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CONTENTS

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Educating Preschoolers to Pro-Environmental Actions: A Metacognition-Based Approach

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Abstract

Metacognition is the process of thinking about one's own thinking, learning, and problem-solving strategies. It involves being aware of one's own cognitive processes and knowing how to regulate and monitor them. Sustainability, instead, refers to the ability to maintain or preserve resources and ecosystems for future generations. Here, we draw from the classical metacognitive approach and propose that metacognition plays an important role in sustainability. The PRISMA (Preferred Reporting Items for Systematic Reviews and MetaAnalyses) Statement was used to perform and recode this review. Given that metacognitive abilities develop early during childhood, metacognition can be viewed as a useful approach to teach pro-environmental behavior from early childhood. Although the interaction between metacognition and sustainability in preschoolers appears to be insufficiently explored, the final aim of this review is to offer a new education-based perspective about metacognition that can be implemented in early childhood to foster pro-environmental actions in the long-term.

Introduction

Metacognition typically refers to the ability to think about the potential of our cognition or, to say it differently, to the knowledge of and control over our cognitive processes, such as learning, memory and decision-making (Flavel, 1979; Hacker, Dunlosky, & Graesser, 2009). Sustainable behavior, instead, can be generally viewed as a series of actions that reduce harmful environmental consequences and result in the use of natural resources (Gardner & Stern, 2002). Metacognition and sustainability are important concepts that can be applied across various fields such as education, business, and environmental protection. In this review, we will explore how metacognition can be used to promote sustainable practices and behaviors in preschoolers.

Generally speaking, metacognition can be used to promote sustainable practices and behaviors in several ways. For example, individuals who are aware of their own thinking processes can identify and challenge their own assumptions and biases about sustainability. They can also evaluate the effectiveness of their own actions and make adjustments as needed to ensure that they are acting in a sustainable manner. Furthermore, metacognition can help individuals develop critical thinking skills that are necessary for making informed decisions about sustainability. By reflecting on their own thinking processes, individuals can become more aware of how their decisions impact the environment, and they can use this information to make more sustainable choices (e.g., Abrahamse et al., 2005). In addition, metacognition can be used to promote sustainability in educational settings. Teachers can help students develop metacognitive skills by encouraging them to reflect on their own learning processes and to think critically about sustainability issues (e.g., Schunk & Pajares, 2005). By doing so, students can develop a deeper understanding of sustainability and become more engaged in efforts to promote it. Overall, metacognition is an important tool for promoting sustainability: by fostering awareness of one's own thinking processes and developing critical thinking skills from early childhood (Flavell et al., 1995), individuals can become more effective advocates for sustainable practices and behaviors later in life.

Although researchers in the sustainability field have indirectly emphasized the role of metacognition (e.g., in terms of self-efficacy, affective reactions, etc., Schutte & Bhullar, 2017; Milfont & Duckitt, 2010), as far as we know, few theoretical or empirical studies have explored how metacognition may influence sustainable behavior in preschoolers and very few studies involved 3 to 5 years old children. The main rationale being that metacognition in early childhood is difficult to be studied under controlled experimental conditions. This review wants thus to further the discussion about the current theories of sustainability in education (e.g., Somerville & Williams, 2015), but also provide a new direction for the culture of sustainable behaviors in early childhood. For instance, previous studies emphasized the importance of contextual knowledge in education (e.g., knowing when/where/how/why to act in a sustainable manner, for a review see Brown, Collins & Duguid, 1989). In addition, a recent review (Mason et al., 2022) have highlighted the relationship between metacognition and environment learning in terms of the following three aspects: (1) the role of environmental cues (; (2) the motivational aspects; (3) the role of monitoring and control processes.

Although theoretical and some empirical studies have thus pointed out that sustainability may benefit from metacognition, the discussion about how the interaction between these two develops during early childhood needs further investigation. This work wants to describe how metacognition and sustainability may be related within the context of sustainability and point out to a series of educational aspects that are relevant for teaching sustainability during early childhood.

Method

The PRISMA (Preferred Reporting Items for Systematic Reviews and MetaAnalyses) Statement was used to perform and recode this review (Liberati et al., 2009).

Eligibility Criteria

The inclusion criteria were relationship between metacognition (knowledge, affective reactions, strategies) and sustainability (behavior, actions); relationships between sustainability and preschoolers, between sustainability and education in early childhood; articles written in English.

Inclusion/Exclusion Criteria

Studies that meet the following criteria were included:

1) Works providing a definition of metacognition, and/or highlighting the relationship between metacognition and sustainability (sustainable behavior, sustainable actions).
2) Works focusing on the relationships between sustainability, education and early childhood.
3) Works on the educational sustainability programs adopted and/or those offering suggestions for teachers.
4) Written in English.

The exclusion criteria were considered as follows:

1) Unrelated topic.
2) Studies without sufficient data provided (e.g., study site, study period, and sample size).
3) Case reports/Editorial comments/Letters to Editor, etc.

Information Sources

A systematic electronic search was undertaken in the following databases between February 2024 and April 2024, with no time limits: PubMed, Scopus, PsychINFO, and Google Scholar. Where applicable, MeSH and Emtree terminology were utilized. A hand search of relevant studies was also carried out. The Rayyan online program was used to import and categorize all of the references.

Search Strategy

Computer searches of the PubMed, PsycINFO, Scopus, and Google Scholar databases were used to perform this review; searches were run until the 15th of April 2024. There were two stages to the article selection process. There was no time limit, no search filters, and no constraints. The first search included the keywords “metacognition”, “sustainability”, “preschoolers”. Then, we searched for some combinations of keywords between sustainability and “knowledge”, “affective reactions”, “control and monitoring”, “childhood”. The articles were identified and then listed in an excel table. Titles and abstracts unrelated to the topic were then excluded, as well as duplicate records. As a result, we read the entire content during the eligibility verification step. All items selected in the previous phases were examined for quality evaluation in the final step; low-quality studies (i.e. insufficient data provided) were excluded.

Data Collection

Following the application of the search strategy, a total of eighty works were identified. Eighty publications were screened after the duplicates were removed. Studies were first included for their titles and abstracts' relevance to the research question. Following that, the screening process resulted in the retrieval of sixty-five works. The full text of the remaining articles was obtained and evaluated for eligibility. Twenty-two reports were reviewed for eligibility and then ranked according to the inclusion criteria. Finally, we included in the present review fifteen publications.

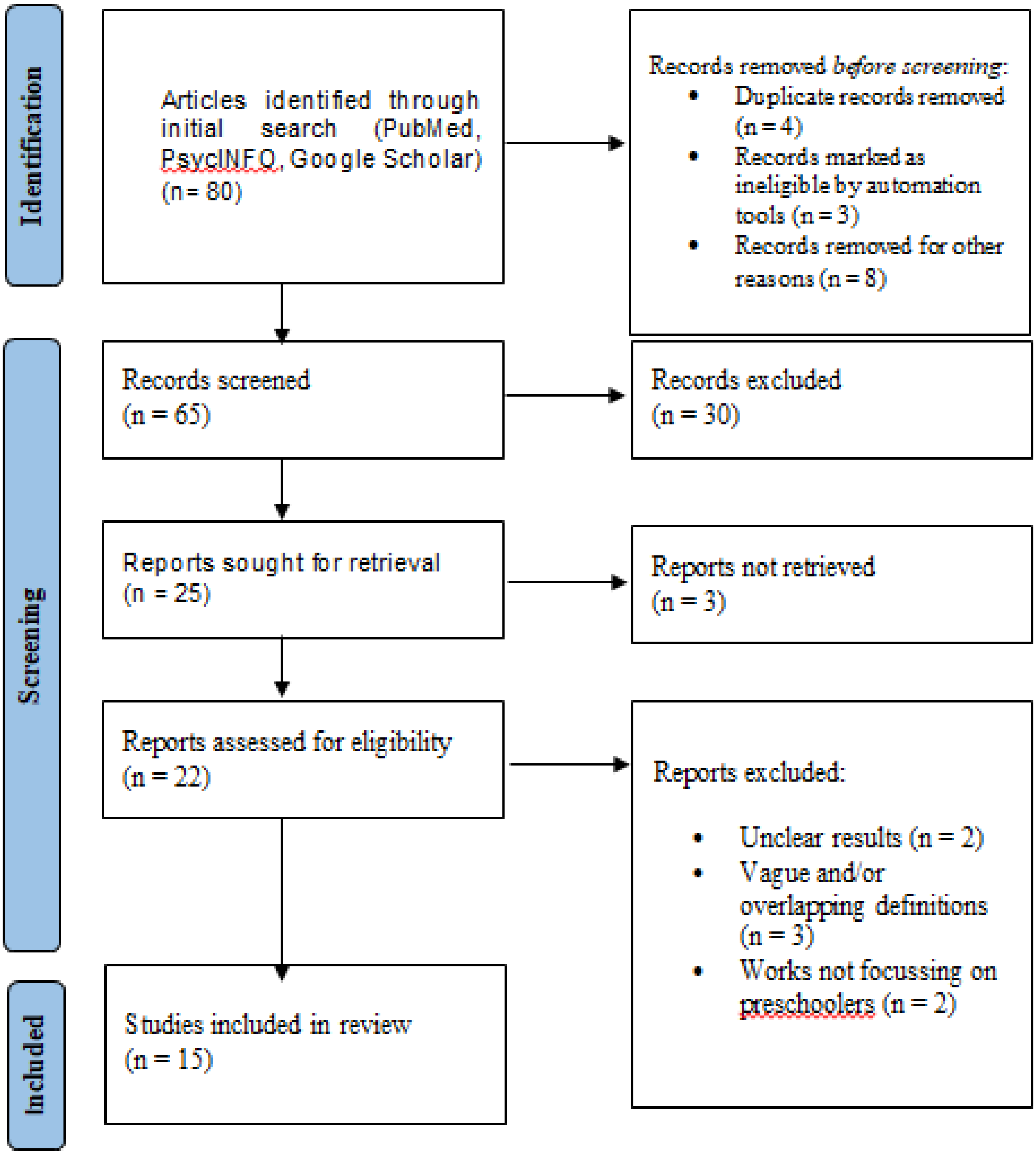

Figure 1. The PRISMA flow diagram depicts the selection process as well as the inclusion decision

For data analysis, we used a standardized form to extract relevant data from each study. This included information on study design, participants, interventions, outcomes, results and discussion. For review studies or book chapters, relevant paragraphs and general discussions were considered. We then summarized and interpreted the findings of the studies. The list of included studies with their main focus of discussion is presented in Table 1.

Table 1. Overview of Included Studies

Authors, year	Focus
Davis (2005)	sustainable education and kindergarten
Davis (2009	sustainable development and early education
Davis (2010)	sustainable development and early education
Edwards and Cutter-Mackenzie (2011)	environmental education and early childhood curriculum
Elliott and Davis (2009)	sustainable education and preschoolers
Elliott and Young (2015)	nature and sustainability and children
Ernst and Burcak (2019)	education to sustainability in preschoolers
Guler- Yıldız et al. (2021)	sustainable development and early education
Haas and Ashman (2014)	sustainable education and practices in kindergarten
Hedefalk et al. (2015)	sustainable development and early education
Musser and Diamond (1999)	environmental attitudes in preschoolers
Sobel (2017)	education to nature and children
Sobel (2020)	education to nature and emotion in children
Somerville and Williams (2015)	sustainability education and preschooler
van de Wetering et al. (2022)	environmental knowledge and children

Results and Discussion

Metacognition in Early Childhood

Metacognition is a crucial cognitive skill that can help individuals become efficient learners and problem-solvers. While it may seem like a complex concept that only applies to adults, metacognition is also important for young children, including preschoolers. In fact, metacognitive skills can be developed at an early age through various activities and experiences (e.g., Godfrey et al., 2022). By fostering metacognition in preschoolers, we can help them become more aware of their own thinking processes and develop strategies to regulate and monitor their learning. In this section, we can explore the importance of metacognition in preschoolers. In particular, early developmental theories of metacognitive abilities typically distinguished between explicit and implicit metacognition. Explicit metacognition refers to the explicit knowledge, monitoring and control over our cognitive abilities, whereas implicit metacognition may be considered a more behaviorally-driven type of metacognition which affect our performance without conscious awareness. These two types of metacognitive abilities may develop at different ages. In fact, while explicit metacognitive knowledge develops later during childhood (from school-aged children to adolescence e.g., Schneider, 2008), some metacognitive implicit abilities may develop earlier between 3 to 5 years old (e.g., Lyons & Ghetti, 2010, Paulus et al., 2011), that is, preschoolers are able to use metacognitive skills before accessing to verbal skills. For example, a series of studies (e.g., Balcomb and Gerken, 2008; Kim et al., 2016) showed that the feeling of uncertainty that preschoolers can show during cognitive tasks (e.g., feeling not sure about the answer, asking for help) may be considered an instance of implicit metacognition that impact on their cognitive performance without explicit control over their judgements. Other instances of implicit metacognition refer to non-verbal behaviors such as gestures that indicate that he/she is not sure about the answer (e.g., shaking their heads or shoulder). In this regards, eye-tracking studies (Paulus et al., 2013) identified some gaze behaviors (e.g., duration of gaze towards the target, persistent searching for information) that also indicate the confidence level and uncertainty shown by children during a cognitive or more-social based task (e.g., Kuzyk et al., 2019). All these more behaviorally-driven metacognitive skills seem to point out that a metacognitive approach (although implicitly-based) can be used among preschoolers to foster different degree of knowledge about learning to act pro-environmentally.

Sustainability in Early Childhood

Sustainability programs for preschoolers are becoming increasingly popular as more and more people recognize the importance of teaching young children about environmental responsibility. These programs aim to instill in young children a sense of care and respect for the environment, as well as an understanding of the impact that their actions can have on the world around them. Through hands-on activities and engaging lessons, preschoolers can learn about topics such as recycling, energy conservation, and reducing waste. By introducing sustainability concepts at a younger age, children can develop a lifelong appreciation for the environment and a commitment to making sustainable choices. As reviewed by Somerville and Williams (2015), the research focus on preschoolers can be grouped according to three main categories. The first category refers to the main aim of connecting children to the natural world, to teach them about its values and to act for its conservation. The second one has the goal of empowering children in relation to major sustainability issues such as social, cultural, and economic global issues of sustainable development. The third one is based on educating children to overcome the classical nature/culture binary, that is, learning to view human sociality and the natural world as interdependent systems. A more recent review (e.g., Yildiz et al., 2021) also highlighted that the most frequently discussed topic when teaching sustainability in preschoolers is the protection of our environment. Another interesting meta-analysis was conducted by van de Wetering et al. (2022): although studies on both children and adolescents were included, it showed that environmental education improved students' environmental outcomes on a series of different categories such as environmental knowledge, attitudes, intentions, and behavior. One of the first interesting attempt to study sustainability in early childhood can be found in the "Children's Attitudes Toward the Environment Scale for Preschool Children" (Musser & Diamond, 2010) which showed that preschoolers' attitude towards the environment was correlated with their engagement in environment-friendly activities at home. Preschoolers were thus able to identify improper actions with regard to the environment if they got used to environment-friendly behaviors at home. This finding points to the need of a continuous interplay between school and family goals for sustainable education to be effective.

The New Concept of "Meta-Sustainability"

In order to show how metacognition may interact with sustainable behavior, we can reframe the concept of sustainability as "meta-sustainability", that is, the ability to have knowledge, awareness, and control over pro-environmental behavior. This approach may help describe the different components of metacognition better within the context of preschoolers' education as shown in the next sections. Knowledge, affective experience, and control are the principal components of meta-sustainability. In particular, meta-sustainability knowledge can be broadly defined as the declarative knowledge of sustainable behaviors that can be person-centered (e.g., ways of thinking about pro-environmental behavior; pro-environmental self-efficacy); action-centered (e.g., actions' goals directed to the protection of the environment); and utility-centered (e.g., pros and cons, the feasibility of each pro-environmental behavior). The affective reactions that may occur during sustainable behavior refer to the subjective perception of the ease or difficulty of certain sustainable actions and thus to the positive or negative emotions that may derive from performing that particular action. Finally, control refers to monitoring and regulation of our sustainable actions, for example, by planning, supervising, executing, and evaluating a sustainable action in terms of goals, time, and attention deployment. Sustainability can be considered as a metacognitive process in that the combination of individual's environment knowledge and action evaluation results in a continuous dynamic integration. Specifically, sustainable behavior requires the acquisition of knowledge and skills that are crucial for the final long-term goal of protecting the planet Earth. An example can be any recycling activities. For recycling to be successful, relevant prior knowledge must be consciously retrieved, and an action plan must be implemented (according, for instance, to a delivery calendar). Moreover, actions can be monitored, for instance, in terms of time spent in recycling and the utility of these actions evaluated. We assume that using all these metacognitive functions would likely enhance sustainable behavior. In the next sections we first detailed how knowledge, affective reactions and control functions generally works and subsequently how they can be applied to preschoolers' learning of sustainability.

Knowledge and Sustainability

Knowledge plays a crucial role in sustainable behavior. In order to act in a sustainable manner, individuals need to have a good understanding of the environmental, social, and economic impacts of their actions. This knowledge can help individuals make informed decisions about how to live in a way that is more sustainable. For example, individuals who are aware of the negative impacts of single-use plastics on the environment may choose to use reusable bags, bottles, and containers instead. Similarly, individuals who are aware of the carbon footprint of various modes of transportation may choose to walk, bike, or take public transit instead of driving. In addition, knowledge can help individuals understand the importance of sustainability and motivate them to take action. When individuals understand the implications of their actions on the environment and future generations, they may be more motivated to make changes in their own behavior. Education and awareness-raising initiatives play a vital role in promoting sustainable behavior by providing individuals with the knowledge and tools they need to make informed decisions. By increasing knowledge and awareness of sustainability issues, individuals can become more engaged in efforts to promote sustainability and can work towards building a more sustainable future. According to the knowledge-deficit model, the assumption is that when people do not know about a specific environmental problem, or they do not know in detail what to do about it, do not engage in sustainable actions (Schultz, 2002). For example, participants who possess much more knowledge of plans, goals, and descriptions of sustainability performed better and feel more engaged in sustainable actions compared with individuals who show lower levels of knowledge. Several intervention studies (for a review see Osbaldiston & Schott, 2012) have found that the training of knowledge promotes sustainable actions. In particular, interventions that focused on knowledge acquisition include typically two types of information. The first one refers to inform about the reasons for performing a specific behavior (also called declarative information or why-to information), such as information about the differences across materials and why we should recycle them. The second one refers to inform on how to perform a specific behavior (also called procedural knowledge), e.g., sort plastics according to their codes. Altogether these results showed that knowledge training can significantly improve sustainable behavior.

Affective Reactions and Sustainability

Understanding the relationship between affective reactions and sustainable behavior is crucial in promoting environmentally friendly actions. Affective reactions, or emotional responses, can have a significant impact on sustainable behavior. Research has shown that positive emotions, such as happiness and joy, can increase pro-environmental behaviors, while negative emotions, such as guilt and anger, can decrease them (for a review see Petersen & Austin, 2017). For example, if an individual feels happy and satisfied after using a reusable water bottle instead of a disposable one, they are more likely to continue using the reusable bottle in the future. This positive emotional response reinforces the behavior and makes it more likely to become a habit. On the other hand, if an individual feels guilty or ashamed after forgetting to bring their reusable bag to the grocery store and having to use plastic bags instead, they may be less likely to use the reusable bag in the future. The negative emotional response can create a barrier to behavior change and make it harder to adopt more sustainable practices. In addition, affective reactions can also be influenced by social norms and the attitudes of others. For example, if an individual sees their friends and family members engaging in sustainable behaviors and expressing positive emotions about them, they may be more likely to adopt those behaviors themselves. Overall, affective reactions play an important role in sustainable behavior. By understanding how emotions can influence behavior, individuals can work to cultivate positive emotional responses to sustainable practices and behaviors, and to minimize negative emotional barriers to behavior change (e.g., O'Brien & Wilson, 2015). Different studies have shown that the core aspect of affective positive reactions during sustainable actions is processing fluency, that is, how individuals perceive the ease of performing that particular action. Previous research, in fact, has highlighted that fluency is crucial in goal setting (e.g., Storbeck & Clore, 2007) which is a relevant aspect for sustainable actions to be performed.

Monitoring and Control of Sustainable Actions

Metacognitive monitoring and control refer to a set of components, such as goal setting, planning execution, strategy selection, and evaluating (Flavell, 1976) that are all crucial for sustainable behavior. Metacognitive monitoring refers to evaluating the process of initiating a sustainable action or current state of knowledge. Metacognition can be a valuable tool for monitoring and controlling sustainable actions. By reflecting on their own thinking processes, individuals can become more aware of how their behaviors impact the environment and the broader community. This awareness can help individuals identify areas where they can make changes to their behavior to become more sustainable. For example, if an individual is trying to reduce their carbon footprint, they can use metacognition to monitor their own behavior and identify areas where they can make changes. They might reflect on their daily routine and identify times when they are using excessive amounts of energy or producing unnecessary waste. Using this information, they can make adjustments to their behavior and develop new habits that are more sustainable. In addition to monitoring their own behavior, individuals can use metacognition to control their sustainable actions. By setting goals and tracking their progress, individuals can hold themselves accountable for their sustainable actions. For example, an individual might set a goal to reduce their water usage by a certain percentage each month. By tracking their water usage and reflecting on their progress, they can adjust their behavior and work towards their goal. Overall, metacognition can be a powerful tool for monitoring and controlling sustainable actions. By fostering awareness of one's own thinking processes and developing strategies for regulating and monitoring behavior, individuals can become more effective advocates for sustainable practices and behaviors. For example, people may engage in monitoring to discover that he/she felt confident in her understanding about recycling and less confident about climate change and to estimate her performance accordingly. Metacognitive control is the regulation of sustainable activities. Individuals decide when to recycle, what strategies he/she would use, and after the action, how he/she would do differently for future actions. Each of these aspects of metacognition can limit or enhance the number of sustainable actions depending on the quality of the students' knowledge, monitoring, and control processes, –how individuals regulate their behavior can make a real difference in sustainability.

A "Meta-Sustainability" Approach for Educational Practice in Preschoolers

Introducing sustainability concepts to preschoolers is an important step in promoting sustainable behaviors and attitudes early on in life. Sustainability programs for preschoolers can include a variety of activities that help them understand the importance of taking care of the environment and its resources (Williams & Sobel, 2017). One approach to sustainability education for preschoolers is through hands-on activities that engage their senses and curiosity. For example, activities such as gardening or composting can help preschoolers learn about the natural world and the importance of reducing waste (e.g., Sobel, 2008). Another approach is through storytelling, where books and stories can be used to introduce concepts such as recycling, conservation, and protecting the environment. Furthermore, preschoolers can be encouraged to engage in sustainable practices such as turning off lights when leaving a room, using reusable containers, and conserving water. These practices can be incorporated into their daily routines to help them develop sustainable habits that they can carry with them into adulthood (Davis, 2009; 2010). Overall, sustainability programs for preschoolers can be effective in promoting sustainable attitudes and behaviors in the next generation (Davis, 2014; Elliott & Young, 2015). By introducing "meta-sustainability" concepts early on, preschoolers can develop a sense of responsibility towards the environment and become more aware of their impact on the planet (e.g., Diamond & Lee, 2011). Here we present some strategies that can be used to increase "meta-sustainability" in preschoolers according to the three main components described above:

Knowledge in preschoolers. Preschool is a critical time to introduce children to the concept of sustainability and encourage them to develop eco-friendly habits. Educational practices may include:

1. Hands-on activities: Preschoolers learn best through hands-on activities. Activities such as planting seeds, composting, and recycling can help children understand the importance of sustainability. 2.Storytelling: Storytelling is an effective way to introduce sustainability concepts to preschoolers. Books that focus on environmental themes can help children learn about sustainability in a fun and engaging way. 3. Role modeling: Adults can model sustainable behaviors for preschoolers. For example, teachers can demonstrate composting, recycling, and conserving energy in the classroom. 4. Field trips: Field trips to local parks, gardens, and farms can help preschoolers connect with nature and learn about sustainability in real-world contexts. 5. Art and craft activities: Art and craft activities that use recycled materials can help preschoolers understand the importance of reusing and repurposing resources. By using these strategies, educators and parents can help preschoolers develop a deeper understanding of sustainability and encourage them to make eco-friendly choices in their daily lives (Schneider & Lockl, 2002).

Affective reactions. There are several ways to increase positive emotions about sustainability in preschoolers. Here are a few strategies:

1. Use positive language: When communicating with preschoolers, it's important to use positive language that emphasizes the benefits of sustainable practices. For example, instead of saying "don't waste water," say "let's save water so we have more for later." This helps children develop a positive attitude towards sustainability. 2. Make sustainability fun: Children learn best through play, so incorporating sustainability into games and activities can be an effective way to promote positive emotions. For example, you can create a recycling sorting game or a gardening activity to teach children about sustainability in a fun and engaging way. 3.Encourage exploration: Preschoolers are curious by nature, so providing opportunities for them to explore and discover the natural world can help foster positive emotions about sustainability. Take children on nature walks, visit local parks, or create a nature corner in the classroom to encourage exploration and appreciation of the environment. 4.Model sustainable behaviors: Children learn by example, so it's important for adults to model sustainable behaviors. This includes things like turning off lights when leaving a room, using reusable bags, and recycling. When children see adults engaging in sustainable practices, they are more likely to adopt these behaviors themselves. By implementing these strategies, preschoolers can develop positive emotions about sustainability and become advocates for environmental protection.

