from the perspective of 9 dimensions proposed from the U.S. department of education's office of educational technology, project-based learning was mainly used as a teaching and learning methods for STEAM education. However, the rest of the factors seem to be very insufficient.

Besides, as the composition of the curriculum for the gifted can secure autonomy compared to regular education, it seems necessary to develop a variety of STEAM education for the gifted in middle and high schools that can demonstrate their capabilities as convergent talents. In addition, when researching the development of STEAM education programs for the gifted, it is not only necessary to develop programs, but more actively researches to verify the educational effectiveness.

5. Conclusions

In this paper, we selected 855 research papers belonged to the KCI accredited journals and candidate journals. The purpose of this paper is to identify the current status and problems in digital technology adoption in STEAM education and to present improvement plans in the future. According to the research papers of the last 10 years, STEAM education is still being conducted centered on primary schools and focusing on the effect of education through instructional design centering on science subjects. However, more researches on real life-centered convergence programs and integrated programs will need to be conducted in the future.

In addition, when STEAM education has been evaluated so far based on the 9 dimensions suggested by the US department of education, there have been insufficient studies on the areas of improving teaching and learning methods such as collaboration, argument skill, immediate feedback, and self-directed learning, for learner-centered education in STEAM education. Therefore, in the future, technology-based teaching and learning methods need to be improved so that student-centered learning, learner evaluation, and feedback can be efficiently performed in STEAM education through an automated system based on digital technology.

Recent technologies include cloud services, social network services, digital textbooks, intelligent tutoring systems, on-line education systems, games and simulations. Recent technologies for STEAM include visualization tools, simulation tools for virtual experiments, computer programming languages, and collaboration tools. In the future, teachers should not only recognize the need for STEAM education, but also apply and educate the above technologies in STEAM education.

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