Monitoring and control. Promoting sustainable behavior in preschoolers is essential for creating a greener and healthier future. One way to increase monitoring and control of sustainable behavior in preschoolers is by using visual aids and modeling. Here are some strategies that can be used:

1. Visual Aids: Use visual aids such as posters, pictures, and diagrams to illustrate the importance of sustainable behavior. For example, posters can be placed in the classroom or playground to remind children to turn off the lights, recycle paper, or conserve water.
2. Modeling: Teachers and parents can model sustainable behavior by demonstrating eco-friendly practices such as turning off lights when leaving the room, using reusable bags, and recycling materials. When children see adults engaging in sustainable behavior, they are more likely to adopt these practices themselves.
3. Reinforcement: Positive reinforcement can be used to encourage sustainable behavior in preschoolers. For example, teachers can offer praise or small rewards such as stickers or stamps to children who engage in eco-friendly practices such as turning off the lights or recycling.
4. Engaging Activities: Engaging children in fun and interactive activities related to sustainability can help them develop an appreciation for the environment. For example, teachers can organize nature walks, gardening activities, or recycling games that can help children learn about the importance of sustainability.
5. Education: Providing education about sustainability can help increase monitoring and control of sustainable behavior in preschoolers. Teachers can teach children about the importance of reducing waste, conserving resources, and protecting the environment.

In conclusion, increasing monitoring and control of sustainable behavior in preschoolers can help create a greener and healthier future. By using visual aids, modeling, reinforcement, engaging activities, and education, teachers and parents can promote sustainable behavior in preschoolers and encourage them to become stewards of the environment.

Conclusion

The present review primarily focuses on highlighting the interaction between metacognition and sustainability. Although increasing research points out that metacognition may play an important role in sustainability, the empirical studies reviewed here point to a lack of studies mainly in the area of early childhood. We believe that a metacognition-based approach can be used to study meta-sustainability in preschoolers and show how, by focusing on the differentiated aspects of metacognition, we can teach and foster sustainable behaviors. In fact, promoting metacognitive skills and sustainability in preschoolers can have a significant impact on their future behaviors and decision-making processes. By teaching young children to think about their own thinking and to understand the importance of preserving resources and ecosystems, we can help them develop a deeper understanding of sustainability and its relevance to their lives. This can also help them become more responsible and engaged citizens who are committed to making positive contributions to the environment. By incorporating metacognition and sustainability into early childhood education, we can help create a more sustainable future for generations to come (Davis, 2014). Accordingly, this work offers some advice on how to use metacognition in order to foster sustainable actions. Our goal in reviewing these studies was twofold. First, we wanted to offer to preschoolers' teachers a metacognition-based approach when dealing with sustainability in the classroom. If, for example, a child shows inaccurate beliefs about the use of plastic, he/she can learn how to use different materials and be trained on how to improve their monitoring and control of their own actions. Thus, finding ways to improve children's metacognitive knowledge, monitoring, and control can lead to insights into how to improve their sustainable actions (e.g., Steg & Vlek, 2009). Second, sustainable education focuses on teaching children about environmental and social responsibility, and how to live in a way that ensures a sustainable future for the planet. By introducing sustainable education in preschoolers, we can help them develop a sense of respect and responsibility towards the environment and instill values that will stay with them for life. This can be achieved through a variety of engaging and interactive activities that are age-appropriate and fun for young children (Ernst & Burcak, 2019). In this context, preschool teachers play a vital role in shaping children's attitudes towards sustainability and the environment. By providing a strong foundation in sustainable education, we can help create a generation of environmentally conscious and responsible citizens who will work towards a sustainable future.

Within the theoretical frameworks of sustainable education, the transformative learning approach fits well with our "meta-sustainability" view. In fact, transformative learning theory is a way of understanding how individuals can learn and change their perspectives, values, and behaviors in response to new experiences and information (Mezirow, 2012). In the context of sustainable education, transformative learning theory can be used to help preschoolers to develop a deeper understanding of the interconnectedness of social, environmental, and economic systems, and to encourage a shift towards more sustainable thinking and practices. According to transformative learning theory, learning is not simply a matter of acquiring new information or skills, but involves a process of reflection, questioning assumptions, and challenging existing beliefs and values. This process can be facilitated through experiences that challenge individuals' existing ways of thinking and being, and that encourage them to consider alternative perspectives and ways of living. In sustainable education, transformative learning can be fostered through a variety of approaches, such as, for instance, experiential learning. These approaches provide opportunities for young children to engage with real-world problems and to develop a deeper understanding of the complex social, environmental, and economic issues that underlie sustainability challenges. Transformative learning in sustainable education can also involve the development of critical thinking skills, such as the ability to analyze complex information, to evaluate different perspectives, and to identify underlying assumptions and biases. By developing these skills, children can become more effective problem-solvers later and agents of change in their communities and beyond. Overall, transformative learning theory provides a powerful framework for understanding how children can develop more sustainable ways of thinking and living, and how education can play a role in facilitating this process by using a "meta-sustainability" approach. In conclusion, teaching sustainability to preschoolers is an important step towards creating a more environmentally conscious future generation: by instilling the values of conservation, recycling, and reducing waste in young children, we can help them develop a lifelong commitment to protecting the environment. Studies (e.g., Somerville & Williams, 2015).) have shown that preschoolers are capable of understanding and engaging in sustainable practices, and that early education in these areas can have a positive impact on their attitudes and behaviors towards the environment. By incorporating meta-sustainability into preschool curriculums and daily routines, we can help shape a better future for our planet and for generations to come.

Recommendations

In the light of our research finding, it is recommended that educational institutions consider adopting and integrating metacognition into their curriculum for preschoolers in order to enhance learning experiences for sustainable behavior. Integrating sustainability concepts into various subjects across storytelling, songs, and laboratory activities may foster early sustainability awareness. For example, teachers may ask preschoolers to think how they can apply sustainability principles in real-life scenarios or encourage them to think about their thinking by asking reflective questions such as "Why do you think recycling is important?" or "What can we do to help the Earth? Furthermore, by promoting a think-aloud method, institutions and teachers can model metacognitive strategies by thinking aloud during activities, demonstrating children how to plan, monitor, and evaluate their actions related to sustainability. Finally, even at a young age, children can draw or use simple words and sentences to reflect on what they learned and how they feel about sustainability activities, so institutions may be recommended towards the use of a reflective drawing or word-based journal on sustainability concepts.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors..

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The Relationship between School Happiness and Digital Game Addiction

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Abstract

The purpose of this research is to examine the relationship between primary school students' school happiness and digital game addictions. The study group of this research, which was designed in the relational survey model, consists of 204 fourth-grade primary school students studying in the Pendik district of Istanbul. In the research, the "School Happiness Scale for Primary School Children" developed by Ozdemir et al. (2021) and "The Digital Game Addiction Scale" which was developed by Lemmens, Valkenburg & Peter (2009) and adapted into Turkish by Yalçın-Irmak & Erdoğan (2015), and later whose validity and reliability analyzes were made for primary school children by Oral and Arabacıoglu (2019) were used. According to the research findings, it was found that the students' school happiness was at a moderate level and their digital game addiction was at a high level. Students' school happiness levels and digital game addiction levels do not show significant differences according to their genders. Similarly, the digital game addiction levels of students do not differ statistically according to the gender of their teachers, but the school happiness levels of students with female teachers are statistically significantly higher than those with male teachers. On the other hand, while the digital game addiction levels of the students do not differ significantly according to the school success of the students, the school happiness levels of the students with medium school success are significantly higher than the students with low or very high school success. According to another finding obtained from the research, there is a negative, low, and significant relationship between students' school happiness levels and digital game addiction levels. As a result of the regression analysis, it was seen that school happiness was a significant predictor of digital game addiction. School happiness explains 3% of digital game addiction.

Introduction

The contemporary understanding of education, which is based on the holistic development of the child, aims to provide children with good educational services so that they can acquire the knowledge and skills they may need, enjoy life and develop coping skills (Ozdemir et al., 2021). The positive psychology approach, which emphasizes character strengths and positive aspects of the person, emphasizes that children's experiencing more positive emotions such as happiness will be a protective and developmental factor in their lives (Duckworth et al., 2005). Happiness, which consists of the cognitive and emotional evaluation of life, can be defined as the sum of pleasant moments in life (Lucas & Diener, 2009; Veenhoven, 2008). According to well-being theory, happiness is one of the components of well-being (Seligman, 2011). School happiness is defined as experiencing positive emotions at school (Lyubomirsky et al., 2005).

When we look at the definitions of happiness for childhood, it is seen that children define happiness through positive emotions such as spending time with family and friends, participating in fun activities, being academically successful, helping others, and the absence of violence (Giacomoni et al., 2014; Nairn et al., 2011; Thoilliez, 2011). When we look at the definitions of happiness of school-age children, it is seen that they define happiness as meeting their psychological needs and expectations, establishing good relationships with their teachers and other friends, having a good school environment, creating a suitable environment where they can realize themselves and establishing effective social relationships (Engels et al., 2004; Konu et al., 2002). Students' subjective well-being at school is defined in terms of the feelings they experience at school and how they evaluate these feelings. As students feel good and have a good time at school, they become happier, and accordingly, school satisfaction increases (Engels et al., 2004). Happiness in the school environment enables students to increase their academic achievement, communicate better with their peers, and cope with stressful situations more easily (Bird & Markle, 2012; Sezer & Can, 2019; Yucel & Vogt-Yuan, 2016). All these suggest that school happiness is an important variable for student well-being (Engels et al., 2004). In this respect, determining the variables related to school happiness can make important contributions for teachers and practitioners (Ozdemir et al., 2021).

School happiness is thought to be important for students to be academically successful, to have high subjective well-being, and to follow their developmental processes successfully. Studies have shown that students who are happy at school have higher attendance rates and get higher grades (Schonert-Reichl & Lawlor, 2010). In addition, a child's happiness at school has a positive effect on mental health (Weissberg et al., 2015). When children move away from positive emotions such as happiness and experience negative emotions including pressure, they may turn to digital games, which are thought to be relaxing, to escape from them (Young, 2009). On the other hand, it is known that playing games can make people addicted as a result of being seen as a means of passing time (Kim et al., 2008).

Technological developments affect individuals of all ages to a great extent and one of the most basic effects it brings to children's lives is the concept of digital games (Erboy & Akar- Vural, 2010). Digital games, which are played using various technologies, created using many different software, and designed by considering technological content, are classified as console games, computer games, and online games (Gokcearslan & Durakoglu, 2014). The fact that visuality is more prominent in digital games and players can easily access the games whenever they want has caused digital games to be preferred more than traditional games (Ceylaner & Yanpar- Yelken, 2017). In addition, studies show that digital game addiction is a threat to adolescents and children (Ministry of Health, 2018).

Looking at the studies, it is known that digital games have many harms in general, but they negatively affect the cognitive, affective, and social development of children, especially those in the development process (Hazar & Hazar, 2017). When we look at the harms of these games, it is possible to isolate children, disconnect them from real life, normalize the sense of violence learned from game content by generalizing it to other areas of life, postpone basic needs such as nutrition, sleep, and toilet as a result of hours of sitting and playing games, experience physical discomfort due to long-term and unhealthy sitting styles, and perhaps most importantly, become addicted to games (Arslan et al., 2014; Griffiths & Meredith, 2009; Hazar & Hazar, 2017; Smith, 2004; Torun et al., 2015). Among all these negative consequences, addiction is perhaps the one that needs to be emphasized the most, and the possibility of digital game addiction in children may increase because the negative consequences of addiction are not fully known, especially in technological conditions that continue to develop, and the formation of environments that may increase children's susceptibility to digital game addiction (Hazar & Hazar, 2017).

Digital game addiction is defined as an individual's obsessive playing of digital games, i.e. computer games, despite causing social and emotional problems and the inability to control this situation (Pallese et al., 2015). Studies have shown that living in a negative family environment encourages stress and negative emotions and that people with negative affect prefer to distance themselves from their real emotions by escaping from the pressures they face in real life (Baturay & Toker, 2015; Sela et al., 2020). This can be shown as one of the reasons for using digital games to cope with the undesirable effects of the external environment (Shi et al., 2019). On the other hand, while examining digital game addictions in the literature, it is thought that examining how variables such as happiness, one of the concepts of positive psychology, are related to game addiction may be beneficial within the scope of preventive services. In a study, how game addiction is affected by protective variables such as subjective well-being was examined and the results showed that there was a negative relationship between online game addiction and subjective well-being, and a positive relationship between happiness and life health and subjective well-being (Chang, 2023). Another study shows that people with low subjective well-being may be more likely to engage in certain leisure activities such as online games to increase their happiness and life health (Nowland et al., 2017). In addition, the seriousness of seeing digital games as a coping tool for mental health (Cho et al., 2020) leads us to examine the variables that will protect individuals especially students from digital game addictions. Another study examined the effect of subjective well-being on online game addiction and found a negative relationship between subjective well-being and digital game addiction (Chang, 2023). In another study, it was observed that high levels of digital game addiction were associated with low psychological happiness (Goh et al., 2019). In another study examining the relationship between secondary school students' happiness levels and digital game addiction levels, it was observed that there was a negative relationship between students' happiness levels and digital game addiction (Cengiz et al., 2020).

The World Health Organization (2018) has shown that digital game addiction negatively affects academic and personal performance. On the other hand, positive emotions that students experience at school, being happy in their lives at school increases school happiness and can contribute to meeting the psychological needs of the students and distract them from undesirable behaviors (Engels et al., 2004). In this context, examining the protectiveness of increased school happiness in decreasing students' digital game addiction may contribute to the field. Despite all these, we have not come across a study that examines the relationship between school happiness and digital game addiction in primary school children. Based on these considerations, this study aimed to examine the relationship between school happiness and digital game addiction in fourth-grade primary school students. In line with this general purpose, answers to the following questions were sought in the study.

1. What are students' levels of school happiness and digital game addiction?
2. Do students' school happiness and digital game addiction show a significant difference according to gender variables?
3. Do students' school happiness and digital game addiction show a significant difference according to the school achievement variable?
4. Is there a statistically significant relationship between students' school happiness and digital game addiction?
5. Does school happiness predict students' school happiness and digital game addiction?

Method

Research Model

This study, which examines the relationship between students' school happiness and digital game addiction, was designed in the relational survey model, one of the quantitative research models. Survey models are research approaches that aim to describe a past or current situation as it exists (Karasar, 2010).

Study Group

The study group of the research consists of 204 primary school fourth-grade students studying in the Pendik district of Istanbul province in the 2022-2023 academic year. Personal information of the study group is presented in Table 1.

Table 1. Frequency and percentage values of personal information

Variable	Groups	Frequency (f)	Percentage (%)
Gender	Female	90	44
	Male	114	56
	Total	204	100
Gender of the teacher	Female	118	58
	Male	86	42
	Total	204	100
School success (Grade point average)	60 points and lower	45	22
	61-80 points	96	47
	81 points and higher	63	31
	Total	204	100

As seen in Table 1, there were 90 (44%) female and 114 (56%) male students in the sample group, totaling 204 students. Of the teachers of the students participating in the study, 118 (58%) were female and 86 (42%) were male. When the year-end grade point averages of the students were analyzed, 45 (22%) had a grade point average of 60 points or less, 96 (47%) had 61-80 points, and 63 (31%) had 81 points or more.

Data Collection Tools

The data collection tool consists of three parts. The first section includes questions to learn the personal information of the participants. The second and third sections include the "School Happiness Scale for Primary School Children" developed by Ozdemir et al. (2021) and the "Digital Game Addiction Scale" developed by Lemmens, Valkenburg & Peter (2009) and adapted into Turkish by Yalcın-Irmak and Erdogan (2015), and then the validity and reliability analyses were conducted again by Oral and Arabacıoglu (2019) for primary school children.

School Happiness Scale for Primary School Children

The "School Happiness Scale for Primary School Children", which measures the school happiness levels of primary school students, was developed by Ozdemir et al. (2021). The total variance explained by the scale consisting of 4 items of 3-point Likert type and one dimension is 47.38%. In addition, the results of the confirmatory factor analysis revealed that the model showed a good fit ($\chi 2/sd = 1.87$, $p<.001$; CFI = .99, TLI = .98, RMSEA = .05). Croanbach's Alpha (α) reliability coefficient of the scale was found to be .61.

Digital Game Addiction Scale

The "Digital Game Addiction Scale", which measures students' digital game addiction levels, was developed by Lemmens, Valkenburg and Peter (2009). The adaptation study of the scale into Turkish was conducted by Yalcın-Irmak and Erdogan (2015), and then the validity and reliability analyses were conducted again by Oral and Arabacıoglu (2019) for primary school children. The total variance explained by the 4-point Likert-type scale consisting of 6 items and a single dimension is 46.23%. The confirmatory factor analysis results revealed that the model showed a good fit ($\chi 2/df=2.17$ $p<.01$; RMSEA= .06; GFI= .98; AGFI= .95; CFI=.98; NFI= .96; SRMR= .039). Croanbach's Alpha (α) reliability coefficient of the scale was found to be .76.

Data Collection, Processing, and Analysis of Data

The necessary legal permissions were obtained from the students who constituted the study group of the research before starting data collection. Then, the data were collected by delivering the link to the online form containing the data collection tools to the students who voluntarily participated in the study by the researchers. The data from 204 scales filled out by the participants through the sent link were included in the analysis. The collected data were analyzed using the SPSS 25.0 program. Before starting the analysis, it was examined whether the collected data met the unidirectional and multidirectional normality assumptions. George and Mallery (2003) state that if the skewness and kurtosis coefficients are within ±2, the distribution of the data meets the normality assumption. Based on this information, the skewness and kurtosis values of the data were examined and it was concluded that the scores of the School Happiness Scale (-,212 to -,830) and Digital Game Addiction Scale (-,174 to -,024) were within the normal distribution limits.

In the analyses, the significance of the difference between the averages was tested at a .05 level. In the interpretation of the arithmetic averages for the 3-point Likert-type scale, the range of 1.00-1.66 was considered as "never", 1.67-2.33 as "sometimes" and 2.34-3.00 as "always". For the 4-point Likert-type scale, the range of 1.00-1.74 was considered as "never", the range of 1.75-2.49 as "rarely", the range of 2.50-3.24 as "sometimes" and the range of 3.25-4.00 as "often" in the interpretation of arithmetic averages. In the interpretation of the correlation analysis, the range of .00-.30 was accepted as "low", .31-.70 as "medium" and .71-1.00 as a "high" level relationship (Buyukozturk, 2011). Descriptive statistics, t-tests, one-way analysis of variance, correlation analysis, and regression analysis were used to analyze the data.

Findings

The arithmetic mean, standard deviation and skewness-blankness values of students' school happiness and digital game addiction levels are presented in Table 2.

Table 2. Arithmetic mean, standard deviation, and skewness- kurtosis values of the variables of the study

Variable	$\bar{x}$	Sd	Skewness	Kurtosis
1. School happiness	1,96	,77	-,21	-,83
2. Digital game addiction	3,04	,64	-,17	-,02

When Table 2 was examined, it was found that the student's school happiness level ($\bar{x}$=1,96) was medium and their digital game addiction level ($\bar{x}$=3,04) was high. An independent group t-test was conducted to determine whether the school happiness scale and digital game addiction scale scores of the students constituting the sample group showed a significant difference according to the gender variable. As seen in Table 3, there was no significant difference between the school happiness ($t= .16$; $P>.05$) and digital game addiction ($t= -85$; $P>.05$) scores of the groups according to the gender variable.

Table 3. Independent groups t test results according to gender variable

Variable	Groups	n	x̄	Sd	Se	*t* Test *t*	Df	*p*
School Happiness	Female	90	1,97	,57	,06	,16	202	.873
	Male	114	1,96	,60	,06			
Digital Game Addiction	Female	90	3,01	,42	,04	-.85	202	.398
	Male	114	3,06	,42	,04			

A one-way analysis of variance was performed to determine whether the school happiness scale and digital game addiction scale scores of the sample group showed a significant difference according to the school achievement variable.

Table 4. One-way analysis of variance (ANOVA) results according to school achievement variable

Variable	Groups	n	x̄	Sd	Source of Variance	Sum of Squares	df	Mean of Squares	F	p	LSD
School Happiness	Low	45	1,79	,67	Between Groups	3.605	2	1.802	5.434	,005	
	Middle	96	2,10	,58	Within Groups	66.663	201	,332			2-1
	High	63	1,88	,50	Total	70.268	203				2-3
	Total	204	1,96	,59							
Digital Game Addiction	Low	45	3,07	,34	Between Groups	.122	2	.061	.342	.711	
	Middle	96	3,01	,43	Within Groups	35.898	201	,179			
	High	63	3,06	,46	Total	36.020	203				
	Total	204	3,04	,42							

As seen in Table 4, no significant difference was found between the digital game addiction (F= .342; p>.05) scores of the groups according to the school achievement variable. However, a significant difference was found between the school happiness scores of the groups according to the school achievement variable (F= 5.434; p<.01). Post hoc analysis was conducted to determine which groups this difference was between. For this, firstly, it was examined whether the variances were homogeneous. As a result of the Levene test, it was seen that the variances were not homogeneous. Therefore, LSD analysis was conducted. The analysis revealed that the significant difference in the school happiness score was in favor of students with moderate school achievement. In other words, students with moderate achievement are happier at school than students with high and low achievement.

Relationships between Variables

The relationships between the dependent and independent variables of the study are presented in Table 5.

Table 5. Relationships between Variables

		Digital game addiction
School Happiness	r	-,157*
	p	,025

**p*<.05; *N*=204

As a result of Pearson correlation analysis, it was found that there was a negative, low, and significant relationship (r= -.157; p<.05) between students' school happiness levels and digital game addiction levels.
Simple linear regression analysis was performed to examine the effect of students' school happiness levels on their digital game addiction levels and the results are presented in Table 6.

Table 6. Simple linear regression analysis results for the prediction of digital game addiction scale

Model	B	Std. E.	β	t	p	R	R^2	F	p
Constant	3.260	.102		31.997	.000				
Digital Game Addiction	-.112	.050	-.157	-2.261	.025	.157	.025	5.113	.000

It was found that students' school happiness levels were effective on their digital game addiction levels. School happiness explains approximately 3% of the variance of digital game addiction [$F_{(1,202)}$= 5.113; p<0.05]. When Table 6 is analyzed, the coefficient of school happiness is B= -.112. This shows that an increase of 1 unit in students' school happiness causes a decrease of -.112 units in students' digital game addiction. According to the regression analysis results, the regression equation predicting the digital game addiction variable is as follows:

$$\text{Digital Game Addiction} = (-.112 \text{xSchool Happiness}) + 3{,}260$$

Results and Discussion

The study aims to examine the relationship between school happiness and digital game addictions of primary school students. According to the research findings, it was found that students' school happiness was at a medium level and their digital game addiction was at a high level. In a study examining the digital game addictions of primary school students, it was found that the digital game addiction levels of third graders were higher than those of fourth graders (Kose, 2023). In the study conducted by Ozturk et al. (2020), the average scores obtained from digital game addiction of fourth-grade students were found to be at a low-risk level. In another study examining the digital game addiction of secondary school students, it was observed that students were in the low-risk group in terms of game addiction, while the digital game addiction levels of students differed in favor of male students (Bircan & Oner, 2022). It is thought that the differences in the results obtained may be due to the different characteristics of the sample groups.

According to another result obtained from the study, students' school happiness levels and digital game addiction levels do not show significant differences according to their gender. Looking at the literature, studies show that digital game addiction does not differ according to gender variables (Kim et al., 2008; Homer et al. 2012; Musluoglu, 2016). However, these studies are more limited than the others. In a study conducted with Generation Y, it was observed that the digital game addiction levels of boys were higher than girls (Akkaya et al., 2021). In another study, the digital game addiction of males was found to be higher than females (Cengiz et al., 2020). Many studies show that digital game addiction is higher in male students compared to female students (Bonannoa & Kommers, 2005; Kawabe et al., 2016). The reason why digital game addiction is seen more in male students is that the game content is designed to appeal to men and the reward and addiction parts of the brain structure of men are faster (Griffiths, 2008; Ogel, 2012). Therefore, although there are studies supporting the findings obtained from the research, it can be said that it does not support the general literature. When the studies between students' happiness levels and gender are examined, it is seen that the results obtained from this study are similar to the literature and happiness does not change according to gender (Cihangir-Cankaya & Meydan, 2018; Mahon et al., 2005).

According to a result obtained from the study, while the digital game addiction levels of the students did not show a significant difference according to the school achievement of the students, the school happiness levels of the students with moderate school achievement were significantly higher than the students with low and very high school achievement. In another study examining the relationship between school achievement and happiness, the happiness levels of students with low academic achievement were also found to be low (Certel et al., 2015). In Arslan's (2021) study with middle school students, it was found that there was a significant negative relationship between digital game addiction and a sense of responsibility. Gentile et al. (2011) concluded that individuals with digital game addiction exhibit low school performance. Kubey et al. (2001) reported that university students with problematic internet use experienced problems such as loneliness, staying up late and fatigued, decreased academic performance, and postponing their responsibilities. These results show that gaming addiction can negatively affect academic achievement.

According to another finding obtained from the study, there is a negative, low, and significant relationship between students' school happiness levels and digital game addiction levels. As a result of the regression analysis, school happiness was found to be a significant predictor of digital game addiction. School happiness explains 3% of digital game addiction. It was observed that the results obtained from this study showed that the rate of school happiness explaining digital game addiction was low and a different result was obtained from the related literature. On the other hand, when other studies in the literature are examined, it was seen that happiness predicted digital game addiction significantly in a study conducted with secondary school students and it was stated that a decrease in students' happiness levels should be considered as a factor that may increase digital game addiction (Cengiz et al., 2020). In another study examining the relationship between subjective happiness and digital game addiction, a negative relationship was found between digital game addiction and subjective happiness (Odabaşı, 2016). In another study conducted with adolescents, it was observed that digital game addiction had a negative relationship between happiness and the meaning of life (Kaya, 2021). It is thought that the results obtained are similar to the literature, but more studies are needed in this field.

Recommendations

The study is limited to the data obtained from this sample and the answers given by the students. The fact that the sample consists of primary school students may lead to various limitations in terms of their ability to understand and answer the questions correctly. In this respect, it is thought that there is a need to conduct more studies in the same age group, collect data from their teachers and families, and examine them in more detail with comparative and longitudinal studies. To obtain outputs on how school happiness levels of primary school students will affect their digital game addictions, it is recommended to collect qualitative data from students, parents, and teachers through interviews. On the other hand, schools should be made more interesting for children, considering that creating an environment where children will be happy at school from an early age will increase school happiness and increasing school happiness will reduce digital game addiction. In addition, it is thought that more studies examining the relationship between school happiness and digital game addiction are needed.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

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Self-control and Problematic Social Media Use: A Meta-Analysis

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Abstract

Failure to exercise self-control is one of the leading causes of substance and behavioral addictions. Problematic social media usage (PSMU), a type of behavioral addiction, has become an increasingly serious problem with a significant impact on the lives of individuals of all generations. Therefore, it is crucial to understand the underlying mechanism of PSMU to effectively address the issue. This study performed a meta-analysis, which systematically synthesized existing research in the field, to establish the current empirical state of the relationship between self-control and PSMU. The study included 57 independent samples that met the inclusion and exclusion criteria (N = 29.576). The analysis results indicated a moderate negative association between self-control and PSMU (r = -.29). Furthermore, the moderator analysis outcomes suggested that the association between self-control and PSMU did not differ significantly based on variables such as developmental period, educational stage, geographic region, and publication status. The study's findings are expected to inspire future investigations and therapeutic approaches.

Introduction

Social media use has transformed into an essential element of everyday life, thanks to technological advancements in the digital age (Cheng et al., 2021; Yıldız Durak, 2020). People can easily visit social networking sites from portable tools like laptops, tablets, or smartphones whenever and wherever they want (He et al., 2021; Hofmann et al., 2017). They take part in a variety of actions on social media sites, including social interaction (i.e., establishing new relationships and keeping in touch with existing social members of the network), entertainment, shopping, marketing, and professional purposes (Huang, 2022; Hyun et al., 2022; Lyvers et al., 2018; Utz & Breuer, 2016). Additionally, through these platforms, they access information and news, give information about themselves or share posts that express their political and social view, and receive feedback from their followers (Boulianne, 2015; Pempek et al. 2009). Online forums, blogs, and sites for social networking websites such as Instagram, WhatsApp, Twitter, and Facebook are examples of popular social media platforms (Hawn, 2009; Huang, 2022; Sharifi Bastan, 2022).

Social networks are currently used by billions of people worldwide across numerous platforms (Sharifi Bastan, 2022). The number of people using social media is growing every day, and the COVID-19 pandemic has increased this growth (Kemp, 2021; We Are Social, 2022). Nowadays, 4.76 billion people utilize social media globally or a little under 60% of the world's population. Even worse, the average internet user now spends more than 2.31 hours per day on social media, which is longer than they typically spend on sleeping, eating, and exercising (We Are Social, 2023). This dramatic rise in usage of social media implies problematic social media use (PSMU), which resembles addiction in many ways (Lyvers et al., 2018). PSMU is described as uncontrolled use of social media (such as compulsive or addicted use) that has an adverse impact on one's personal, social, familial, and career life (Schou Andreassen & Pallesen, 2014; Sun & Zhang, 2020). PSMU is referred to by a variety of terms, such as social media addiction (Cheng et al., 2021), social networks use disorder (Wegmann & Brand, 2019), disordered social media use (Lyvers et al., 2018), social media dependence (He & Yang, 2022), and compulsive social media use (Aladwani & Almarzouq, 2016). Because it is a broader concept, the term problematic social media use was selected for this research.

PSMU has been recognized as a type of behavioral addiction that shares features with other excessive or compulsive non-drug behaviors including internet addiction, video game addiction, compulsive shopping, exercise addiction, and workaholism (Grant et al., 2010; Griffiths, 2013). Similar to addictions caused by substances, it appears that some PSMU sufferers experience the typical signs of addiction, such as mood changes, salience, tolerance, and symptoms of withdrawal (Griffiths, 2013). The negative impact of PSMU on mental health has been extensively studied in the literature (e.g., Cerniglia et al., 2019; Huang, 2022; Przepiórka et al., 2021). Studies have also shown that PSMU can damage individuals' well-being and psychosocial functioning (Cudo et al., 2020; Koç et al., 2023; Meier et al., 2016). Accordingly, it's crucial to understand the underlying reasons for PSMU.

One of the most difficult desires to withstand for social media users is the urge to use these platforms (Hofmann et al., 2017). They therefore commonly fail to exercise self-control (Du et al., 2018). In the literature, self-control failure has consistently been identified as the primary cause of PSMU (Du et al., 2018; Koç et al., 2023; Üztemur & Dinç, 2022). Previous research has found a positive association between PSMU and low self-control (Barbar et al., 2021; Cudo et al., 2020; Kandee et al., 2022; Wang et al., 2022). Studies, however, have shown inconsistent findings; they have discovered a low, moderate, or high association between self-control and PSMU. Furthermore, no meta-analysis study was realized even though there are numerous studies investigating the link between self-control and PSMU. This study aimed to realize the listed objectives below to fill in these significant gaps in the literature:

(i) to synthesize empirical evidence on the relationship between self-control and PSMU,
(ii) to explore potential moderator roles of developmental period, educational stage, geographic region, and publication status in this relationship.

Literature Review

The Relationship between Self-Control and Problematic Social Media Use

Since self-control research is addressed by various theoretical traditions, a variety of definitions have been produced in the literature and are used interchangeably with a number of terms (Duckworth & Kern 2011; Hofmann et al., 2017; Şimşir Gökalp & Haktanir, 2022). Some concepts used interchangeably with self-control include self-discipline, self-regulation, conscientiousness, and impulsivity (Baumeister et al., 2007; Duckworth & Kern, 2011; Duckworth et al., 2019; Şimşir & Dilmaç, 2021). Although there is controversy regarding the nature and characteristics of self-control (Duckworth et al., 2019; Gillebaart & de Ridder, 2015; Şimşir & Dilmaç, 2021; Şimşir Gökalp & Haktanir, 2022), the following definition is the most typical: the capacity to manage one's responses such as emotions, impulses, thoughts, and actions in order to accomplish personally valued long-term objectives (Baumeister et al., 2007; Duckworth et al., 2019; Metcalfe & Mischel, 1999). People commonly need self-control when confronted with self-control dilemmas, which entail the resolution of a conflict between two distinct behavioral inclinations. The struggle between the want to indulge in a bag of chips in front of the TV after a difficult day and the desire to eat healthily is a typical instance of this dilemma (Gillebaart & de Ridder, 2015). The following example may be employed to illustrate this dilemma when it comes to social media use: The decision to study for a math exam or to browse the newest Instagram photographs is a self-control dilemma for a student. While browsing through Instagram may provide immediate pleasure, it lacks long-term value. On the other hand, studying for a math test may not be enjoyable at the moment, but it holds long-term importance (Duckworth et al., 2019). In sum, it can be quite difficult for people to maintain self-control when they are tempted to use social media.

Hofmann et al. (2017) suggested that three features of communication and media technologies, especially instant satisfaction, habituated usage, and ubiquitous accessibility, raise the probability that users will succumb to temptation. Furthermore, a fourth factor that appears to be crucial for exercising self-control concerning mobile information and communication technologies like mobile phones is the attention requirements of messages and push notifications. In other words, social media platforms have features that can easily activate impulses. Duckworth et al.'s (2014; 2019) process model of self-control outlines the generation of impulses and, in connection, the various approaches to managing these impulses. According to this model, impulses are inclinations to act that gradually develop and can be reinforced or weakened through a recursive sequence involving situational factors, attentional focus, evaluation, and response. Initially, a person comes across a specific circumstance (e.g., the student goes into his dormitory), then he/she focuses on specific aspects of this circumstance in a particular manner (e.g., directs attention toward his buzzing smartphone rather than their math books), and subsequently evaluates the circumstance in a way (e.g., considers how succeeding in mathematics will make it possible to pursue a career as a doctor later in life.) that ultimately produces an urge or inclination to respond (e.g., this idea encourages the student to grab a pencil and start working). The progression of events in this sequence only goes in one direction, both in terms of time and cause-effect relationship. The earlier stages have a causal impact on the later stages, but the opposite is not true.

Previous studies have well-documented the importance of self-control in media activities (Panek, 2014; Turel & Qahri-Saremi, 2016; Yıldız Durak, 2020; Zahrai et al, 2022). For instance, the research by Ekşi et al. (2019)

determined that undergraduates with poor self-control and a tendency to procrastinate are more prone to acquiring social media addiction. Yıldız Durak (2020) reported that failure to exercise self-control resulted in adolescents using the internet more problematically, which in turn, enhanced PSMU. According to the meta-analysis conducted by Li and colleagues (2021), there is a positive correlation between impulsivity and internet addiction, while a negative correlation exists between self-control and internet addiction. Furthermore, Du et al. (2018) created a scale called the Social Media Self-Control Failure Scale to evaluate how frequently individuals succumb to social media enticements.

The Role of the Developmental Period

Regarding the association between PSMU and age, there is no agreement among the research in the literature. For instance, some studies highlighted that emerging adults (Holmgren et al., 2017; Koç et al., 2022) and adolescents (Cerniglia et al., 2019; Yıldız Durak, 2020) are more prone to PSMU, whereas others have found no such correlation (Koc & Gulyagci, 2013) or indicated that older users (Barbar et al., 2021) have a greater tendency to engage in such behavior. On the other hand, according to the Digital 2023 report, social media users between the ages of 16 and 24 utilize 7.7 platforms per month on average, while users between the ages of 25 and 34 use 7.9. With aging, these numbers are decreasing (We Are Social, 2023)

When the current literature is reviewed in terms of self-control, there is no consensus regarding how self-control changes with age. According to Gottfredson and Hirschi (1990), self-control is a stable disposition that does not alter throughout life. On the other hand, many researchers asserted that self-control develops throughout life (Murray & Rosanbalm, 2017; Tao et al., 2014; Tarullo et al., 2009; Zondervan-Zwijnenburg et al., 2020). Tao and colleagues investigated the self-control levels of 2135 children between the ages of three and nine. The research's findings showed that levels of self-control significantly increased, particularly between the ages of five and six. Additionally, the development of self-control between the ages of 13 and 19 was investigated in the longitudinal study by Zondervan-Zwijnenburg et al. (2020). The researchers concluded that self-control improved during adolescence.

The development of self-control capacity is dependent on brain growth. Self-control-related brain areas are not sufficiently formed at birth and steadily mature during development (Tarullo et al., 2009). The prefrontal cortex is a crucial area for self-control and is placed directly behind the forehead (Gajos & Beaver, 2016; Tarullo et al., 2009). Several researchers suggested that doing intervention studies with high school and university students may be more effective because the brain regions responsible for self-control develop with age (e.g., Duckworth et al., 2016). In this regard, this study hypothesized that the developmental period (adolescence, adulthood) may have a moderator role in the relationship between self-control and PSMU.

The Role of Education Stage

The majority of studies on problematic social media use have been conducted with student participants. Studies have put forth that middle school (Üztemur & Dinç, 2022), high school (Cerniglia et al., 2019), or college students (Koç et al., 2022) may be at higher risk for PSMU than other groups. However, to the best of the authors' knowledge, there is no evidence on which education stage has a higher frequency of PSMU among students. In a similar vein, studies have noted that self-control improves with age (Tarullo et al., 2009), but no research on how self-control varies with the education stage has been identified. Based on these limitations, this study investigated whether the level of education affected the association between self-control and PSMU.

The Role of Geographic Region

PSMU is influenced by both individual and contextual factors (Marino et al., 2018). Cross-cultural changes in PSMU have been identified by previous studies. The study carried out by Cheng and colleagues (2021) to investigate the incidence of social media addiction in 32 regions has yielded startling findings. According to analyses by geographic location, it is most prevalent in Africa (37%), followed by Asia (31%) and the Middle East (29%). It was found that Western/Northern Europe (8%) scored last. In sum, collectivist nations are more prone to PSMU than individualist nations. When we review meta-analysis studies in the literature, Huang (2022) found that the moderator role of the country in the relationship between self-control and life satisfaction is significant. According to the findings, the link was weak for the US and medium for Turkey. In their investigation of the country's effect on the relationship between problematic Facebook use and distress, Marino et al. (2018) reported that studies from Western countries were more likely to find a correlation than those from Asian nations. Furthermore, Li et al.'s (2021) research showed that individuals in East Asia had a more adverse relationship with self-control and internet addiction than individuals in Western Europe and North America. In this context, the moderator role of the geographic region may moderate the relationship between self-control and PSMU in this study.

Publication Status

The heart of competent meta-analysis studies is comprehensive literature reviews. Publication bias endangers systematic reviews and meta-analyses (Şen & Yıldırım, 2020). Publication bias occurs when the studies included in a particular analysis are not representative of the entire pool of relevant studies, which can be attributed to factors such as their availability and accessibility (McShane et al., 2016). The absence of publications such as theses and conference presentations from the analysis is the primary cause of publication bias. It is crucial to resolve these problems in order to eliminate the possibility of publication bias (Şen & Yıldırım, 2020). Therefore, the research included the theses that were published and examined the moderator role of publication status (e.g., article, and thesis).

Method

This study aimed to determine the mean effect size of the relationship between self-control and PSMU using meta-analysis. Meta-analysis allows combining different research results in a valid/effective way to obtain holistic results (Tsagris & Fragkos, 2018). While conducting the meta-analysis, the guidelines of the American Psychological Association (2010) and the PRISMA guidelines of Moher, Liberati, Tetzlaff, Altman, and Prisma Group (2009) were followed.

Selection and Coding of Studies

The first literature search for the meta-analysis study was conducted in December 2022, and the complementary search was conducted in January 2023. The main searches were carried out in English language, and complementary searches were also conducted in Turkish. Both articles and theses were included in the scope of the study. In order to reach these studies, searches were carried out on Web of Science, EBSCO Host Google Scholar, PsycINFO, PsycARTICLES and ProQuest Dissertations & Theses Global databases ("self-control" OR "self control" OR "self-regulation" OR "self regulation" OR "self discipline" OR "self-discipline" OR impulse* OR "low self-control" OR "executive function" OR "delay of gratification" OR "delayed gratification") AND ("social medi*" OR "social network* site" *" OR SNS OR "online networking site*" OR "online social network*" OR instagram OR youtube OR facebook OR twitter OR snapchat OR whatsapp OR wechat OR tiktok) AND (addict* OR dependenc* OR problematic OR disorder OR misuse OR overuse * OR excess* OR compulsi* OR abuse OR patholog*). In the end, 1336 studies examining the variables in the research scope were recorded. The recorded studies were processed into a coding key created by the researchers. This coding key includes the study author, study type, developmental period, educational level, and geographic region.

When the studies processed in the coding key were examined, criteria were determined for the inclusion of the 1336 studies that were coded based on the theoretical foundations of the research for meta-analysis: (i) It must aim to determine the relationship between self-control and problematic social media use perceptions, (ii) Studies must be in the form of articles or theses (doctoral and master's theses), (iii) The data collection tools used in the research must be aimed at determining self-control/impulsivity and PSMU, (iv) The research findings must include sample size and correlation values or the necessary statistics to calculate these values. (v) The study must be conducted on normal participants (non-clinical). These criteria have also been used as exclusion criteria; studies that did not meet the identified criteria were not included in the study. In addition, there was no limitation in terms of publication year or age of participants in the searches.

After determining the inclusion and exclusion criteria, all complementary searches were performed with "advanced search". In addition, the references of the studies recorded in the first search were reviewed, and studies that could meet the inclusion criteria were also examined. Moreover, in studies where the correlation coefficient value (r) was not provided, the authors were contacted by email to request missing data, and the studies of authors who provided feedback were included in the research. In this context, 72 studies were found as a result of the first complementary search (December 2022), and no new studies on the subject were found as a result of the second complementary search (January 2023). After the complementary searches, a total of 72 studies were entered into the coding key. Based on the inclusion criteria, 57 (55 articles and 2 theses) of the 72 individual studies were included in the meta-analysis. The remaining 15 articles were excluded because they did not include/calculate the correlation between the variables. The flowchart of the search and review process according to PRISMA [Preferred Reporting Items for Systematic reviews and Meta-Analyses (Moher, Liberati, Tetzlaff, Altman and The PRISMA Group, 2009)], which explains the principles of reporting meta-analysis studies and was used throughout the study, is shown in Figure 1.

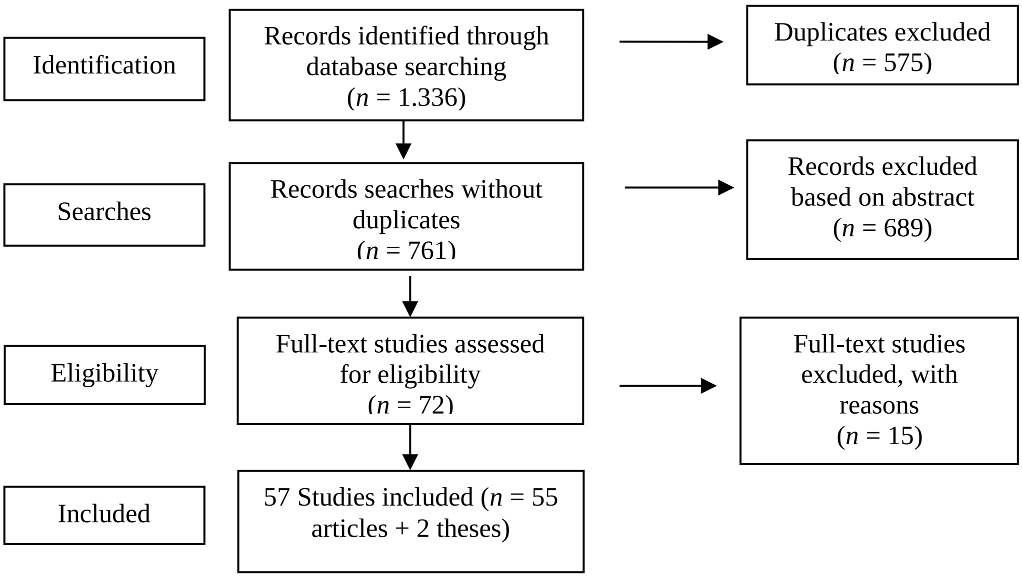

Figure 1. Flowchart of the search and review process

It is important that the studies included in the meta-analysis are searched correctly and checked by the coders in terms of validity-reliability-completeness (Stewart & Kamins, 2001). In this context, the studies were first searched by researchers from different fields (Guidance and Psychological Counseling, Educational Management) from the Department of Educational Sciences, and then the studies obtained were integrated and entered into the coding key created by the researchers. Thus, studies that met the inclusion criteria were taken into account. The data for these studies were independently entered into a second coding key by two researchers, and the intra-group correlation coefficient of the values was determined as .94. As a result of the systematic interviews carried out for the differences between the coded effect size values, all the data were correctly and completely coded (r = 1.00). In addition, the data related to the determined subgroups were added to the coding key independently by two researchers, and the intragroup correlation coefficient of these values was determined as .97. As a result of the systematic interviews conducted for the data belonging to the subgroups, all data were correctly and completely coded (r = 1.00).

Table 1. Characteristics of the studies included in the meta-analysis

Variable	**Category**	***N* (=57)**
Study Type	Article	55
	Thesis	2
Developmental period	Adolescent	11
	Adult	46
Education level	Middle school	3
	High school	8
	University	19
Geographic region	Europe	14
	East Asia	10
	South Asia	2
	South America	2
	North America	11
	New Zealand-Australia	3
	Middle East	12
	Interregional/International	3

Included Studies

57 studies were included in the meta-analysis regarding the relationship between self-control and PSMU. The total sample size of the studies included in the analysis is 29.576. The characteristics of the included studies are given in Table 1.

Model Selection

After determining the publication bias in the current meta-analysis study, the statistical model to be used in the calculation of the mean effect size was selected. There are two models of mean effect size in the traditional meta-analysis literature; fixed effects model and random effects model. The model "fixed effect", which assumes that the parameter measuring the effect size or experimental effect is the same in all studies. The model that allows this parameter to act as a random variable that takes different values from study to study is defined as the "random effects" model. If working with a single population, the "fixed effect" model should be used, and if working with multiple populations, the "random effects" model should be used (Sen & Yıldırım, 2020). In meta-analysis studies conducted in the field of social sciences, it is recommended to use random effects model for effect size analysis, since sample characteristics are affected by different parameters and mostly vary between effect sizes (Field & Gillett, 2010). The conditions for selecting the statistical model and the model selection should be determined prior to the analysis, taking into account the structure of the meta-analysis study to be conducted (Borenstein et al., 2007). In this context, it was decided to use the random effects model, considering the different cultural and demographic characteristics, scopes and designs of the samples of individuals of different ages and groups included in the meta-analysis.

Heterogeneity

After determining the mean effect size in meta-analysis, the heterogeneity distributions of the studies included in the analysis were examined. It is crucial to assess heterogeneity in meta-analyses since high heterogeneity may arise from the existence of different true effects in the data or the presence of more sub-group studies (Harrer et al., 2021). To control for inter-study heterogeneity, many methods have been recommended. The most commonly recommended ones are creating graphics (such as forest plots), obtaining Q-statistics, and calculating the I^2 value (Şen & Yıldırım, 2020). If the Q value exceeds the $\chi 2$ value calculated based on the degrees of freedom, it indicates that the average effect sizes are heterogeneous (Card, 2011). For I2, values of 25%, 50%, and 75% are considered to indicate low, moderate, and high heterogeneity, respectively (Higgin et al., 2003).

When heterogeneity is encountered in the studies included in the meta-analysis, the causes of heterogeneity can be examined depending on some characteristic features of individual studies, namely moderator (subgroup) variables. Features that may be related to heterogeneity between studies can be interpreted through moderator/subgroup analyses (Deeks et al., 2008). In the current meta-analysis, it was assumed that heterogeneity in the relationship between self-control and PSMU could be explained by study type, developmental period, educational level, and geographical region. In this context, subgroup analyses were conducted on the highlighted variables.

Interpretation of the Mean Effect Size Value

In meta-analysis studies, when variance is affected by correlation coefficients (Pearson r) (Borenstein et al., 2009) and the correlation values in the combined studies are close to each other, the Pearson correlation value is converted to Fisher's z-value for analysis (Makowski et al., 2019). In the present study, the correlation coefficients were first converted to Fisher z values for analysis. For the reporting/interpretation of relationships and confidence intervals, it was converted back to Pearson r after analysis. The mean effect size analysis was reported in the form of correlation (Pearson *r*) coefficient. Lipsey and Wilson (2001) suggest that the criteria that can be used for correlation are as follows: Small effect=0.10, medium effect=0.25, large effect=0.40. The differentiation status of the subgroups of the study type, developmental period, education level, and geographical region was determined by the $Q_{between}$ test, the χ^2 value determined according to the degree of freedom and the *p* value. Analysis of research data was performed with CMA v2 (Comprehensive Meta-Analysis Software Version 2).

Findings

Publication Bias Analysis

Before determining the average effect size of the relationship between self-control and PSMU, publication bias was examined. Publication bias was evaluated visually with the "funnel plot" and the "trim and fill method". The evaluation was made in terms of the relationship between self-control and PSMU. Figure 2-3 shows the funnel scatter plots.

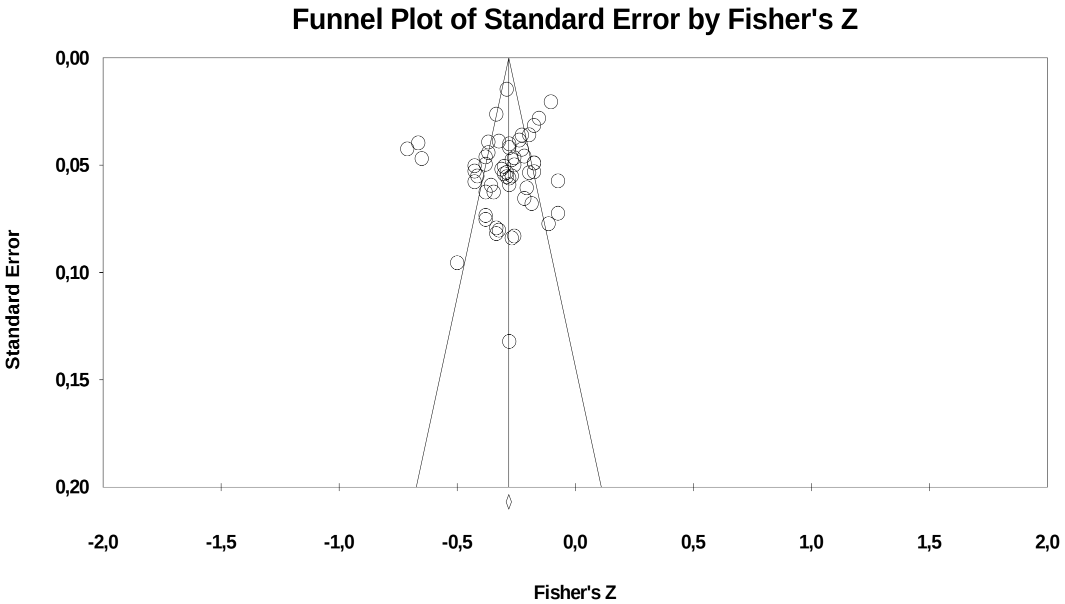

Figure 2. Funnel plot with observed studies only

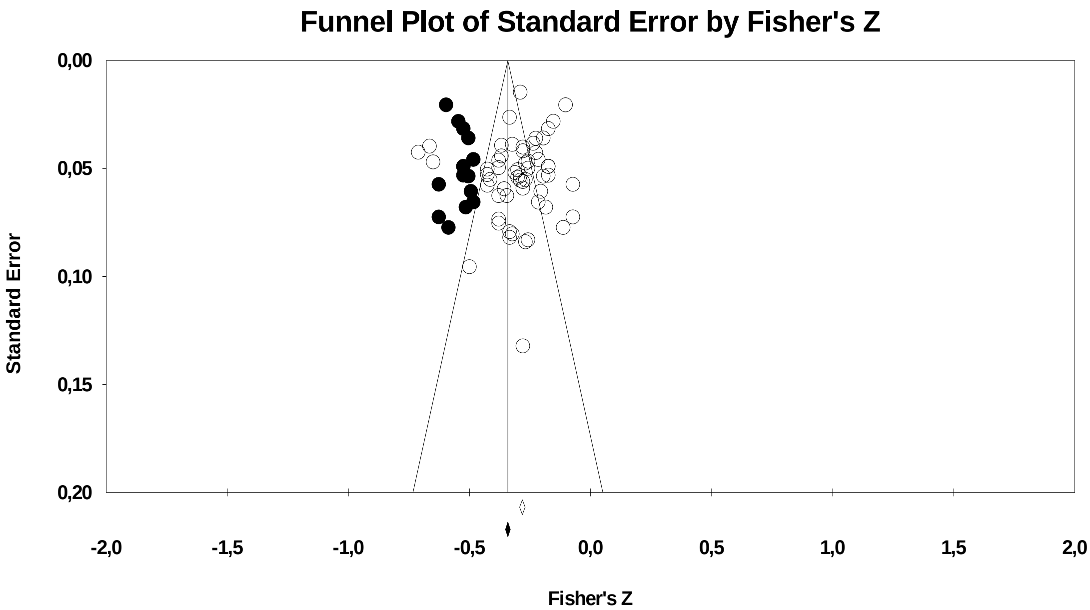

Figure 3. Funnel plot including filled (black dots) studies (Random-effects model-to the left of mean)

In order to assume that there is no publication bias according to the funnel scatter plot, the effect sizes are distributed symmetrically on both (right-left) sides of the standard error axis of the mean effect size (Borenstein et al., 2009). Additionally, in the funnel plot, large studies appear at the top of the graph and cluster around the average effect size, while smaller studies are located at the bottom of the graph (Şen & Yıldırım, 2020). When examined for publication bias, Figure 2 shows that the studies are clustered near the top of the graph, but the effect sizes are distributed relatively symmetrically around the standard error axis. Due to the subjectivity of the interpretations made about the symmetry of funnel plots (Card, 2011) and the difficulty in deciding whether there is publication bias only based on funnel plots (Pigott, 2012), different methods should also be examined. Empty circles in the funnel plot created according to the trim and fill method in Figure 2 show the studies included in the meta-analysis (existing), while the filled circles (with black dots) show the studies that should be included in the meta-analysis in order to reduce the publication bias (missing/added). According to Figure 3, the inclusion of 15 studies in addition to the existing studies in terms of the relationship between self-control and PSMU in the meta-analysis is sufficient to reduce publication bias. Considering the inclusion of 57 individual studies in the meta-analysis and other publication bias analyses regarding the relationship between self-control and PSMU, additional studies that could be included are negligible.

The trim and fill method may also reveal the new/corrected center of the funnel plot when conducting a meta-analysis that includes these studies (Duval & Tweedie, 2000). The trim and fill method helps both to reveal publication bias and to correct it (Sen & Yıldırım, 2020). According to Figure 2, it can be stated that there is no change in the center of the symbols. However, further analysis was performed using Orwin's fail-safe N analysis, Duval and Tweedie's trim and fill method, Egger's regression test, and Begg and Mazumdar's rank correlation method to obtain more information about publication bias (Table 2).

Table 2. Publication bias analyzes and results

Relationship Between Variables	**Orwin Safe N** (.01 Fisher *z*)*	**Duval and Tweedie** Trimed	Observed/Rectified	**Egger Test** (*p*)	**Begg and Mazumdar** (*p*)
Self-control and PSMU	5993	15	-.281/-.341	.17	.44

* .01 was taken as the criterion value.

According to Table 2, Orwin Safe N analysis indicates the number of studies required to reduce the mean effect size below a certain insignificant value (Orwin, 1983). In this framework, the large number of N indicates that the average relationship will not be zero if some studies are excluded, and the publication bias is very low (Sen & Yıldırım, 2020). In the current study, the fact that the N value is above the tolerance value ($N > 5k + 10$) formed by the number of effect sizes (Mullen et al., 2001) indicates that there is no publication bias. According to Duval and Tweedie trim-and-fill method, the inclusion of 15 individual studies thought to be incomplete in the meta-analysis study (added to the right of the funnel plot) shows that the mean effect size value is relatively reduced but not significantly differentiated. The fact that the results of the Egger and Begg and Mazumdar analyses are not statistically significant also indicates that there is no publication bias. The results of the publication bias analysis conducted for this meta-analysis indicate that the studies included in the meta-analysis on the relevant topic are sufficient and the internal validity of the mean effect sizes is high.

Mean Effect Size and Heterogeneity Analysis

In the context of the first question of the research, the mean effect sizes and heterogeneity test results of the relationship between self-control and PSMU are given in Table 3.

Table 3. Effect sizes (pearson r) and heterogeneity test results

Model	***k***	ES_{mean}	**S.E.**	***Z***	***p***	**%95 CI** Low. limit	Up. limit	***Q***	***df***	***p***
Fixed	57	-.275	.006	-48.283	.000	-.285	-.265	485.256	56	.000
Random	57	-.288	.018	-16.520	.000	-.319	-.257			

* k=Number of studies

Subgroup Analysis

In the context of the second research question, Table 4 presents the results of analogue ANOVA regarding the extent to which the mean effect size of the relationship between self-control and PSMU differs in terms of study type, developmental period, education level, and geographic region subgroups. The random effects model was used and reported accordingly because analyses were conducted to investigate the source of between-group variance.

Study name	Fisher's Z	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Assunçao & Matos, 2017	-0,224	0,036	0,001	-0,295	-0,152	-6,158	0,000
Awad et al., 2022	-0,172	0,049	0,002	-0,268	-0,075	-3,480	0,001
Barbar et al., 2021	-0,377	0,046	0,002	-0,468	-0,286	-8,110	0,000
Baþer et al., 2022	-0,224	0,043	0,002	-0,308	-0,140	-5,212	0,000
Bernal-Ruiz & Rosa-Alcázar, 2022	-0,662	0,040	0,002	-0,741	-0,584	-16,588	0,000
Blachnio & Przepiorka, 2016	-0,354	0,060	0,004	-0,471	-0,237	-5,936	0,000
Boer et al., 2022	-0,332	0,027	0,001	-0,384	-0,280	-12,480	0,000
Bouna-Pyrrou et al., 2018a	-0,070	0,073	0,005	-0,213	0,072	-0,964	0,335
Bouna-Pyrrou et al., 2018b	-0,100	0,021	0,000	-0,141	-0,060	-4,825	0,000
Burnell et al., 2016	-0,377	0,063	0,004	-0,500	-0,254	-5,995	0,000
Cerniglia et al., 2019a	-0,321	0,039	0,002	-0,397	-0,244	-8,191	0,000
Cerniglia et al., 2019b	-0,365	0,040	0,002	-0,443	-0,288	-9,245	0,000
Chen & Roberts, 2019	-0,070	0,058	0,003	-0,183	0,043	-1,216	0,224
Cudo et al., 2020a	-0,213	0,066	0,004	-0,342	-0,084	-3,240	0,001
Cudo et al., 2020b	-0,234	0,039	0,001	-0,310	-0,158	-6,062	0,000
Cudo et al., 2021	-0,172	0,032	0,001	-0,234	-0,109	-5,396	0,000
Davey et al., 2020	-0,255	0,050	0,003	-0,354	-0,157	-5,089	0,000
Du et al., 2018	-0,377	0,050	0,002	-0,475	-0,279	-7,557	0,000
Efrati et al., 2021	-0,213	0,046	0,002	-0,303	-0,123	-4,626	0,000
Ekþi et al., 2019	-0,424	0,051	0,003	-0,523	-0,325	-8,377	0,000
Fýrat, 2017	-0,277	0,132	0,018	-0,536	-0,017	-2,090	0,037
Foroughi et al., 2019	-0,424	0,053	0,003	-0,528	-0,320	-7,982	0,000
Fowler et al, 2020	-0,277	0,056	0,003	-0,387	-0,166	-4,914	0,000
Gugushvili et al., 2022	-0,332	0,082	0,007	-0,493	-0,171	-4,035	0,000
Guo et al., 2022	-0,288	0,056	0,003	-0,397	-0,178	-5,162	0,000
He & Yang, 2022	-0,192	0,036	0,001	-0,263	-0,121	-5,316	0,000
He et al., 2021	-0,182	0,068	0,005	-0,316	-0,048	-2,668	0,008
Holmgren & Coyne, 2017	-0,266	0,048	0,002	-0,360	-0,173	-5,576	0,000
Iranmanesh et al., 2021	-0,192	0,054	0,003	-0,298	-0,087	-3,573	0,000
Kandee et al., 2022	-0,709	0,043	0,002	-0,793	-0,625	-16,580	0,000
Khan et al., 2021	-0,277	0,059	0,004	-0,393	-0,160	-4,658	0,000
Khosravani et al., 2022	-0,424	0,058	0,003	-0,537	-0,310	-7,301	0,000
Khoury et al., 2019	-0,172	0,049	0,002	-0,268	-0,075	-3,484	0,000
Koessmeier & Büttner	-0,412	0,055	0,003	-0,520	-0,303	-7,435	0,000
Lee et al., 2022	-0,110	0,078	0,006	-0,263	0,042	-1,423	0,155
Lerema, 2021	-0,203	0,061	0,004	-0,322	-0,083	-3,331	0,001
Lyvers et al, 2020	-0,321	0,081	0,006	-0,478	-0,163	-3,978	0,000
Lyvers et al., 2019	-0,255	0,083	0,007	-0,419	-0,092	-3,065	0,002
Meier et al., 2016	-0,172	0,053	0,003	-0,276	-0,067	-3,216	0,001
Nicole Wilke et al., 2020	-0,277	0,040	0,002	-0,356	-0,198	-6,855	0,000
Orosz et al., 2016	-0,343	0,063	0,004	-0,466	-0,220	-5,453	0,000
Osatuyi & Turel, 2018	-0,332	0,080	0,006	-0,488	-0,176	-4,169	0,000
Panek, 2014	-0,255	0,047	0,002	-0,347	-0,164	-5,448	0,000
Pilatti et al., 2021	-0,365	0,044	0,002	-0,453	-0,278	-8,220	0,000
Przepiórka et al., 2021	-0,288	0,015	0,000	-0,317	-0,258	-19,281	0,000
Quinn, 2018	-0,266	0,084	0,007	-0,431	-0,101	-3,160	0,002
Rebecca & Blanca, 2019	-0,277	0,042	0,002	-0,359	-0,194	-6,575	0,000
Sahranç & Duç-Urhan, 2021	-0,266	0,055	0,003	-0,375	-0,158	-4,805	0,000
Savci et al., 2017	-0,377	0,074	0,005	-0,521	-0,232	-5,112	0,000
Sharifi Bastan et al., 2022	-0,288	0,054	0,003	-0,393	-0,182	-5,359	0,000
Ting & Essau, 2021	-0,377	0,076	0,006	-0,525	-0,229	-4,986	0,000
Turel & Qahri-Saremi, 2016	-0,299	0,054	0,003	-0,405	-0,192	-5,489	0,000
Üztemur & Dinç, 2022	-0,310	0,052	0,003	-0,412	-0,207	-5,930	0,000
Wang et al., 2022	-0,151	0,028	0,001	-0,207	-0,095	-5,311	0,000
Wegmann et al., 2020	-0,497	0,096	0,009	-0,685	-0,310	-5,192	0,000
Yildiz Durak, 2020	-0,648	0,047	0,002	-0,740	-0,555	-13,705	0,000
Zahrai et al., 2022	-0,299	0,051	0,003	-0,398	-0,199	-5,866	0,000
	-0,297	0,018	0,000	-0,332	-0,262	-16,520	0,000

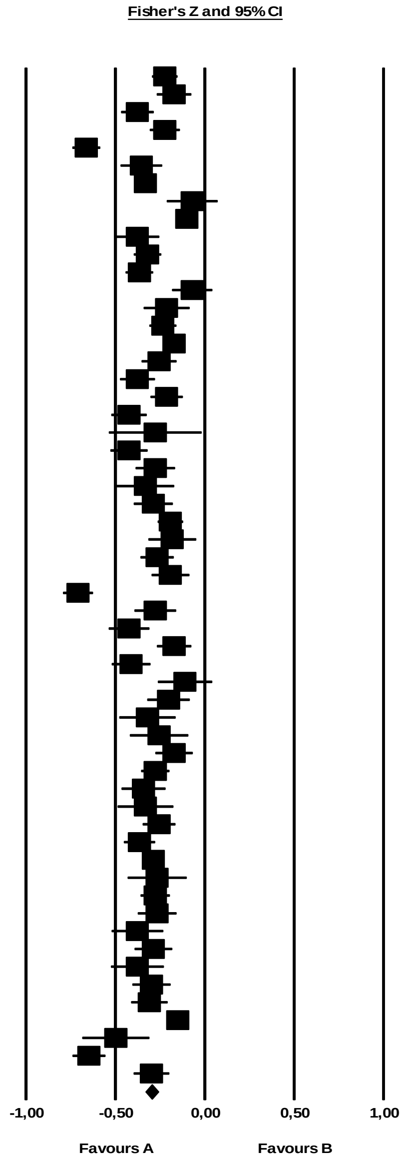

Figure 4. Forest plot obtained with random effects model

Table 4. Effect sizes (pearson r) and heterogeneity test results

Variable	**Category**	***k***	***r***	***95%CI* [low.-up. limit]**	Q_B	***df***	***p***
Study type	Article	55	-.289	[-.321, -.258]	1.994	1	.158
	Thesis	2	-.220	[-.310, -.127]			
Developmental period	Adolescent	11	-.293	[-.358, -.225]	0.029	1	.866
	Adult	46	-.287	[-.322, -.251]			
Education level	Middle school	3	-.286	[-.335, -.235]	0.54	2	.973
	High school	8	-.297	[-.399, -.188]			
	University	19	-.293	[-.368, -.215]			
Geographic region	Europe	14	-.262	[-.295, -.227]	12.809	7	.077
	East Asia	10	-.251	[-.300, -.198]			
	South Asia	2	-.343	[-.404, -.279]			
	South America	2	-.491	[-.639, -.308]			
	North America	11	-.305	[-.385, -.221]			
	New Zealand-Australia	3	-.362	[-.551, -.137]			
	Middle East	12	-.262	[-.338, -.194]			
	Interregional/International	3	-.232	[-.340, -.117]			

When Table 4 is examined; according to the type of study variable, the relationship between self-control and PSMU does not differ statistically, as the heterogeneity value (Q_B) does not exceed the value of χ^2 (3.841) determined according to the degree of freedom (p > .05). The Q test results show the homogeneity of the relationships between self-control and PSMU in terms of the type of studies. According to the developmental period variable, the relationship between self-control and PSMU does not differ statistically, as the heterogeneity value (Q_B) does not exceed the χ^2 (3.841) value determined according to the degree of freedom (p > .05). The Q test results show the homogeneity of the relationships between self-control and PSMU in terms of the developmental periods of the participants.

The relationship between self-control and PSMU according to the level of education variable does not differ statistically, as the heterogeneity value (Q_B) does not exceed the value of χ^2 (5.991) determined according to the degree of freedom (p > .05). The Q test results show that the relationships between self-control and PSMU are homogeneous in terms of educational levels in which independent studies are conducted. The relationship between self-control and PSMU according to the geographical region variable does not differ statistically, as the heterogeneity value (Q_B) does not exceed the χ^2 (14.067) value determined according to the degree of freedom (p > .05). Q test results show that the relationships between self-control and PSMU are homogeneous in terms of geographic regions where independent studies were conducted.

Discussion

Poor self-control has long been documented as a factor contributing to behavioral addictions such as multi-screen addiction (Şimşir Gökalp, 2022), internet addiction (Li et al., 2021), internet gaming disorder (Cerniglia et al., 2019), smartphone addiction (Davey et al., 2020), and social media addiction (He et al., 2022; Koç et al., 2022). The present study employed meta-analysis to investigate the associations between self-control and PSMU and quantitatively synthesized the findings of studies performed between 2014 and 2022. A total of 29.576 people were included in the analyses, which were based on 57 research from 8 distinct geographical locations. The study's findings revealed that self-control was moderately negatively correlated with PSMU.

Previous cross-sectional studies in the literature have commonly reported a negative relationship between self-control and PSMU (e.g., Boer et al., 2022; Koç et al., 2023; Pilatti, et al., 2021; Zahrai et al., 2022). The strength of this study is that it combines the previous studies and presents a more comprehensive and summarized result. Another advantage of this study is that it is the first study in the literature to examine the relationship between self-control and PSMU using the meta-analysis method. The result of this meta-analysis regarding the connection between self-control and PSMU is consistent with the findings of earlier reviews addressing the role of control behavior on addictive tendencies. The study conducted by Li et al. (2021) revealed a negative relationship between self-control (impulsivity, and restraint) and internet addiction. Lee and colleagues (2019) investigated the impact of impulsivity on addictive behaviors, including drug and behavioral addictions in their quantitative meta-analysis study. The researchers showed that impulsivity was linked to alcohol addiction, tobacco usage, and gambling disorders. Drug dependence on psychostimulants such as cocaine and MDMA was also observed to be most frequently correlated with impaired inhibitory control. Results from a meta-analysis study by Dezhkam et al. (2022) showed that impulsivity positively influences addictive tendencies and behaviors (such as internet and social network addiction, sex addiction, and shopping addiction). Additionally, other meta-analysis studies in the research literature reported that impulsivity positively correlated with addictive behaviors including gambling disorder (Ioannidis et al., 2019), mobile phone addiction (Li et al., 2020), and adolescent alcohol use (Coskunpinar et al., 2013). In conclusion, a low level of self-control makes people more susceptible to addictive behaviors across a range of drug and behavior use.

The findings of this review showed that the developmental period had no moderating impact on the connection between self-control and PSMU. To put it another way, there's not much difference in the relationships between self-control and PSMU throughout age groups. Although these results appear to conflict with the research findings in the literature (e.g., Li et al., 2021), they are in accordance with the theoretical perspective. The body of research suggests that self-control improves with age (e.g., Tao et al., 2014; Tarullo et al., 2009) and social media addiction diminishes (Cheng et al., 2021). In this direction, the associations obtained across all age groups will be similar. In other words, the reports suggest that people will exhibit self-control at a rate consistent with their age and that their propensity for social media addiction will decline at a similar rate. It implies a linear inverse proportion mathematically. Furthermore, the moderator role of the educational stage was found to be insignificant in the relationship between self-control and PSMU. These results may be interpreted akin to the developmental period.

Additionally, the study's findings revealed that the anticipated moderator role of the geographical location between self-control and PSMU was insignificant. Research in the literature has shown that social media addiction varies by geographic location (Boer et al., 2020; Cheng et al., 2021; Marino et al., 2018).The prevalence of PSMU has shown to be higher in regions such as Africa, Asia, and the Middle East and lower in regions such as Western and Northern Europe (Cheng et al., 2021). The fact that the countries within the geographical regions (i.e., Asia and Europe) differ from one another may be the cause of the similarities in the correlations between the researches variables in the regions studied in this study. For instance, research by Boer et al., 2020 showed that PSMU varies across Europe. Spain has the highest incidence of PSMU, while the Netherlands has the lowest rate. In this regard, reviewing the PSMU country-by-country may be more beneficial. Lastly, it has been found that publication status does not affect the association between self-control and PSMU. The research includes a total of 57 studies, 55 articles, and 2 theses. The lack of distinction between the thesis articles might be interpreted as the absence of publication bias.

Limitations, Implications, and Future Studies

While interpreting the research findings, some limitations need to be taken into account. The study was unable to incorporate papers published in other languages because the databases could only be searched in Turkish and English. There could be variations in the usage of various social media platforms across different nations or the prevalence of PSMU may vary at different rates. Second, since the studies included in the meta-analysis did not examine the links between self-control and PMSU in children and older people, the moderator analysis based on developmental periods was categorized into adolescents and adults. Future studies may investigate the relationships between self-control and PSMU in children and the elderly. Third, since self-report scales were employed in the research that comprised the study, there is a high probability that subjectivity and personal biases were included in the assessments. Fourth, the studies that made up the study used a variety of scales, such as Facebook addiction and social media addiction. It is debatable how accurately the scales employed measure PSMU. Thus, when evaluating the findings, this restriction should not be overlooked. Future studies might also examine how different social media platforms affect PSMU. Fifth, the study comprised studies with normal subjects who did not have any clinical problems. Hence, it is important to avoid generalizing to clinical populations (i.e. with attention deficit hyperactivity disorder) when drawing interferences. Lastly, while this study presents robust findings by combining relational studies from the literature, it does not establish a causal relationship between variables. To address this issue, it might be beneficial to undertake experimental and longitudinal studies in the future.

Notwithstanding these limitations, the study significantly enhances our comprehension of the underlying mechanism of PSMU. Even while the Diagnostic and Statistical Manual of Mental Disorders (5th Edition) does not classify social media addiction as a behavioral addiction, research on the topic is growing daily. A new one was also added to the body of knowledge by this study. The findings of the research may be helpful to psychiatrists, psychologists, counselors, educators, and researchers. For example, educators, school counselors, and psychologists can develop and implement self-control intervention programs for students or clients to prevent and reduce PSMU. Furthermore, the fact that the study presents a summarized result by bringing together many studies in the literature using the meta-analysis method may facilitate researchers to make inferences and guide future research.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors

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Exploring the Impact of Early STEM Education on Science and Visual Literacy

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Abstract

Early STEM (Science, Technology, Engineering, and Mathematics) education plays a pivotal role in shaping children's science and visual literacy skills. However, in South Africa, there are notable challenges such as delayed initiation of science education and inadequate emphasis on visual literacy. This study aims to investigate the influence of early STEM education on science and visual literacy in South African educational contexts. Drawing upon the post-positivist paradigm and Mayer's cognitive theory of multimedia learning, this research employed a mixed-method approach combining quantitative and qualitative analyses, integrating autoethnography to engage with lived experiences during my master's and doctoral studies. The findings suggest that children exposed to STEM education demonstrate higher levels of science and visual literacy. These findings have implications for curriculum design and educational practice, urging stakeholders to integrate STEM principles early in children's educational journey and to prioritize visual literacy to enhance communication and comprehension of scientific concepts. Recommendations are provided for educational institutions and policymakers to facilitate the implementation of effective strategies addressing these challenges and fostering a generation of learners equipped with essential skills for success in the modern world.

Introduction

This study aims to explore the profound impact of early STEM education on nurturing science and visual literacy while advocating for effective strategies to cultivate these essential skills from the earliest stages of development. I used autoethnography as a gateway to engage with my lived experiences during my journey pursuing my master's and doctoral degrees (Méndez, 2013). Ellis and Bochner (2000) define autoethnography as a qualitative research method where the researcher uses their personal experiences to explore and understand broader cultural phenomena. Although my research approach was not strictly formulated around autoethnography, it played a pivotal role as an entry point into the study. This personal narrative provided valuable context and helped shape subsequent research questions and the overall study design.

According to Gotz et al. (2019), pursuing a master's or doctoral degree is often an intensely personal endeavor, which resonates with my own experience. As a mother of two young boys who experienced language delays in their early years, my research interests were sparked by a desire to find innovative ways to support their language development. Delving deeper into language learning, I became increasingly intrigued by the potential of digital educational games to enhance my children's linguistic abilities (Dicheva et al., 2015). Videnovik et al. (2020) describe digital educational games as interactive learning experiences that utilize technologies such as computers, tablets, smartphones, gaming consoles, and online platforms to deliver educational content in a game-like format. Similar to Ozdilek et al. (2020), my exploration of digital educational games revealed their potential to stimulate children's interest in science and mathematics education. This personal journey has directed my research towards enhancing science education through digital educational games, aiming to bridge the gap between early childhood development and STEM learning.

Early exposure to science is widely recognized as crucial for success in STEM fields (Wan et al., 2021). Research indicates that young children possess a natural curiosity about the world, making them ideal scientists (Glauert & Stylianidou, 2021). Therefore, by nurturing this curiosity and providing opportunities for exploration and discovery, early science education can foster a lifelong passion for science, lay the foundation for future STEM learning, promote critical thinking, and improve scientific literacy. Moreover, early science education enhances children's social and emotional skills, including problem-solving, collaboration, and perseverance, all essential for their overall development (Reimers, 2020). Additionally, research suggests that early childhood is crucial for shaping attitudes toward science (Hansson, 2021).

Research Problem

The delayed introduction of science education in early childhood education in South Africa has profound implications beyond immediate academic performance. While early childhood education in South Africa prioritizes various facets of children's development, such as language, mathematics, life skills, physical development, and creative expression (Department of Basic Education, 2019), science education receives comparatively less attention. Although mathematics is seamlessly integrated into the curriculum with a focus on foundational concepts (Chikiwa et al., 2017), science education often remains neglected until later stages, typically starting from the fourth grade onwards (Piasta et al., 2014). This delay has sparked concerns among educators regarding its impact on students' academic readiness and overall scientific literacy.

Delaying science education until the fourth grade hinders students' long-term academic outcomes by impeding their comprehension of complex scientific concepts and meaningful engagement with scientific inquiry (Ramulumo, 2023; Botha, 2012). Furthermore, delayed exposure to science may restrict students' exploration of potential STEM career paths, thereby affecting their future opportunities and the nation's competitiveness in these fields (Newell et al., 2015). Additionally, postponing science education can shape students' attitudes toward science, potentially fostering negative perceptions and discouraging them from pursuing STEM-related studies or careers (Lelliott, 2014; Reddy et al., 2013). This exacerbates the shortage of skilled professionals in the science and technology sectors, impeding national innovation and economic growth (Tytler et al., 2008).

In contrast, countries like Finland and Singapore prioritize early science education, resulting in higher scientific literacy and positive attitudes toward science (Lavonen and Laaksonen, 2009; Ayieko, Gokbel, and Nelson, 2017). To address the delayed introduction of science education in South Africa, understanding potential contributing factors such as curriculum constraints, resource limitations, and pedagogical approaches is essential (Troy et al., 2014). Inadequate training and professional development opportunities for early childhood educators in teaching science further complicate the situation (Van Driel et al., 2001). Moreover, resource constraints, including a lack of teaching materials and access to science facilities, hinder effective implementation (Bauer et al., 2015).

Examining these factors provides a comprehensive understanding of the barriers to early science education. Therefore, addressing these challenges is crucial for developing effective strategies to promote science education from an early age, thereby fostering academic success, career readiness, and national competitiveness in science and technology fields.

Rationale

During my Master of Science degree, I assessed the visual literacy of first-year science students in South African universities, identifying a significant deficiency in their skills (Ramulumo, 2020). According to Schönborn and Anderson (2006), this lack of proficiency impedes students' comprehension of complex scientific concepts due to insufficient emphasis on visual vocabulary in science education. Moreover, this deficiency is concerning given the pivotal role of visual literacy in digital literacy, including applications such as digital educational games (Reddy et al., 2023).

These findings underscore the importance of introducing visual literacy early in education. Research indicates that integrating visual literacy instruction into science curricula enhances students' understanding of scientific phenomena and their ability to interpret visual data (Kobe, 2020; Mnguni, 2018; Guzzetti et al., 2016; Schönborn & Anderson, 2006). Exposure to visual representations from an early age has also been shown to foster interest and engagement in science, laying a foundation for lifelong learning in STEM fields (Shabiralyani et al., 2015). While emphasizing the necessity of early science education, the study highlights the critical need for developing visual literacy skills from a young age. The challenges observed among university-level students in grasping complex scientific concepts may partly stem from the delayed introduction of science education (Ramulumo, 2020). However, even with earlier exposure to science, students would still require strong visual literacy skills to effectively visualize the abstract nature of scientific concepts (Ramulumo, 2023).

Visual literacy research in South Africa may not receive as much global attention as in countries like the United Arab Emirates, Switzerland, Germany, and Australia (Flood et al., 2015). Nonetheless, South Africa has made significant contributions to this field. In an increasingly digitalized world, the importance of visual literacy in comprehending information across diverse contexts has become apparent (Mnyanda & Mbelani, 2018; Jordaan & Jordaan, 2013). Visual literacy encompasses a range of abilities, including spatial visualization, visual-spatial reasoning, perception, and interpretation of visual information (Gadanidis & Namukasa, 2017; Hoffler & Leutner, 2007). Proficiency in visual literacy is crucial for academic success, fostering cognitive development and critical thinking skills essential for effective learning (Braden et al., 2018). Consequently, the intersection of visual literacy and science literacy has become a focal point of research, highlighting their interconnectedness and impact on students' learning outcomes (Aberšek, 2008; Trumbo, 2006). Visual representations, such as diagrams, graphs, and models, play an indispensable role in science education, facilitating the conveyance of complex scientific concepts (Schonborn & Anderson, 2006).

In this context, the study aims to explore the influence of early STEM education on science and visual literacy. It seeks to determine whether children exposed to STEM education demonstrate higher levels of these literacies compared to those who do not receive such exposure. Through this investigation, the study aims to assess whether STEM learning is the optimal approach for introducing these essential skills in early childhood. Additionally, the findings have the potential to inform educational policies and practices aimed at enhancing science education and promoting visual literacy from an early age.

Theoretical Framework

This study adopts a theoretical framework that integrates the Post-Piagetian Theory of Cognitive Development and Mayer's Cognitive Theory of Multimedia Learning to explore the mechanisms influencing children's science learning. This synthesis aims to provide a comprehensive understanding of how cognitive development and multimedia learning principles intersect to enhance educational outcomes for young learners.

The Post-Piagetian perspective challenges Piaget's assertion that young children lack the cognitive abilities for abstract thinking and scientific reasoning. Instead, it emphasizes that children as young as 4 to 6 years old exhibit domain-specific knowledge structures, particularly in subjects like science and mathematics (Case, 1999; Gelman, 1990). This framework delineates developmental milestones and transitions in children's understanding of scientific concepts, from concrete operational thinking to more abstract reasoning, guiding educators in tailoring curricula to match cognitive abilities and conceptual frameworks.

Mayer's theory underscores how multimedia, particularly visual representations, can enhance learning by leveraging cognitive processes such as dual-channel processing and limited working memory capacity (Mayer, 2005). Visuals, when integrated effectively with minimal text, facilitate information retention and cognitive processing, tapping into children's cognitive architecture to optimize learning outcomes. This approach aligns with children's developmental stages and cognitive load constraints, ensuring that educational materials are designed to support effective comprehension and retention of scientific content (Gilbert, 2005).

Research by Chang et al. (2007) implemented Mayer's Cognitive Theory by utilizing animations and diagrams to teach chemistry concepts to middle school students. These visual representations were designed to enhance cognitive processing by presenting complex chemistry concepts in a simplified and interactive format. By aligning with the Post-Piagetian framework, which acknowledges children's evolving cognitive abilities in understanding abstract scientific concepts, this study demonstrated improved comprehension and retention among students compared to traditional text-based instruction.

The Post-Piagetian Theory's emphasis on domain-specific knowledge structures complements Mayer's Cognitive Theory, which advocates for the integration of visually rich materials to enhance cognitive processing. This synergy allows educators to not only acknowledge children's evolving cognitive abilities in science but also strategically design multimedia learning experiences that cater to these developmental stages.

Therefore, by integrating Post-Piagetian insights into children's progression from concrete to abstract thinking with Mayer's strategies for optimizing multimedia learning, educators can foster a comprehensive approach to cognitive development in science. This integration supports the design of instructional materials that scaffold scientific reasoning while respecting children's cognitive load constraints. Scaffolding techniques, such as guided exploration and interactive simulations, support children in constructing and refining their understanding of scientific concepts while managing cognitive load effectively (Wood et al., 1976).
While this framework is promising, it may have limitations in diverse educational settings and among different populations. Future research should explore innovative approaches, such as augmented reality and adaptive learning technologies, to further enhance the application of this theoretical framework. Additionally, investigating the long-term effects of these integrated strategies on children's scientific literacy would be valuable.

In essence, the integration of the Post-Piagetian Theory of Cognitive Development with Mayer's Cognitive Theory of Multimedia Learning provides a robust foundation for advancing children's science education. This theoretical synthesis not only informs instructional practices but also underscores the need for ongoing research to optimize learning environments that foster cognitive and educational development in science and beyond. Therefore, by leveraging developmental insights and multimedia learning principles, educators can create impactful learning experiences that promote deeper engagement and understanding of scientific concepts among young learners.

Method

General Background

The study is rooted in the post-positivist paradigm, which emphasizes epistemological pluralism (Blackwell, 2019). This paradigm reconciles the constraints of positivist and constructivist methodologies by valuing empirical evidence and emphasizing the need for methodical and rigorous research methods (Guba & Lincoln, 1989). Therefore, by embracing a post-positivist perspective, the study integrates quantitative and qualitative methods to thoroughly examine this influence. In this regard, this approach seeks to produce robust evidence on the role of early STEM education in shaping science and visual literacy in young children (Blackwell, 2019; Guba & Lincoln, 1989).

Research Design

The study employed an embedded mixed-method research design to integrate both quantitative and qualitative data, offering a comprehensive understanding of the research questions. Drawing from Creswell's methodology (2014), known for its adaptability, this design ensures flexibility across various research contexts. Quantitative data were prioritized for their structured insights into the impact of early STEM education on science and visual literacy, enabling statistical examination to reveal patterns and trends. Complementarily, qualitative data provide depth and contextualization to the quantitative findings through interviews and analytical processes, resulting in a comprehensive mixed-method structure. Therefore, by integrating autoethnographic insights, the study gained a unique perspective that informed the development of interview questions and guided the interpretation of qualitative data. This methodological blend enhances the breadth of evidence, credibility, guards against biases, enriches conclusions, and maintains a balanced approach, facilitating a more robust exploration of the research questions than a purely quantitative or qualitative approach would allow.

Data Collection

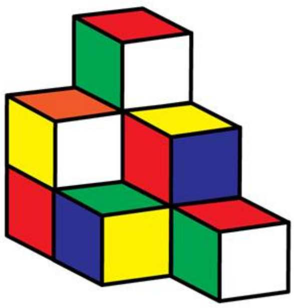
In the quantitative phase of the study, 121 preschool Grade R children from STEM schools and 87 from non-STEM schools in Bloemfontein, South Africa, were purposively selected. These children, aged 5 to 6 years, were chosen in accordance with guidelines established by the Department of Basic Education. These guidelines specify that Grade R learners must be at least five years old and turning six or older by 30 June of the current year (The Department of Basic Education, 2015). Purposive selection was employed to ensure the sample encompassed children from both STEM and non-STEM schools in Bloemfontein, South Africa. This approach aimed to capture a broad range of educational backgrounds and approaches, thereby enhancing the generalizability of the study's findings while minimizing selection biases.

STEM schools were chosen for their dedicated focus on STEM education, particularly science literacy. These schools implement structured STEM curricula aimed at fostering early scientific understanding and skills among preschoolers. In contrast, non-STEM schools were selected based on their adherence to the South African National Curriculum Framework for children aged birth to four years, as sanctioned by the South African Department of Education. This framework guides educational programs for young children but often places less emphasis on science compared to STEM-focused schools (Campbell & Chittleborough, 2014). Including children from both STEM and non-STEM schools aims to capture diverse educational experiences and understand how different approaches impact cognitive development and early childhood science learning. This approach broadens the study's scope, enhancing the applicability of findings while minimizing biases in participant selection.

The quantitative assessment tool was meticulously designed with distinct sections, each comprising closed-ended questions aimed at providing a comprehensive evaluation of children's science learning and cognitive abilities. The tool included two main sections: Firstly, the Content Knowledge Test aimed to assess proficiencies in life sciences, physical sciences, and earth sciences. For instance, within the life sciences section, children were tasked with identifying living and non-living things, employing circling or selection methods (see Figure 1). This approach was chosen to align with children's developmental stages, ensuring the assessment's accessibility and age-appropriateness.

Figure 1. Life science: Knowledge of living and non-living things

Secondly, the Psychometric Test targeted patterns, spatial visualization, visuospatial working memory, and visual perception. An example question from this section involved asking children to count blocks in a visual representation (see Figure 2), which was crucial for evaluating cognitive processing abilities fundamental to scientific learning.



A. 6
B. 7
C. 9
D. I don't know

Figure 2. Spatial visualization: Mental manipulation of two-dimensional and three-dimensional objects

The validation of the assessment tool involved collaboration with a panel of 10 experts, following Hyrkäs et al. (2003), achieving a content validity index score of 82%, exceeding the accepted threshold of 0.79. Reliability was assessed using pilot data, which yielded a Cronbach alpha coefficient of 0.72, indicating satisfactory consistency (Reddy et al., 2022; Taber, 2018). These rigorous validation procedures ensured the tool's reliability and validity in measuring targeted cognitive and science-related competencies among preschool-aged children.

In the subsequent qualitative phase of the study, six preschool participants—three from STEM schools and three from non-STEM schools—were purposively selected from those who had taken part in the earlier quantitative phase. This selection aimed to encompass diverse perspectives and delve deeper into the inquiries raised by the quantitative data. Semi-structured interviews were conducted as the primary method to explore the children's understanding and experiences based on the quantitative findings. Each participant engaged in these interviews using flashcards, a method noted for its unique application in data collection (Cammisa et al., 2011). Each flashcard displayed visual representations corresponding to closed-ended items from the quantitative survey. This approach was chosen to maintain a playful and interactive atmosphere, crucial for engaging young children. The flashcards were shuffled randomly to prevent bias in responses.

Ethical considerations were rigorously upheld throughout the study, with clearance obtained under reference number 2022/02/09/51915987/28/AM. These measures ensured compliance with ethical standards, including obtaining informed consent from parents or guardians, securing assent from the children themselves, and implementing safeguards to protect participants' privacy and well-being.

Data analysis

For the data analysis, SPSS software was utilized to conduct quantitative analysis, enabling the calculation of descriptive and inferential statistics. This approach facilitated the comparison of mean scores related to science literacy and visual literacy between preschool children attending STEM and non-STEM schools. Qualitative data gathered from interviews underwent analysis using a deductive coding approach structured around predetermined themes assessing levels of science and visual literacy. This methodological framework provided deep insights into the proficiency of preschool children across science and visual literacy domains.

Results

The quantitative results reveal that both STEM and non-STEM school children demonstrated a high level of science literacy; however, STEM school children exhibited significantly better performance, achieving an average score of 90.8 (SD = 7.52), compared to non-STEM school children who achieved an average score of 84 (SD = 9.79) (see Table 1). Within the STEM group, the highest performance was observed in the item assessing their ability to determine mass (M = 93, SD = 7.74), while their lowest performance was in the item evaluating their ability to differentiate between living and non-living things (M = 89, SD = 7.74). Conversely, non-STEM school children excelled in the item assessing their ability to determine the weather (M = 87, SD = 10.67), but their lowest performance was evident in the item evaluating their ability to differentiate between living and non-living things (M = 81, SD = 10.01).

Table 1. Summary of the content knowledge test scores on science literacy

Item assessed	Group	N	M	SD	SEM
Living and non-living things	non-STEM schools' children	121	81	10.01	0.91
	STEM schools' children	87	89	7.74	0.83
Weather	non-STEM schools' children	121	87	10.67	0.97
	STEM schools' children	87	91	8.86	0.95
Mass	non-STEM schools' children	121	85	10.01	0.91
	STEM schools' children	87	93	7.74	0.83
Temperature	non-STEM schools' children	121	83	8.48	0.68
	STEM schools' children	87	90	5.69	0.61
Average science Literacy	non-STEM schools' children	121	84	9.79	0.87
	STEM schools' children	87	90.8	7.52	0.81

In the life sciences items, the results indicate that STEM preschoolers outperformed their non-STEM peers by 4%, as evidenced by a significant t-test result (t(105) = 2.946, p < .001) (see Table 4). Regarding Earth Sciences, STEM preschoolers demonstrated an 8% higher performance compared to non-STEM peers (see Table 2), supported by a significant t-test result (t(105) = 6.495, p < 0.001) (see Table 4). Overall in science, STEM preschoolers exhibited a mean performance advantage of 7% over non-STEM peers (see Table 2), with a significant t-test result (t(105) = 3.917, p < .001) (see Table 2) specifically in their ability to distinguish items or objects with different temperatures.

Table 2. A comparison of level of science literacy

Items assessed	T	Df	P	MD	Std. Error Difference	99% Confidence Interval of the Difference	
						Lower	Upper
Living and non-living things	6.496	105	*p*<.001	8	6.4959	4.66	11.34
Weather	2.946	105	*p*<.001	4	1.3576	0.36	7.64
Mass	6.495	105	*p*<.001	8	1.2315	4.66	11.34
Temperature	3.917	105	*p*<.001	7	1.7873	1.67	12.33

In essence, the findings reveal intricate patterns in the science literacy performance of children enrolled in both STEM and non-STEM schools. While both groups demonstrated commendable levels of science literacy, a deeper investigation uncovers significant disparities highlighting the influence of school type on proficiency. These performance differences provide compelling insights into the profound impact of a STEM-focused curriculum on the development of science literacy skills among preschoolers. Notably, a curriculum centered on STEM appears to create a conducive environment for fostering higher levels of scientific understanding, thereby preparing children effectively for their academic journey.

Furthermore, children attending STEM schools exhibited superior performance compared to their peers in non-STEM schools across all assessed items, as indicated by their average visual literacy score of 60.5 (SD = 39.83) (see Table 3). They achieved their highest scores in tasks involving pattern completion (M = 81, SD = 28.81). However, it is noteworthy that children in STEM schools showed relatively lower performance in tasks assessing visual-spatial working memory skills (M = 49, SD = 41.88). Conversely, children enrolled in non-STEM schools attained an average visual literacy score of M = 50.8 (SD = 48.02). Similar to their STEM counterparts, the lowest performance among non-STEM school children was observed in tasks measuring visual-spatial working memory, yielding a score of M = 31 (SD = 52.58). Their strongest performance was evident in tasks requiring pattern completion (M = 70, SD = 35.31), highlighting their proficiency in this specific area.

Table 3. Summary of psychometric test scores on visual literacy

Skills assessed	Group	*N*	*M*	*SD*	*SEM*
Patterns	non-STEM schools' children	121	70	35.31	3.21
	STEM schools' children	87	81	28.91	3.10
Spatial visualization	non-STEM schools' children	121	31	52.58	4.78
	STEM schools' children	87	39	43.93	4.71
Visual-spatial working memory	non-STEM schools' children	121	35	50.93	4.63
	STEM schools' children	87	49	41.88	4.49
Visual perception	non-STEM schools' children	121	67	53.24	4.84
	STEM schools' children	87	73	44.58	4.78
Average visual literacy	non-STEM schools' children	121	50.8	48.02	3.21
	STEM schools' children	87	60.5	39.83	4.27

The results indicate that children exposed to science education are anticipated to exhibit higher levels of visual and science literacy. Supporting this hypothesis, Table 4 reveals that 81% of STEM schools' children correctly identified the missing shape, compared to 70% from non-STEM schools (t(105)=2.465, p<0.001). Additionally, both groups of children displayed deficiencies in spatial imagination, with non-STEM school children lagging by 8% (t(105) = 1.192, p < .001). Furthermore, STEM school children demonstrated better performance in visual-spatial working memory, with a mean difference of 6% (t(105)=2.171, p<0.001). Both groups exhibited improved performance in visual perception, with a mean difference of 6% (t(105)=0.882, p<0.001).

The findings indicate that the STEM school environment enhances visual literacy skills, particularly in tasks involving pattern completion and visual perception. Moreover, performance differences were evident among children attending different school types, especially concerning visual literacy aspects. Both STEM and non-STEM children faced challenges in spatial visualization and visual-spatial working memory. Despite these challenges, STEM school children showed notable proficiency in tasks related to pattern completion and visual-spatial working memory. Similarly, their peers in non-STEM schools demonstrated competence in tasks focusing on patterns and visual perception.

Table 4. A comparison of level of visual literacy

Items assessed	t	Df	P	MD	Std. Error Difference	99% Confidence Interval of the Difference Lower	Items assessed Upper
Patterns	2.465	105	p<.001	11	4.4622	Patterns	2.465
Spatial visualisation	1.192	105	*p*<.001	8	6.7105	-9.96	25.96
Visual-spatial working memory	2.171	105	*p*<.001	14	6.4496	-.3.31	31.31
Visual perception	.882	105	*p*<.001	6	6.802	-12.2	24.2

These results suggest a positive impact of science education on visual literacy, underscored by significant performance disparities between STEM and non-STEM school children. These outcomes highlight the potential benefits of integrating science literacy with visual literacy in early childhood education to enhance overall learning outcomes. Furthermore, the performance differences underscore the importance of tailoring teaching methods to individual skills, addressing unique attributes that may influence performance regardless of school type.

In the qualitative exploration, the analysis of children's responses revealed a diverse range of viewpoints. However, the presentation of findings will primarily focus on those that notably highlight significant differences between the two participant cohorts. This approach aims to improve clarity in understanding variations in the utilization of visual and scientific understanding between STEM and non-STEM children. While statistically significant disparities were observed, it's crucial to acknowledge that individual responses from children in both groups highlighted their unique strengths and encountered challenges when interacting with and interpreting visual and scientific information. Regarding the spatial visualization item, children were asked: "Can you tell me how many blocks are in Figure 3? Why do you think that is the correct number of blocks?"

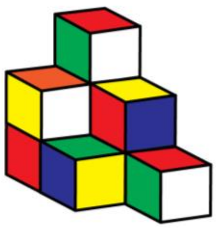


Figure 3. Spatial visualization: Mental manipulation of two-dimensional and three-dimensional objects

STEM Child 1 responded, "9, because other blocks are hiding behind the blocks I see in the picture."
Non-STEM Child 1 answered, "6, because I counted them."

The comparison of responses from children in both STEM and non-STEM schools reveals that both groups were able to count the blocks in Figure 3, demonstrating a fundamental cognitive skill reflective of the initial phase of cognitive functioning internalization. This suggests that both sets of children have reached this cognitive developmental stage.

However, STEM participants exhibited superior levels of spatial visualization ability compared to non-STEM participants. They demonstrated proficiency in mentally manipulating and rotating the image using principles of visual occlusion, indicative of the advanced externalization phase—the highest level of cognitive functioning. This advanced cognitive function requires refined spatial reasoning skills and indicates a deeper comprehension of spatial relationships.

These findings underscore the positive influence of exposure to STEM education and training on spatial visualization skills. They also emphasize the importance of nurturing these skills from an early age, as they are crucial for success across various STEM disciplines. Educators can contribute to the development of these skills by providing opportunities for children to engage in activities that promote spatial thinking and visualization.

Such efforts will establish a foundation for children to excel in their future academic and professional endeavours.

To evaluate the visual-spatial working memory of the children, they were instructed to closely observe Figure 4. Subsequently, they were asked to fold the paper along the broken line and copy the elements from the left side of the paper onto the folded right section, relying on their memory of the visual details. This task assesses their ability to retain and recall spatial information.

Figure 4. Visual-spatial working memory: Ability to recall their perceived observations

Figure 5 depicts drawings by children from both STEM and non-STEM schools based on their memories. The drawing on the left was created by a child from a non-STEM school, while the one on the right was made by a child from a STEM school.

In Figure 5 it is apparent that the child from the non-STEM school depicted a total of 13 apples on the tree, whereas the child from the STEM school drew only three apples on the same tree.

non-STEM school child | STEM school child

Figure 5. Pictures drawn by the children from memory

Following the drawing task, the children were asked to estimate the number of apples in their recreated image and explain their reasoning for their count. A comparison of responses from children in both STEM and non-STEM schools is as follows:

STEM child 2: "3, because that is how many I remember seeing on the tree."
non-STEM child 2: "13, because there were many apples on the tree."

The findings indicate that both STEM and non-STEM children possess the ability to recall all elements of the image depicted in Figure 5, including the sun, the butterfly, and the presence of apples on the tree. This observation suggests they exhibit a cognitive competence known as ground perception, involving an internalized visualization process (Mnguni et al., 2016), representing the foundational level of cognitive function. However, the results also highlight that exclusive accuracy in recalling the specific count of apples depicted in the image was demonstrated solely by the STEM school child. This observation suggests that cognitive processes rooted in memory retrieval, requiring a heightened cognitive stage characterized by conceptualization and externalization (Mnguni et al., 2016), are more pronounced in this context.

An intriguing insight emerges from the drawings of the non-STEM child, suggesting they retained a memory of more apples than were actually depicted in the image. This proposition could indicate that the presence of multiple objects within the image introduced a potential distraction. This finding aligns with the principles established by the Cognitive Theory of Multimedia Learning, emphasizing that excessive use of visuals can lead to overstimulation, potentially hindering the learning process (Mayer, 2011).

In response, the study underscores the pivotal importance of incorporating Mayer's Redundancy Principle into the design of educational materials for children. This principal advocates for the omission of extraneous images, even if contextually relevant, with the goal of mitigating cognitive overload and optimizing the pedagogical experience.

For the item assessing the children's ability to differentiate between living and non-living entities, they were asked two questions. First, they identified items in Figure 6 they perceived as living and non-living. Then, they elaborated on the attributes or traits influencing their determination of whether an entity is classified as living or non-living. These questions aimed to understand the reasoning behind their classifications and assess their comprehension of living and non-living characteristics.

Figure 6. Life science: knowledge of living and non-living things

The comparison of responses from children in both STEM and non-STEM schools is as follows:

STEM child 3: “It is the dog, the boy, and the chicken because the dog, boy, and chicken can breathe and need water to grow.”
non-STEM child 3: “It is the boy because the dog and chicken cannot talk.”

The findings suggest that children from STEM schools exhibited a heightened aptitude for discriminating between living and non-living entities. Their ability to discern traits such as growth and the importance of water underscores the effective integration of the seven fundamental characteristics of life within STEM curricula. This proficiency reflects a comprehensive understanding of the defining attributes of life, highlighting the enduring impact of STEM education. In contrast, the response from the non-STEM child, which associates vitality with communication, underscores the need for a more comprehensive educational approach regarding living organisms. For the item assessing the children's comprehension of mass, they participated in an interview where they were prompted to explain which of the two entities, the elephant or the insect (depicted in Figure 7), they considered to be heavier. Additionally, they provided reasoning for their choice, specifying why they perceived either the elephant or the insect to possess greater mass.

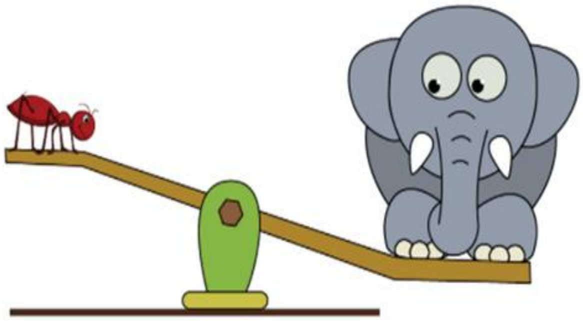


Figure 7. Physical science: Comprehension of mass

The comparison of responses from children in both STEM and non-STEM schools is as follows:

STEM child 2: “The elephant, because the elephant has more kilograms.”
non-STEM child 1: “The elephant, because the elephant is big.”

The findings highlight that STEM school children demonstrate a more robust understanding of mass concepts compared to their non-STEM counterparts. This distinction is evident as non-STEM participants associated weight with size, whereas the STEM school child exhibited a deeper awareness that mass is quantified in kilograms, indicating their advanced understanding rooted in subject-specific knowledge. These results underscore the importance of subject-specific education, particularly in STEM disciplines, in fostering a comprehensive grasp of fundamental concepts like mass. The enhanced understanding among STEM school children suggests the effectiveness of STEM curricula in laying a strong foundation in scientific principles. Conversely, the observation of non-STEM participants associating weight with size underscores the need to address misconceptions and provide holistic education across all disciplines. This highlights the significance of educational strategies that promote critical thinking and subject-specific knowledge to ensure a well-rounded understanding of scientific concepts.

Fundamentally, the qualitative findings enriched the understanding of how contextual factors influence students' outcomes in science and visual literacy. Therefore, by exploring students' reasoning processes, educational backgrounds, and learning experiences, the qualitative analysis provided valuable insights that complemented the quantitative results. This comprehensive approach helped uncover the complex relationship between STEM education and students' proficiency in science and visual literacy skills.

Discussion

The findings of this study echo the National Science Foundation's call for increased STEM education during early childhood, aligning with the growing demand for STEM-related careers (Dickman et al., 2009). Tsai et al.'s (2016) research complements these assertions by illustrating how STEM education not only enhances visual literacy skills but also fosters critical thinking and problem-solving abilities essential for science literacy. This perfectly aligns with the study's objective of investigating the relationship between STEM education and the development of science and visual literacy in early childhood. Therefore, by emphasizing visual and science literacy through STEM education, children can be better prepared for success in various STEM disciplines.

For science literacy, the study's findings corroborate the research conducted by McClure et al. (2017), which highlights the significant role of early STEM exposure in shaping children's comprehension of intricate scientific concepts, such as differentiating between living and non-living entities. This alignment underscores the importance of early engagement in STEM education to foster a solid foundation in science literacy among young learners. Moreover, as previously stated, Gelman (1990) provides further support by indicating that children between the ages of 5 to 6 have competence in learning science, contrary to Jean Piaget's proposition that they lack the abstract thinking abilities required for science literacy. Additionally, Spektor-Levy et al. (2013) further support these findings, highlighting the potential of early STEM education in nurturing children's scientific understanding and challenging conventional assumptions about their cognitive capabilities in this domain.

The study's findings on the significant correlation between early STEM exposure and improved visual literacy in preschoolers align with Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2005). According to

Mayer's theory, learning is enhanced when information is presented through both visual and auditory channels. Early STEM exposure, which includes visual representations and interactive technologies like digital educational games, supports this theory and can effectively enhance visual literacy among children. This perspective is supported by the World Economic Forum's Future of Jobs Report (World Economic Forum, 2018), which emphasizes the importance of nurturing visual skills from childhood. Therefore, by aligning educational resources with children's cognitive capacities, educators can optimize learning outcomes and promote visual literacy from an early age. This approach equips children with the necessary skills and competencies for future careers in visual-centric fields.

Conclusion

Akin to the study by Tsai et al. (2016) emphasizing the pivotal significance of early STEM education in cultivating visual and science literacy skills among preschoolers, our study reinforces the imperative for the seamless integration of STEM education into early curricula. This integration not only equips children with vital proficiencies in STEM domains but also fosters versatile competencies spanning diverse fields. We advocate for educators to prioritize the cultivation of visual literacy through early STEM education, empowering young intellects to embrace a future abounding in prospects. The implications of our study resonate across the domains of early childhood education, STEM-based pedagogy, such as digital educational games, and the augmentation of science and visual literacy.

Recommendations

We recommend that educational institutions and policymakers duly acknowledge the importance of instilling STEM principles from the commencement of a child's educational journey. Such integration must be accompanied by a discernible emphasis on visual literacy, recognizing its role in fostering efficacious communication and comprehension of intricate concepts. Therefore, by enacting these recommendations, educators can lay a sturdy foundation for the comprehensive growth of children, furnishing them with the proficiencies and outlooks requisite for thriving in an increasingly STEM-oriented world. While offering valuable insights, our study has limitations. Data collection from young children may introduce response biases, and the quantitative assessment tools might overlook certain aspects of literacy. Additionally, the subjectivity of qualitative analysis and the study's cross-sectional nature limit causal inference. Longitudinal research would provide more comprehensive insights. Nonetheless, the mixed-method approach offers a holistic understanding of science and visual literacy development in early childhood.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the author.

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Using Technology in Science Education: A Bibliometric Analysis

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Abstract

The aim of this study is to reveal the bibliometric profile of articles published in the field of science education and technology. In the study, in which descriptive research model was used, bibliometric analysis method was preferred in order to reveal and examine the research trends of scientific publications on science education and technology. In the study, Web of Science Core Collection was preferred as the database and VOSviewer program was preferred as the bibliometric network analysis program. In the Web of Science Core Collection database, 2485 articles were accessed after searching with the keywords "science educat*" and "technology*". As a result of the research, it was determined that the first article in the relevant subject area was published in 1980 and the most articles were published in 2022. The country with the highest number of publications in the related field is the USA. The researcher who published the most in the related field is Franz Xaver Bogner. The most publications were published in the Journal of Science Education. Most frequently used keyword in the related articles is science education. The study is important in terms of revealing the research trend of science education and technology articles.

Introduction

The adventure of technology started its journey as the construction and use of simple tools in daily life. Today, technology is an indispensable part of the age we live in and is involved in every aspect of life. The invention of computers and the spread of the internet have made technology an indispensable factor of daily life. Today, new information is produced every second, new inventions and new discoveries are made. These rapid changes and developments in science and technology bring about change in the field of education as in all fields (Turvey & Pachler, 2020). From the beginning of the history of education until today, education has continued its existence with two purposes. One of these purposes is the transfer of scientific knowledge, that is, what is known, while the other has been to support change and development in this context, to support creativity, to turn towards the unknown and to encourage innovation (Haddad & Draxter, 2002). In this context, it is not possible to consider technology and education as two separate elements. In today's world where scientific knowledge and technological developments are increasing rapidly, the ways of meeting the need for information may also differ. Educational systems and learning activities should be updated and made more effective in order to raise individuals with the qualifications to keep up with the age. This has been possible with the integration of technology into education systems (Dickinson & Bass, 2020; Means, 2010).

New competencies and skills required for the sustainability of knowledge-based societies necessitate continuous change in educational practices. Learners growing up in the digital age need to be skilled and equipped to process information faster than previous generations. For this reason, in recent years, information technologies, especially computer materials and other resources, have been used extensively in national educational institutions as part of the activities of many of the subjects. Digital games, web-based learning, video-conferencing, simulation programs, digital textbooks, virtual reality applications are some of these applications (Fernandes, et al., 2019; Plumb & Zamfir, 2008; Salazar, 2010). Many benefits such as designing appropriate learning environments focused on individual differences, developing these environments, making education and training services unlimited, delivering them to large masses (online, hybrid education, etc.), creating up-to-date, interactive and dynamic content, organizing in-class and out-of-class activities, ensuring active participation, ease in accessing and accessing information, realizing meaningful learning, designing alternative learning and measurement methods have been possible with the integration of technological information and systems into educational processes and programs. In the digital age we live in, technology is one of the leading factors affecting education systems, their effectiveness and efficiency. The most striking example of this situation is the global pandemic. Shortly after the start of the Covid-19 outbreak, schools and workplaces were closed to combat the pandemic. In some countries, curfews were imposed for control purposes. If technological systems that enable online education had not been developed and integrated in this process, millions of students around the world would not have been able to attend education, online classes during the pandemic. Due to all these benefits, technology is used at every level and field of education (Melo et al., 2020; Raja & Nagasubramani, 2018; Teräs et al., 2020).

Although technology is used in all areas of education, science education is a field in which the relationship between education and technology is examined and questioned. When science education curricula from past to present are examined, the emphasis on technology in almost all curricula stands out. Over time, the relationship between science and technology has been emphasized with different concepts such as science, technology and society (STS) and STEM. When the nature of science and curricula are examined, it is clearly seen that they aim to provide individuals with many knowledge, skills, attitudes and behaviors on the nature, use, and development of technology. One of the clearest indicators of this aim is that one of the skills that science aims to provide individuals with is technological literacy. Science education and technology are two elements that support and develop each other (Barak, 2006; Looi et al., 2014; Young, et al., 2002). In this context, the aim of this study is to examine the bibliometric profile by determining the research trends of studies on science education and technology. Profile analysis of science and technology studies with bibliometric maps is of great importance considering that it can guide researchers who will work in this field. Researchers who want to conduct a study in the field of science education and technology will be able to access many bibliometric data such as the research areas in this field, the years with the most publications, the journals with the most publications, the authors, the most cited documents, the most frequently used keywords by examining the current study. Presenting these data to the literature will be a guide for future studies in the field of technology and science education.

Method

Research Model

The aim of this study is to examine the research trends of scientific publications on science education and technology and to reveal the bibliometric profile of the published articles. The study is a quantitative study. In the study in which the descriptive research model was preferred, it was deemed appropriate to use the bibliometric analysis method in order to reveal and examine the research trends of scientific publications on science education and technology. The bibliometric analysis method is one of the quantitative analysis methods because it presents the bibliographic characteristics of the literature in the subject area from past to present in the database in the form of numerical data (Hawkins, 2001). With the bibliometric analysis method, which is a popular method especially in recent times, it is possible to process large volume of scientific data obtained from scientific databases such as Scopus and Web of Science through bibliometric software such as Gephi, Leximancer, R, VOSviewer, and to determine the research trend and research profile for the selected topic (Donthu, et al., 2021; Donthu et al., 2021; Verma & Gustafsson, 2020).

Research Data

In the research, Web of Science Core Collection was preferred as the database from which bibliometric data would be obtained and VOSviewer program was preferred as the bibliometric network analysis program. The Web of Science Core Collection database was searched with the keywords “science educat*” and “technology*” in the topic title. In order to ensure that the documents that will constitute the data set consist of documents that are maximally related to the topic of science education and technology, which is the focus of the research, searches were made with these two key concepts. The title, abstract, keyword plus and author keywords tabs are searched with the searches made in the topic heading. For this reason, it was preferred to search under the topic heading in the research.

Through the search, 3983 scientific publications were reached. Among these publications, articles were what we focused on. Articles were the focus type of the study because they are the most common and representative type of scientific publications, have bibliometric indicators, contain original research findings, are comparable, and can be analyzed with bibliometric methods (Prahani et al., 2024). While creating the data file of the research, data for the year 2024 were not included in the data set. The interpretation of the data of 2024, which belongs to a year that has not yet been completed, was not included in the study on the grounds that it could affect the bibliometric profile and bias it. In this context, this study reveals the research trend of scientific articles on science education and technology until 2024. After the elimination process 2485 articles were selected in the relevant database constituted the data file of the study.

Data Collection Process

The data of the study were collected by the researchers in the spring semester of 2023-2024. Web of Science (WoS) database (Web of Science Core Collection provided by Clarivate Analytics) was used as the database in the study. Web of Science (WoS) was chosen as a database because it provides data from many different disciplines, has a wide coverage area, and contains reliable and high-impact scientific publications (Goodman & Deis, 2007; Zyoud et al., 2017). During the data collection process, the Web of Science Core Correlation database was searched with the keyword groups "science educat*" and "technology*" and the total number was recorded. The data file of the study consists of scientific articles published in the relevant subject area until 2024 in the Web of Science Core Collection database. After the creation of the data file, the data were analyzed. The data selection process is presented in Figure 1.

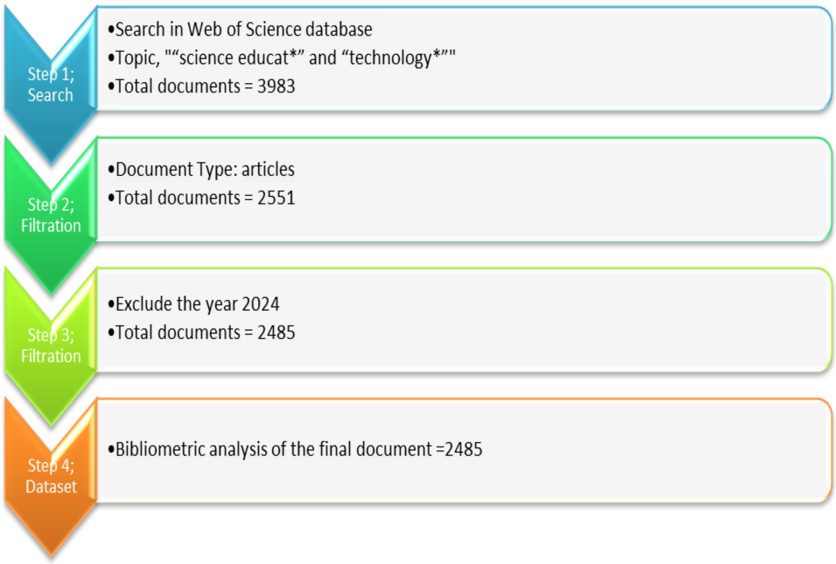


Figure 1. Data Selection Process

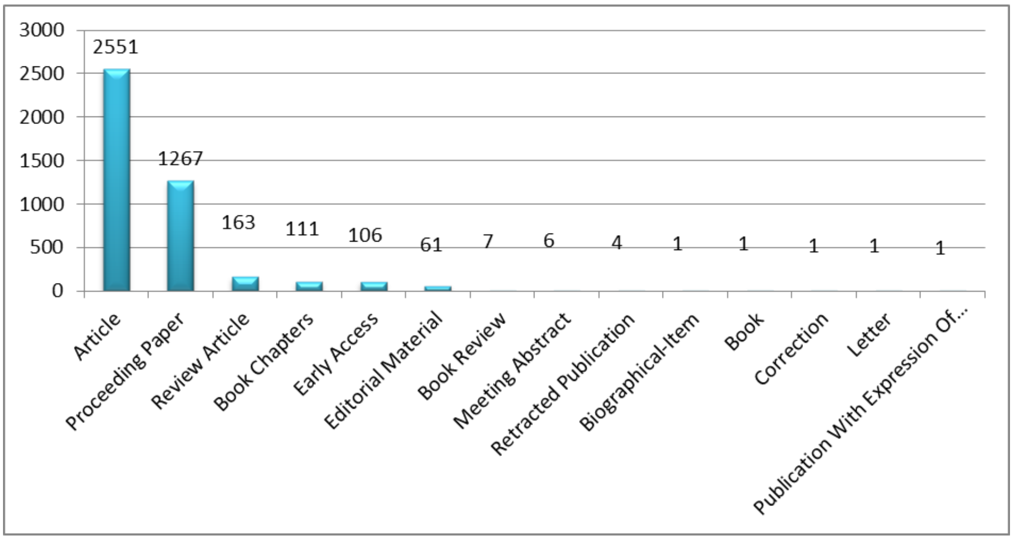
Data Analysis

As a result of the filtering for the research, the data file was created and analyzed. Descriptive analysis was performed to identify the main information, source titles, countries producing the most publications, and links in the research on science education and technology. The VOSviewer program uses the VOS (Visualization of Similarities) algorithm to visualize the data (Van Eck & Waltman, 2009). The biggest advantage of this program for the researcher is that it presents high quality visual material to the reader (Sinkovics, 2016). In addition, the program makes large-scale scientific network graphics easy to understand (Van Eck & Waltman, 2017). For all these reasons, the VOSviewer program was preferred for the analysis of bibliometric data in this study. As a result of the analysis performed with the VOSviewer program, co-occurrence network maps of the data were obtained. The circles in these visuals are related to the number of publications produced in the relevant unit (country, institution, journal, author, etc.). As the number of publications increases, the circle size increases. The links between the circles show the relationship between the units. The frequency of use of keywords is an indicator of the popularity of themes in a research area. In this context, in this study, keyword co-occurrence mapping was used to determine the frequency of keywords used in articles and to reflect the centrality of these concepts with a visual. In this map, the stronger the correlation between two keywords, the higher the frequency of their co-occurrence in the same publication (Pie et al., 2021; Van Eck & Waltman, 2014).

Results

In this part of the study, the distribution of articles published on science education and technology according to years, countries, institutions, authors and journals were examined. Graphs were used to visualize these distributions. While creating the graphs, the top 20 highest values were included in the graph to ensure data readability. Afterwards, unit collaborations were analyzed through network analysis. Within the scope of the research, the number of citations and the distribution of the relationship strength of these units were examined.

Finally, 20 frequently used keywords and the relationship between these words were analyzed. Before this information, the distribution of total documents by type is given to create a general framework about the documents on science education and technology published in the Web of Science database until 2024 (Graph 1).

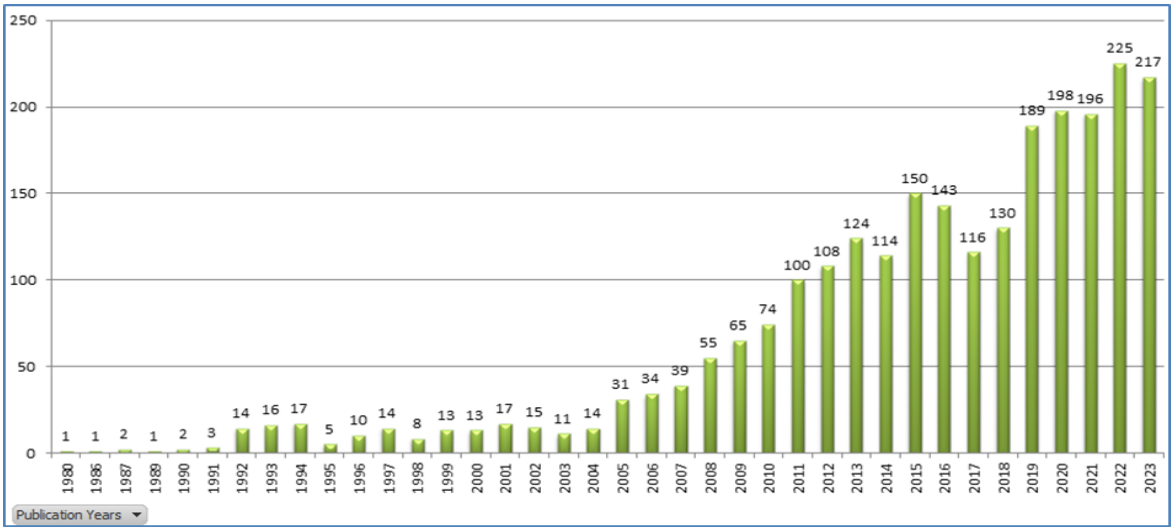


Graphic 1. Types of documents and numbers

In the Web of Science database, 3983 scientific documents on science education and technology have been published from past to present. As can be seen in the graph, the type of document with the highest publication rate is articles. Of these documents, 2551 are articles. 66 of the 2551 articles were published in 2024. In the Web of Science database, 2485 articles were published until 2024.

Findings Related to the Distribution of Science Education and Technology Articles by Years

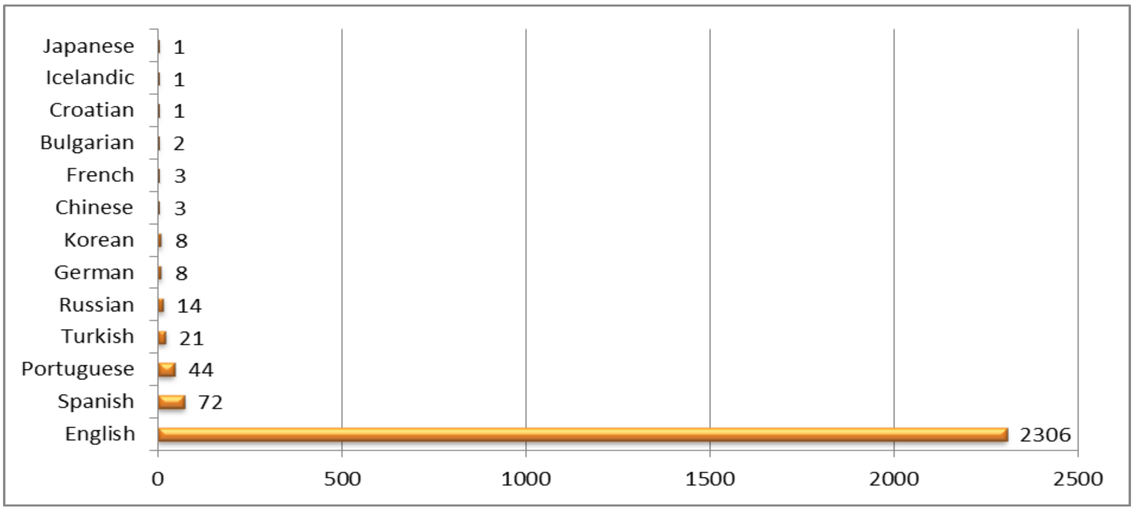
The first article on science education and technology in the Web of Science database was published in 1980. The first article published in the related database is "Technology in Science Education: The Next 10 Years." The article was published in a journal called "Computer". The publication year of the article after the first article is 1986. This article, "Science and Technology Related Global Problems - An International Survey of Science Educators", published 6 years after the first article, was published in the "Journal of Research in Science Teaching". From 1980 to 2023, there is a general increase in the trend of the number of articles is observed. The year with the highest number of articles published is 2022. In 2022, 225 articles on science education and technology were published in the Web of Science database. The least number of articles were published in 1980, 1986 and 1989. In all three years, 1 article was published (Graph 2). In this context, this study reflects the indicators and trends of the 44-year research trend between 1980 and 2023.



Graphic 2. Publication year and number of articles

Findings Related to the Language of Publication of Science Education and Technology Articles

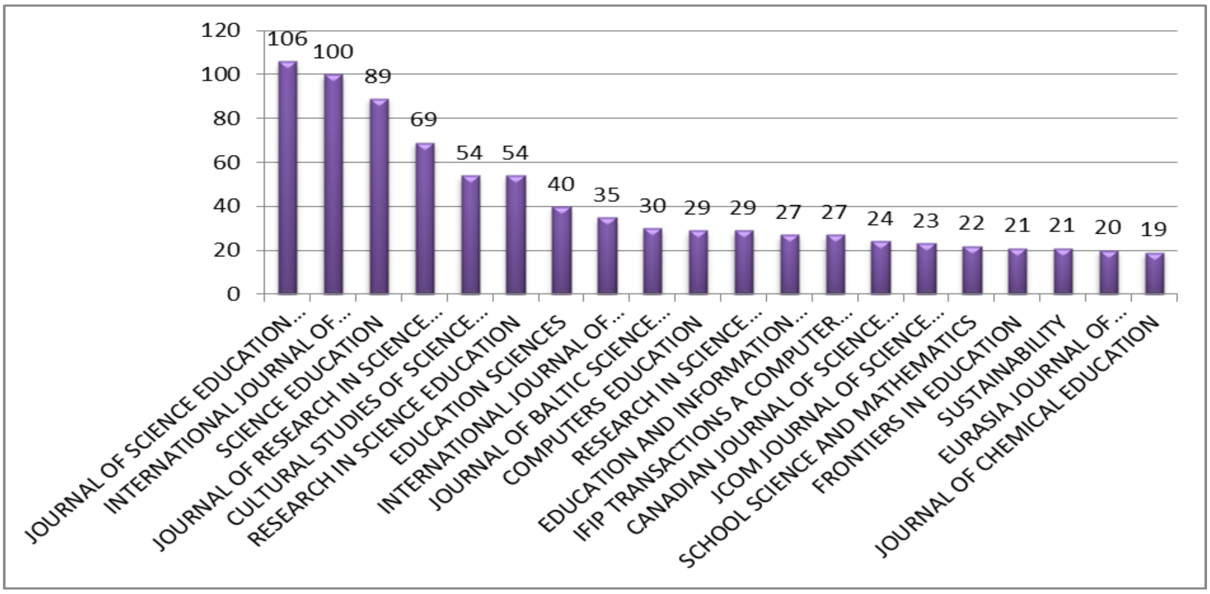
At this stage, the publication language of 2485 articles in the Web of Science database on science education and technology was analyzed. Among these articles, 2306 of them were published in English. 72 articles were written in Spanish, 44 in Portuguese, 21 in Turkish and 14 in Russian. In database, 13 different languages in which articles in the relevant subject area were published were identified. The publication languages and the number of publications in these languages are presented in Graph 3.



Graphic 3. Publication language and number of articles

Findings Related to the Distribution of Journals in which Science Education and Technology Articles Published

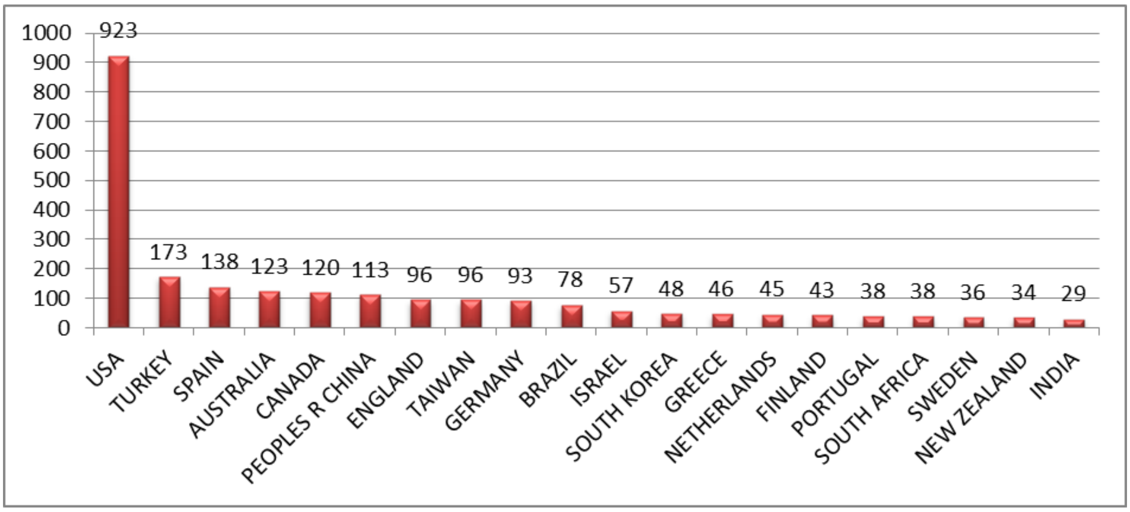
In the Web of Science database, the journal "Journal of Science Education and Technology" hosts the highest number of publications on science education and technology. It was determined that the journal published 106 articles on science education and technology. The second journal with the highest number of articles in the related subject area is "International Journal of Science Education" with 100 articles in the related subject area. "Science Education" ranked third with 89 articles, "Journal of Research in Science Teaching" ranked fourth with 69 articles, "Cultural Studies of Science Education" and "Research in Science Education" ranked fifth with 54 articles. There are 890 journals publishing articles on the subject in the relevant database. For the ease of data visualization, first 20 journals are presented (Graph 4).



Graphic 4. Publication titles and numbers

Findings on the Distribution of Science Education and Technology Articles by Country

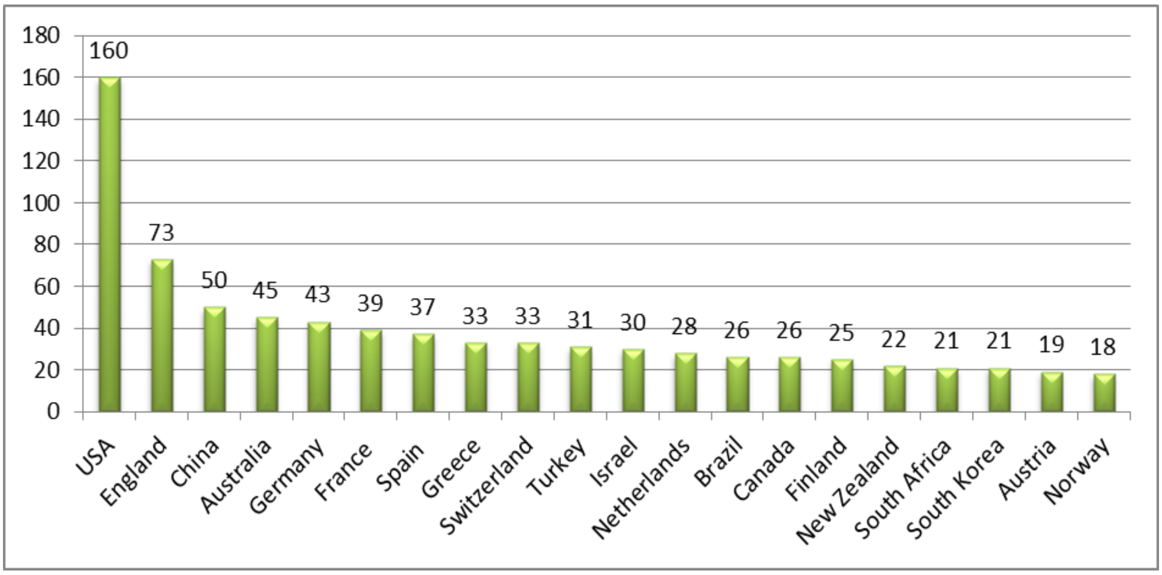
In the Web of Science database, the country with the highest number of publications in the subject area of science education and technology is the United States of America. The USA has 923 articles. Turkey ranks second with 173 articles. Spain ranks third with 138 articles, Australia ranks fourth with 123 articles and Canada ranks fifth with 120 articles. Although there are 116 countries/regions in the relevant database with articles on science education and technology, the first 20 countries are included for the ease of data readability (Graph 5).



Graphic 5. Countries and number of articles

Findings Related to Country Collaboration Publication Distribution of Science Education and Technology Articles

The countries with the highest number of publications on science education and technology in the Web of Science database are presented in Graph 5. The information on the relationship strength of the top 20 countries with the highest level of collaboration in articles on science education and technology published in the Web of Science database is presented in Graph 6.



Graphic 6. Countries and total relationship strength

When Graph 6 is analyzed, it is observed that the country with the highest number of collaborative publications in the field of science and technology is the United States of America. The United States is followed by England (73), China (50), Australia (45) and Germany (43). The network map of country-based collaboration of science and technology articles is presented in Figure 2.

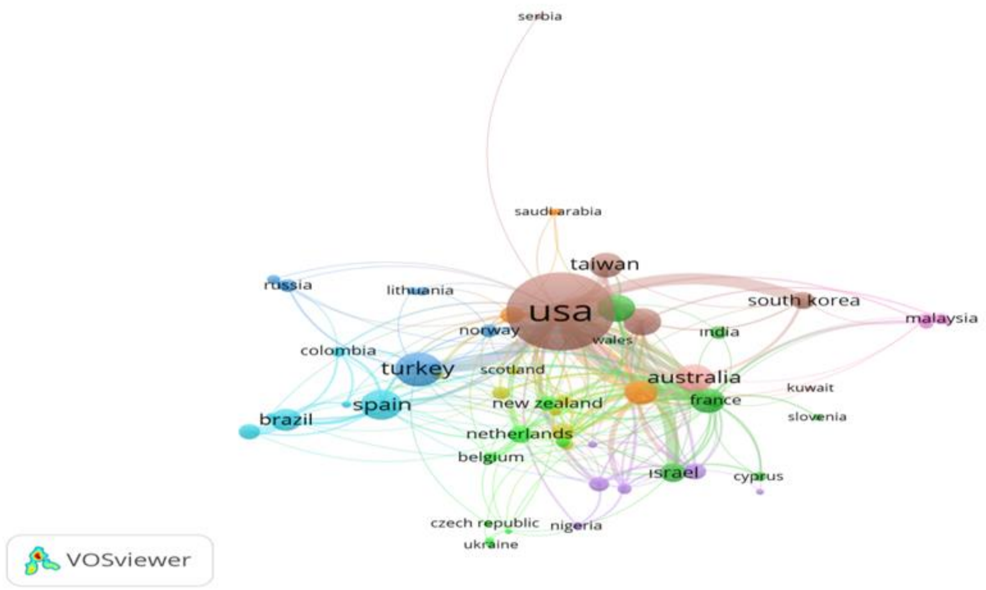
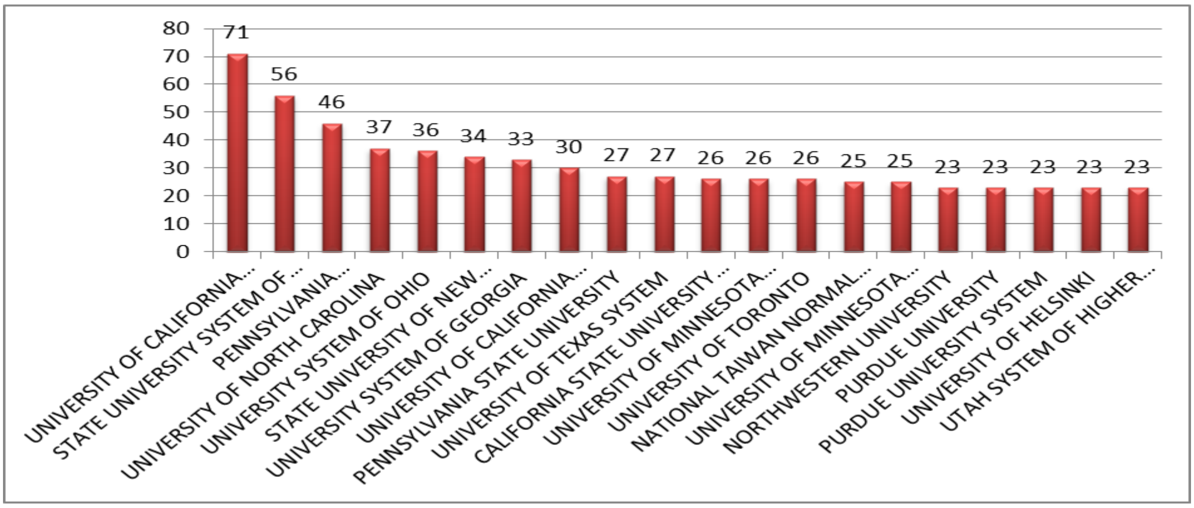


Figure 2. Country collaboration network map

When the network formation map presented in Figure 2 is examined, it is seen that the country with the highest number of collaborative and joint publications in the related subject area is the USA.

Findings Related to the Distribution of Science Education and Technology Publications by Publishing Institutions

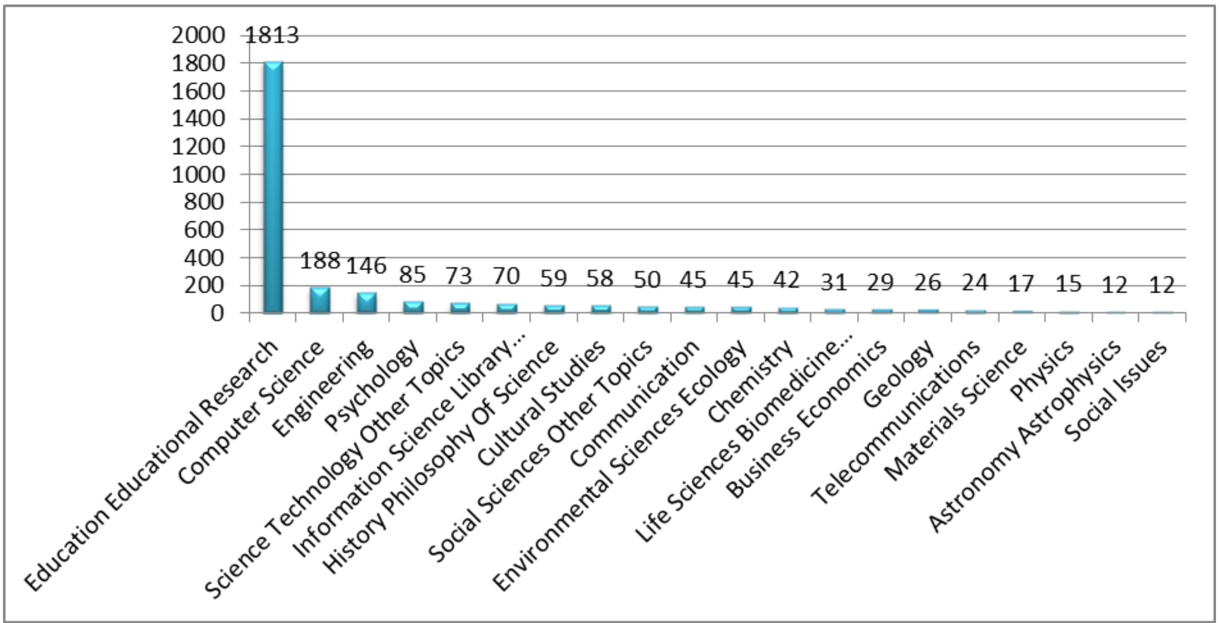
When the institutions where analyzed, 2211 different institutions were observed as a result of the analysis. The institution with the highest number of studies in the related subject area is the "University of California System". University Of Calıfornia System was the institution where 71 articles on science and technology were studied. In the second place was the State University System of Florida (56), third was the Commonwealth System of Pennsylvania (46), fourth was the University of North Carolina (37) and fifth was the University System of Ohio (36). The top 20 institutions with the highest number of publications are presented in Graph 7.



Graphic 7. Affiliations and number of articles

Findings Related to the Research Areas of Articles on Science Education and Technology

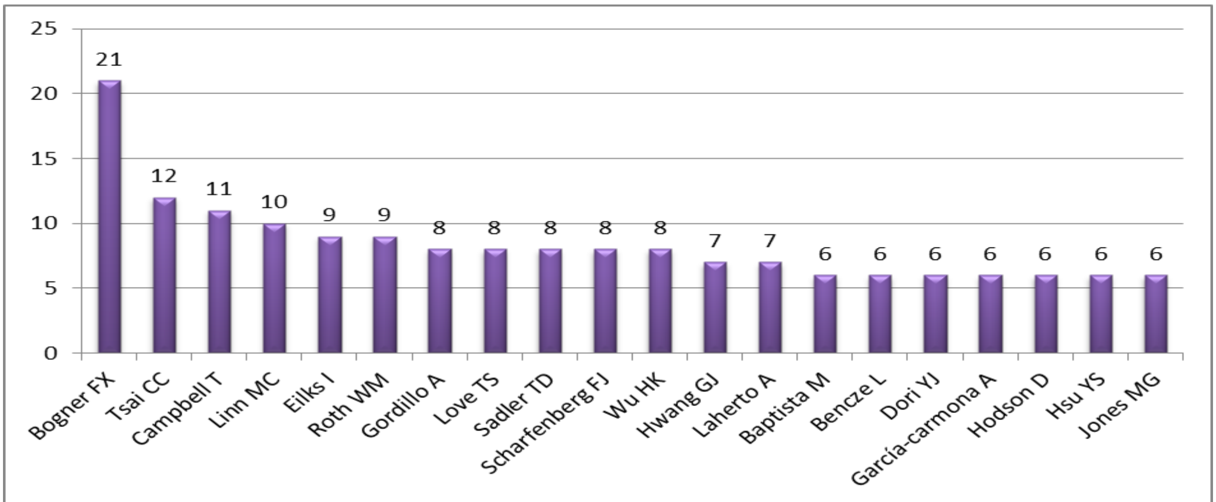
When the research areas of the articles on science education and technology published in the Web of Science database were analyzed, it was determined that the highest number of publications on this subject was in the field of Educational Research. Of the 2485 articles analyzed, 1813 were in the field of Educational Research. Educational research is followed by Computer Science (188), Engineering (146), Psychology (85) and Science Technologies (73). Although 106 research areas with related topics are presented in the Web of Science database, the top 20 areas with the highest number of articles are presented in Graph 8.



Graphic 8. Research areas and number of articles

Findings Related to the Distribution of Science Education and Technology Articles by Author

When the Web of Science database was searched, there were 6401 authors who worked as researcher authors in articles on science education and technology. Among these authors, the researcher with the most articles in the related subject area is Bogner, Franz Xaver. The institution where the researcher author works is University of Bayreuth. The researcher has 21 articles in the area of research. The second author with the highest number of articles is Tsai, Chin-Chung (12), the third author is Campbell, Todd (11), the fourth author is Linn, Marcia C. (10) and the fifth author is Eilks, Ingo (9). The top 20 authors with the highest number of publications are listed in Graph 9.



Graphic 9. Research authors and number of articles

Within the scope of the analysis, the relationship strength of the collaboration of the authors working on science education and technology articles was also examined. The network formation map of the relationship strength of the authors is presented in Figure 3.

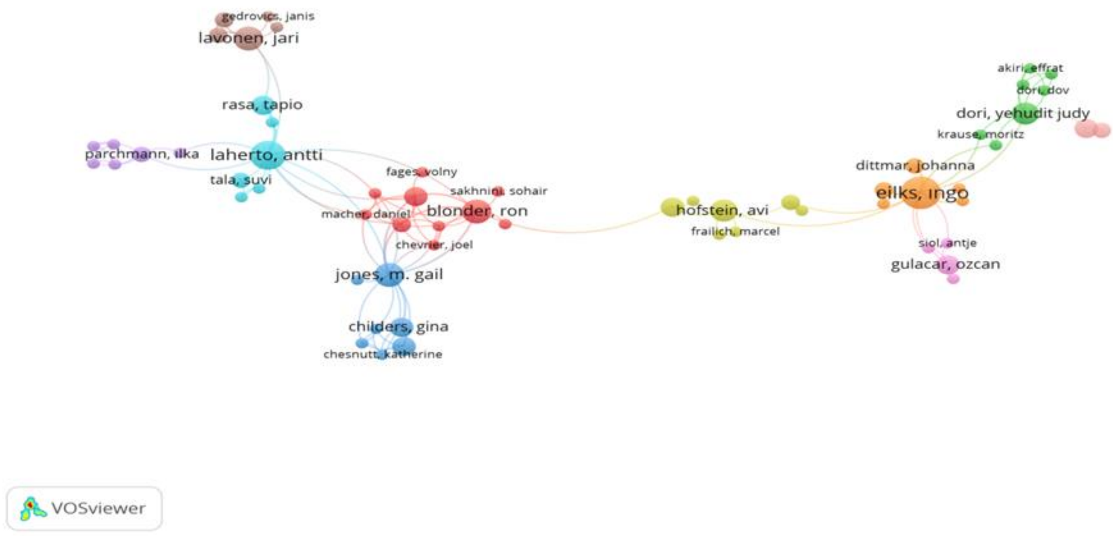
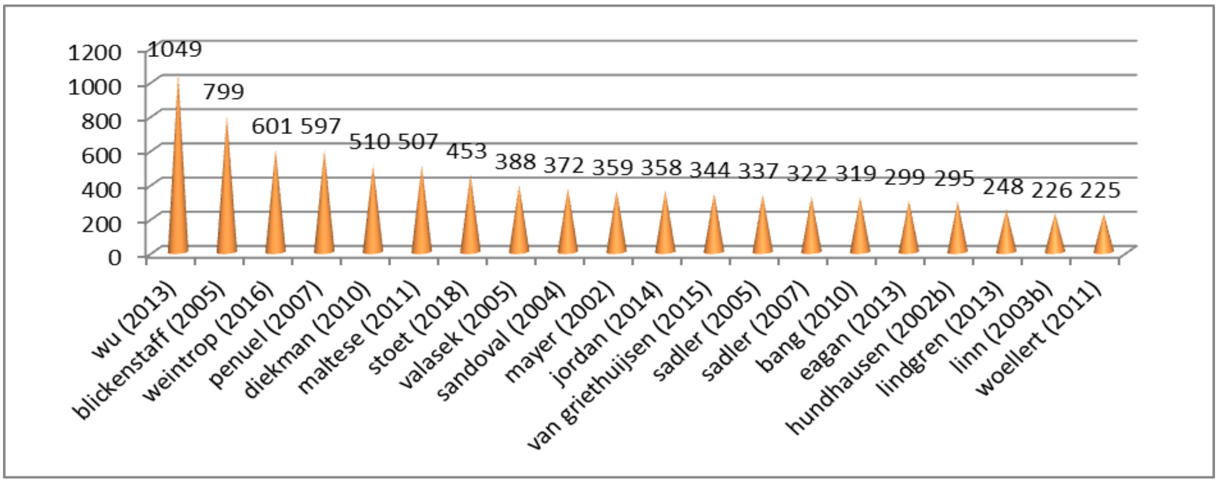


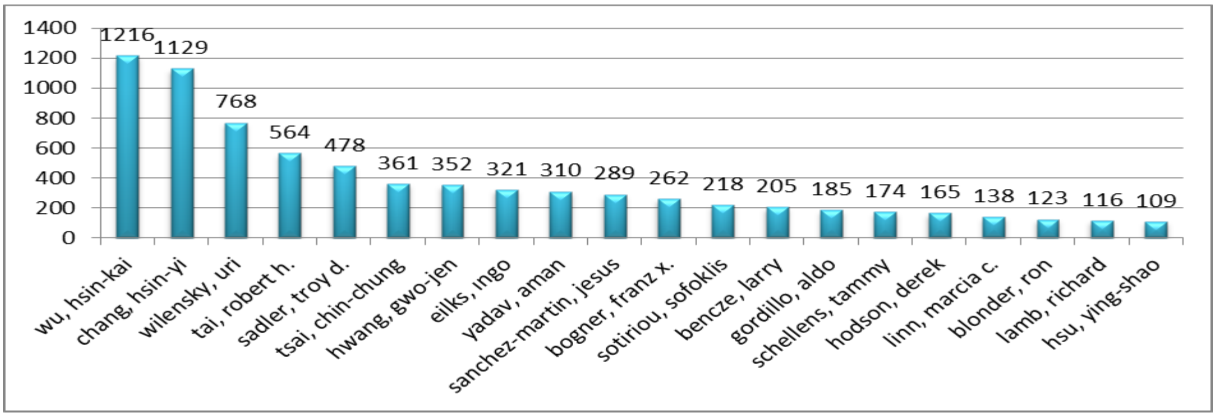
Figure 3. Author collaboration network map

Findings Related to Citation Statistics of Articles on Science Education and Technology

The document with the highest number of citations among the articles on science education and technology published in the Web of Science database is the study titled "Current status, opportunities and challenges of augmented reality in education" published in the journal "Computers and Education" in 2013. The document has 1049 citations. The 20 documents with the highest number of citations are presented in Graph 10.



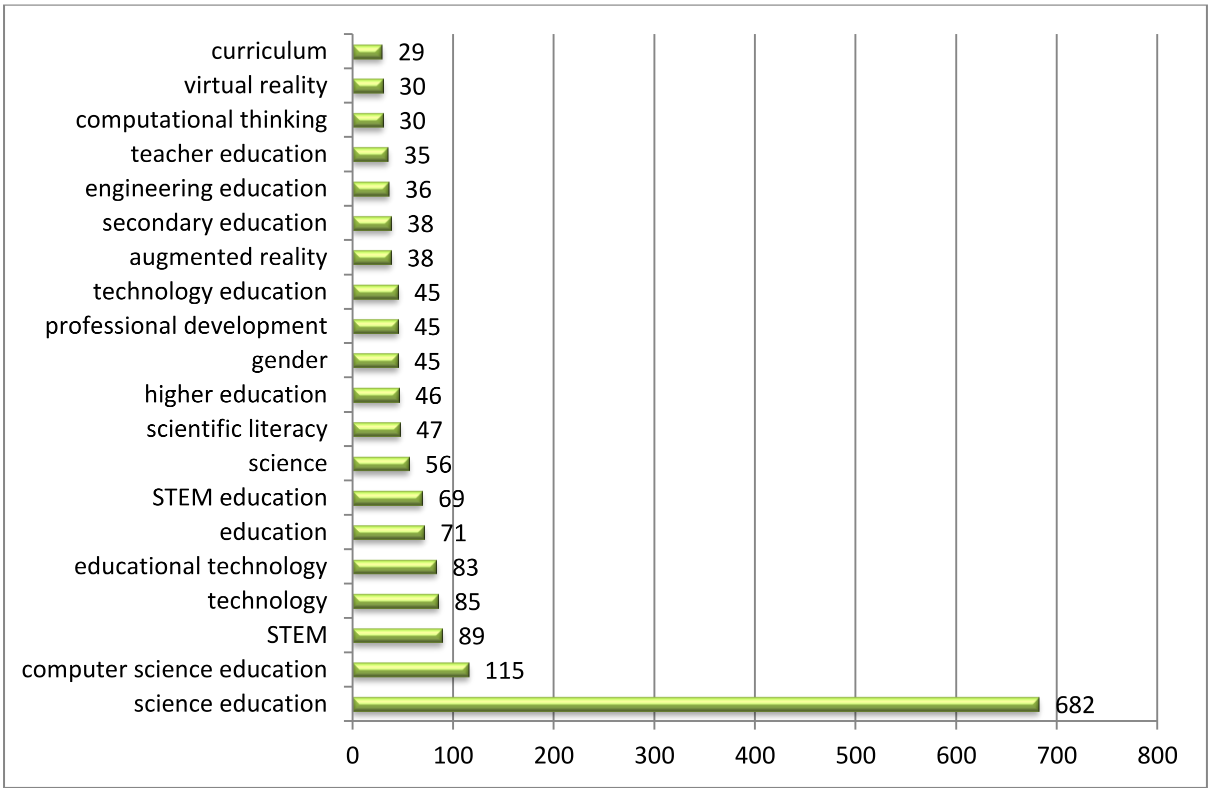
Graphic 10. Documents and citations



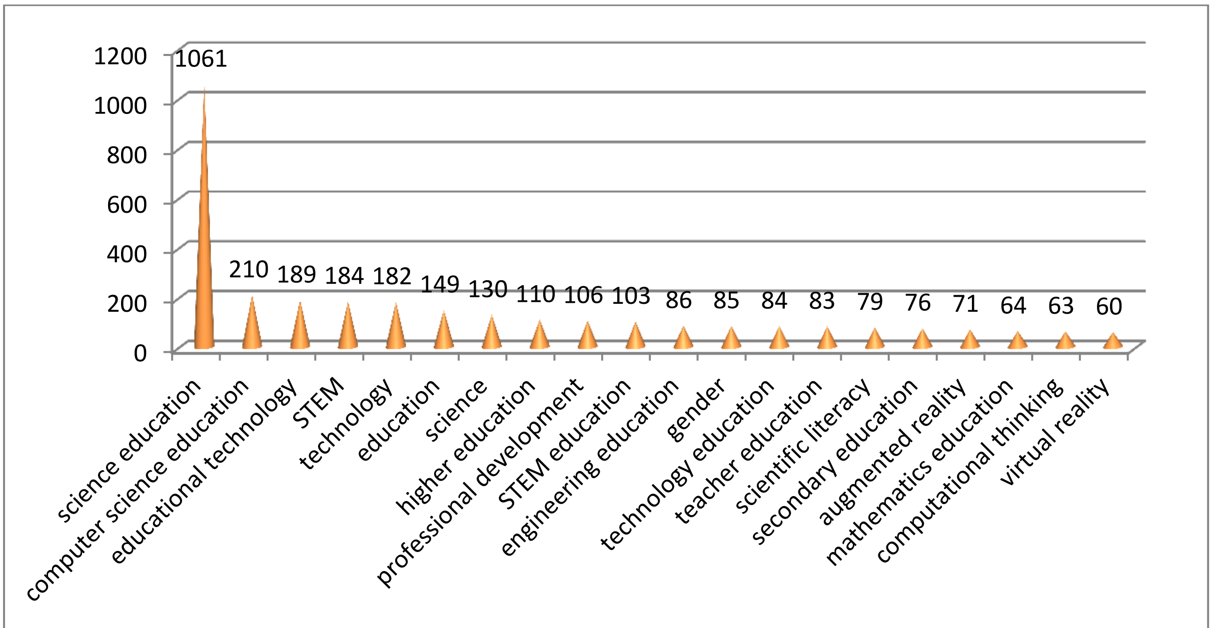
Graphic 11. Authors and citations

Findings Related to Keywords Used in Articles on Science Education and Technology

When the keywords used in the articles on science education and technology published in the Web of science database were analyzed, 5567 keywords were identified. 207 of these keywords were used at least 5 times or more. The most frequently used keyword is “science education”. Science education has a frequency of use of 682 in related articles. The second most frequently used keyword is “computer science education” (115), the third keyword is “stem” (89), the fourth keyword is “technology” (85) and the fifth keyword is “educational technology” (83). The top 20 most frequently used keywords and their frequency of use are presented in Graph 12.



Graphic 12. Keywords and frequency of usage



Graphic 13. Keywords and total link strength

The total relationship strength of the 5 most frequently used keywords is as follows: science education (1061), computer science education (210), educational technology (189), stem (184) and technology (182). The keyword with the highest association strength is "science education", which is the most frequently used keyword. The top 20 keywords with the highest total relationship strength are presented in Graph 13.

The centrality and frequency of keywords are shown by co-occurrence mapping. As seen in the figure, the keywords with the largest ring are the most frequently used keywords. The larger the area of the figure with the keyword, the higher the frequency of use (Figure 4).

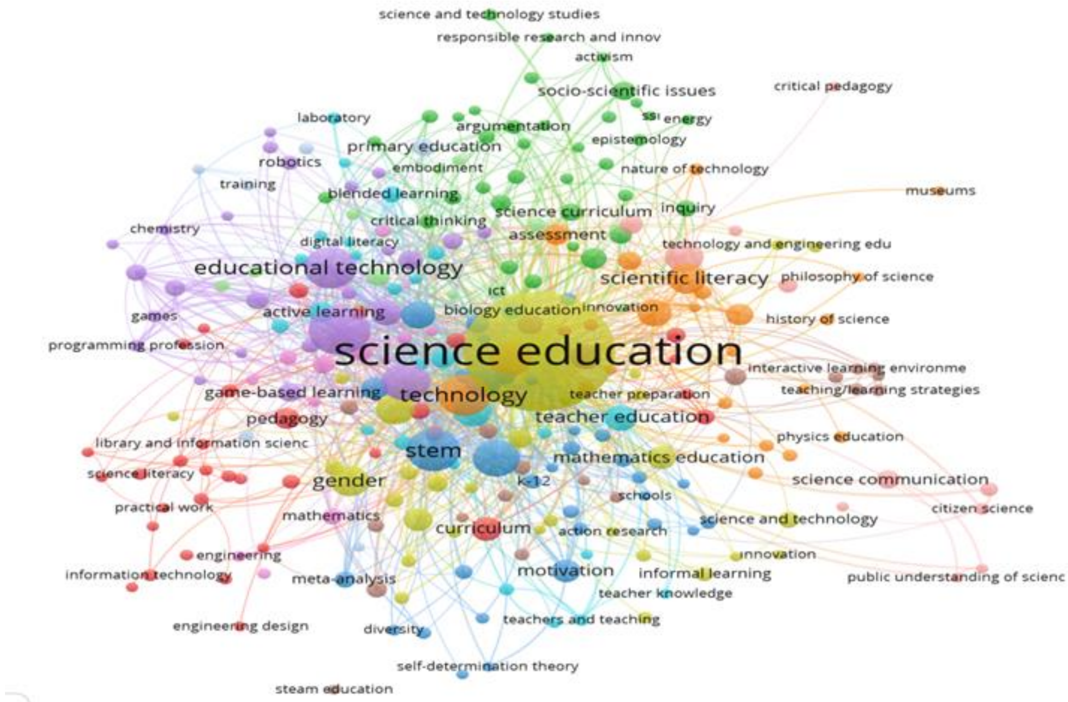


Figure 4. Keyword co-occurrence map

The co-occurrence map showing the keywords used together with the term science education, which is the most frequently used keyword, is presented in Figure 5.

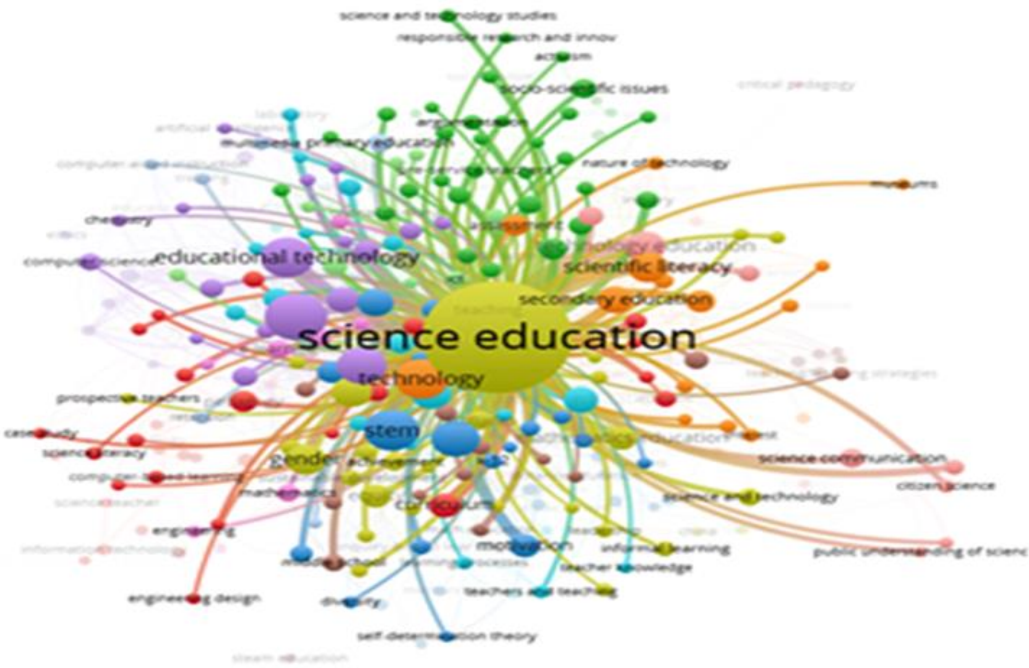


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Figure 5. "Science education" co-occurrence map

Conclusion and Discussion

This study was conducted to determine the bibliometric profile of the articles on science education and technology in the literature. The research is a quantitative research. In the study where descriptive research model was adopted, bibliometric analysis method was used. In the study, bibliometric data were visualized and presented with graphs and co-occurrence maps. Web of Science database was used as the database to be scanned in the research and VOSviewer program was used as the analysis program. As a result of the first search in the database with keywords, 3983 documents on science education and technology were found in the Web of Science database. The documents were filtered by type and year. Due to the fact that scientific publications in the field of science education and technology may show the research profile incompletely, may negatively affect the interpretation of the research trend, and may lead to incorrect inferences, the current year 2024 data were not included in the study. After this filtering process, the analysis continued with the remaining 2485 articles.

When the data of the research are analyzed, it is seen that the first article on science education and technology in the relevant database was published in 1980. From 1980 to 2023, it can be said that there is a general increase in the number of publications. The year with the highest number of publications in the related subject area is 2022; the years with the least number of publications are 1980, 1986, and 1989. According to the results of the analysis, 92.7% of the 2485 articles were published in English. This is not surprising considering that English is the most widely spoken language in the world and academic world. The journal that hosts the highest number of publications in the related subject area is “Journal of Science Education and Technology”. As the name of the journal suggests, it is a science education and technology themed journal. The journal hosted 4.26% of the total publications from 1992, the first year of publication, until 2023. Another finding of the study is the result regarding the countries where the publications were made. According to the results of the analysis, 37.1% of the articles in the relevant subject area were published in the United States of America. When the cooperation relationship of these countries was analyzed, it was determined that the USA was the country that cooperated the most in the related subject area publications. When the institutions where science education and technology subject area publications were made were examined, it was determined that the institution with the highest number of publications in the relevant subject area was the University of California System. As a result of the institutional analysis, 2211 institutions were observed and among these institutions, Unıversıty Of Californıa System ranked first with 71 articles on the subject. As seen in the results of the study, the country that publishes the most and cooperates the most on the relevant subject is the USA. The institution with the highest number of publications on the relevant subject is also located within the borders of the USA. These results can be interpreted as a result of the fact that science education and technology is a subject that is taken very seriously in USA educational institutions. In the United States, many societies such as the International Society for Technology in Education and the National Research Council have emphasized the importance of integrating technology into science education through their reports. It is known that science education and technology integration took place in university programs in the United States in the 1970’ s with the Science-Technology-Society (STS) trilogy (Yager & Roy, 1990). It is also known that the concept of STEM, which is based on the integration of science and technology, originated in the United States (Cunningham & Higgins, 2015). Another finding of the study is the results related to the fields of study of the related articles. The results of the analysis show that most of the articles on science education and technology were conducted in the field of educational studies. 72.9% (1813 articles) of the related articles were conducted within the scope of educational research. Educational research is followed by computer science and engineering. When the authors of science education and technology articles are analyzed, 6401 researchers are listed in the database. The name with the most publications among the researchers is Bogner, Franz Xaver. The researcher author has 21 articles on the related subject and his institution is University of Bayreuth.

Another result of the research is the findings related to the citation statistics of articles in the field of science education and technology. When the citation statistics were examined, it was determined that the most cited article in this field was the publication titled “Current status, opportunities and challenges of augmented reality in education” written by Wu et al. (2013). The publication has 1049 citations. The researcher with the highest number of citations is Hsin Kai Wu, who one of the authors of the article with the highest number of citations. The researcher has 1216 citations. When the researcher author's research areas are examined, science education, technology learning and early STEM education attract attention. The most cited journal in the related field is “Science Education”. The total number of citations of the journal's articles in the related subject area is 4017. The institution with the highest number of citations is Northwestern University. The total number of citations from the articles published in the related subject is 2248. The country with the highest number of citations is the United States of America, the country with the highest number of publications and collaborations. The United States of America received a total of 24281 citations from the articles published on the related subject. The keywords used in articles on science education and mathematics were analyzed. According to the results of the analysis, the most frequently used keywords in science education and technology subject areas were science education (1061), computer science education (210), educational technology (189). In the fourth place is the concept of STEM (184), which is one of the most current and popular terms for the integration of technology into science education. The fact that the most frequently used word in the academic studies published on the related subject is science education can be interpreted as a result of the emphasis on the integration of technology and science education. It is only possible for individuals to acquire a behavior through education. In this context, one of the skills that individuals should acquire in the age of technology we are in is technology literacy skill. Science and technology cannot be considered separately, they are the locomotive of each other. For this reason, it is a situation that all facts related to technology should be included in science education. Technology learning and all skills related to technology are closely related to science education.

In this study, 44 years of research trends of articles on science education and technology were analyzed and bibliometric profile was revealed. The results of the study serve as a guide for researchers who want to conduct research or study in the field of science education and technology. By examining the study, a researcher interested in the field will be able to access the fields of study, journals, institutions, and countries that identify the relevant subject area as a theme. In addition, researchers will be able to have information about the authors who work and collaborate in this field the most, the most referenced articles, and will be able to access internationally influential sources. They will be able to access the most frequently used keywords in this field. In this context, researchers will be able to determine in which disciplines they will continue their research and which concepts they can include in their study. A researcher who has all this information will be able to conduct a literature review and plan his/her research in these contexts by accessing the research trends of articles on science education and technology. Another benefit of presenting bibliometric data is that it provides information about the institutions, documents and researchers that researchers who need information or support in the relevant field can turn to for help. Presenting this information to the literature is of great importance for researchers who want to examine the research trend of the subject area.

Recommendations

Researchers who want to have more detailed information on the relevant subject can conduct content analysis with the documents that make up the data file and reach detailed results about the methodology and findings of these studies. Researchers who want to study on the subject can expand their study data by searching different databases.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the author.

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The Nested Knowledge System of TPACK: A Case Study on Physics Teachers' Educational Resource Selection and Integration

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Content knowledge

Abstract

The aim of this research is to explore the system of knowledge of the Lebanese secondary physics teachers that affects the selection and integration of educational resources. This teachers' knowledge was studied through their pedagogical and technological pedagogical content knowledge (PCK and TPCK) concerning instructional strategies, students understanding, curricula, and curriculum materials, including technology that is mobilized in their practice. For this aim, a qualitative approach was employed, and four physics teachers purposefully selected from four secondary schools participated in this study. Classroom observations and interviews were used as research data collection tools. The data analysis revealed that the system of the different teachers' knowledge studied in this research could be seen as a whole, while one system of knowledge was highly related to another. This study, hence, called these consistent knowledge systems "nested knowledge system." This study also showed that this "nested knowledge system" determines teachers' didactical decisions in general and influences the selection and integration of resources in particular. It also revealed that misconceptions are persistent and cannot be changed easily. Moreover, the context of the teaching-learning process reshapes the teacher's knowledge about students' understanding, which is the only knowledge that shows inconsistency between intended and operational practice. In addition, it showed that teachers' knowledge about students' understanding (PCK/U) has a significant effect on teachers' knowledge about curricula and instructional strategies (TPACK/C & TPACK/S).

Introduction

Investigating a teacher's professional knowledge is one of the ways to understand the act of teaching and the objectives of the different activities adapted by teachers in classroom (Sarkim, 2004). Planning and teaching processes are complex activities where teachers should use knowledge from different domains (Chazbeck & Ayoubi, 2018). The education research did not consider the importance of studying the influence of the content taught on the teaching process; it just dealt with the pedagogical knowledge independently (Shulman, 1986a). Shulman was the first in the literature to introduce a new concept where pedagogical knowledge and content knowledge are treated together as one domain of investigation named Pedagogical Content Knowledge (PCK). This concept is also known as content-specific or subject-specific pedagogical knowledge (McDiarmid et al., 1989). The main question of Shulman (1986b) that drove his research was about the essential knowledge of teachers to transform their disciplinary knowledge into effective teaching. Shulman developed a new framework for teacher education by introducing the concept of PCK as the knowledge base for teaching. Thus, teachers must mobilize their pedagogical knowledge (PK) and their content knowledge (CK) in order to introduce.

Nowadays, the proliferation of technologies and their use become an essential element in most domains of human work. In the last decade, research in the field of education focused on technology and not on its usage, which could be attributed to the lack of a theoretical framework that can develop, explain, and understand the process of integration of technology (AAAS, 1999). Nowadays, the integration of technology enables teachers to develop their system of resources to a certain extent and make them easy to share (Webb, 2008). Merely introducing technology in the classroom is not sufficient; teachers should be knowledgeable about how this technology is better used and adapted in order to present comprehensive materials to students. Moreover, the content and the nature of knowledge play a role in the determination of the type of the chosen technology. This progression has changed the routines and practices of the teaching and learning process in the domain of education (Mishra & Koehler, 2006). Mishra and Koehler (2006) developed a new theoretical frame to study the integration of technology in education and the factors affecting it. This framework conceptualized the relationship between technology and teaching. It related the triad of teachers' knowledge about technology, pedagogy, and content in one frame called the Technological Pedagogical Content Knowledge (TPCK).

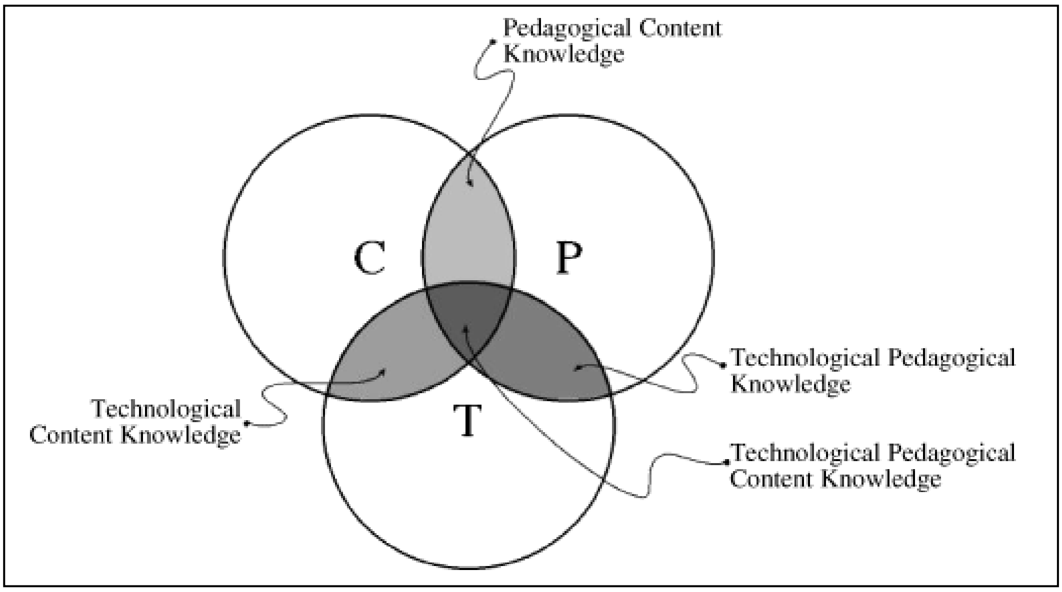

Figure 1. The technological pedagogical content knowledge (Mishra & Koehler, 2006).

Figure 1 shows the new frame developed by Mishra and Koehler, represented by the intersection of three circles presenting the technology (T), the pedagogy (P), and the content (C). However, this relationship emphasized the interrelations, affordances, and constraints between and among the triad of teacher knowledge: the content, the pedagogy, and the technology. Moreover, this frame distinguished between this knowledge and looked at them as pairs: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK).

A few research in Lebanon studied teachers' professional knowledge or pedagogical content knowledge (PCK) that affects the selection and the use of available resources. The PCK has become one of the essential elements of investigation in science education and the most affecting factor in the pedagogical decisions of teachers (Chen & Wei, 2015). Therefore, the present study came to fill a gap in the literature in Lebanon about Physics teachers' professional knowledge and its influence on the selection and integration of resources in general.

The selection and the integration of different resources are affected by many factors. One of the ways to study these factors is to explore teachers' professional knowledge through their PCK. Moreover, some of the resources used are digitals and require some technological skills. Thus, this study attempts to investigate teachers' technological knowledge through the investigation of their TPCK. This research aimed to investigate teachers' professional knowledge, particularly their pedagogical content knowledge (PCK) and technological pedagogical content knowledge (TPCK) that affects the selection and integration of educational resources. For this purpose, this study intended to answer the following questions:

1. What are the secondary physics teachers' PCK and TPCK that directed their documentary work on the available educational resources?
2. What is the difference between the intended practices and the operational practices in teaching electricity in terms of teachers' PCK and TPCK?

Theoretical Background

The aim of this study is to investigate teachers' pedagogical and technological content knowledge (PCK and TPCK) that affects the selection and integration of different resources in the professional work of secondary physics teachers. Educational resources include everything that can be selected by the teacher and help him to present his course to enhance students' understanding, and it exceeds the material resources to cover human resources, social and cultural resources, and time (Adler, 2010). In this study, the resources are divided into two categories: the material resources (MR) and the non-material resources (NMR). Moreover, they are distinguished between object resources (OR), audio-visual resources (AVR), paper resources (PR), and evoked resources (ER) (Chazbeck et al., 2018).

Teachers' knowledge, or simply "knowledge," formed the subject of much research in the field of education for many years. This word took many forms in the literature and carried different definitions, including several components. Shulman differentiated several types of teachers' professional knowledge and introduced, for the first time, the notion of pedagogical content knowledge (PCK), and he categorized PCK into two main categories: knowledge of teaching strategies and knowledge about student difficulties. These two categories are based on the strategies and methods used by teachers to build and present disciplinary content, taking into consideration the misconceptions of students and their learning difficulties. The debate on the categorization of PCK and the nature of knowledge that constitutes it remains unclear. From the literature, scholars distinguished many components in the system of knowledge constituting the PCK; some of them were similar, while others were different (Park & Olivier, 2008). These components varied between students' understanding, instructional strategies, and many other components about assessment, media, curriculum, context, pedagogy, and subject matter. Indeed, the views of researchers differed about the categorization reference components of PCK while they all argued about the importance of PCK in the field of education. This importance is manifested in teaching as a whole, teachers' preparation programs, studying teachers' professional knowledge, enhancing the learning process, etc. The commonly argued definition of PCK is the needed professional knowledge for teachers to link their pedagogical knowledge to their disciplinary knowledge in teaching specific content for particular students in a specific context.

What makes the categorization of PCK in science education difficult is the inconsistency of research on it (Abell, 2007). Kind (2009) suggested that among the various models of the categorization of PCK, the model of Magnusson et al. (1999) is best adopted to characterize the work of science teachers since it includes the best needs of the scientific training of teachers. In physics education, Sarkim (2004) and Cross (2009) adopted the model of Magnusson to study secondary teacher's professional knowledge. This model distinguished five components of knowledge: *knowledge of science curricula, knowledge of instructional strategies, knowledge of students' understanding of science, knowledge of assessment of scientific literacy, and orientation towards teaching sciences.*

In the 21st century, technology has become a very important domain that affects the majority of professional domains, especially in the field of education. For example, Computer Assisted Teaching (CAT) in science has become affordable to a larger population. By using CAT, physics teachers may enhance visual characteristics in teaching specific topics (e.g., radioactivity, complex motions, electricity...) with less effort using available wizards. In addition, using technology in teaching physics requires teachers' skills in technology. Therefore, for teaching specific content using technology, teachers should be knowledgeable of the content itself, the general pedagogy, and the technology. Thus, by referring to the PCK conceptualization, scholars develop another domain of knowledge called "*Technological Pedagogical Content Knowledge*," or TPCK.

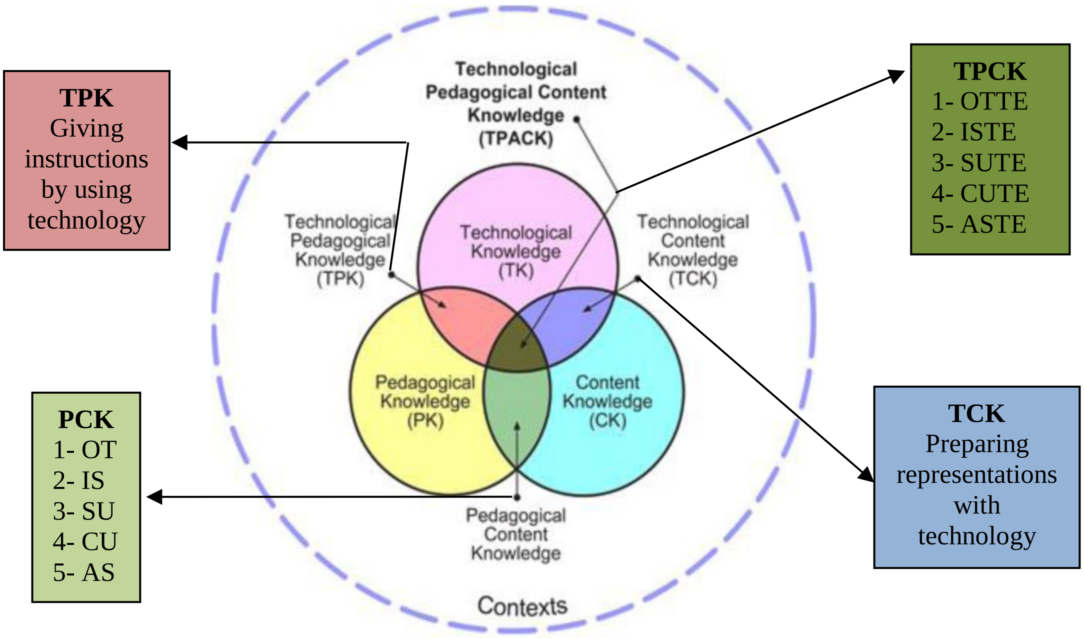

Figure 2. An expanded model of TPCK (adapted from Koehler and Mishra, 2006; conceptualization of TPCK (Magnusson et al. 1999)

According to Graham et al. (2009), when a teacher knows how technological tools transform pedagogical strategies and content representations for teaching particular topics and how it affects student's understanding, then TPCK is achieved. Extending Grossman's (1990), Niess (2005) proposed that teachers exhibit TPCK when they overmatch teaching particular subject for particular students by integrating particular technology to enhance students' learning. Therefore, the teacher mobilized TPCK mainly when he built a convenient strategy using a specific technology to teach particular topics from the curriculum of a specific discipline to enhance students' understanding of learning specific topics. Thus, TPACK covered the components of PCK with a specification of using a specific technology.

Figure 2 shows an expanded model of TPCK, developed by TaĢar (2010) and based on the work of Magnusson (1999) and the model of Mishra and Koehler (2006). This model conceptualized the TPCK by: *Knowledge of instructional strategies and representations for teaching specific topics with technology* (ISTE); Purposes and goals of teaching *specific content using technology (OTTE) (Orientation to teaching with technology); of students' understandings, thinking, and learning with technology in a particular subject* (SUTE); *Knowledge of curricula and curriculum materials that integrate technology with learning* in the subject area (CUTE) and *knowledge of assessment with technology* (ASTE).

Indeed, during their professional work, teachers were expected to facilitate students' learning of a specific concept. Therefore, they should be aware of the typical students' learning difficulties and misconceptions related to specific content. Furthermore, students might also have trouble with teaching strategies adopted by teachers. Therefore, to help students overcome their difficulties at several levels (content or teaching strategies), physics teachers were expected to develop their teaching by selecting appropriate strategies in order to promote students' understanding of specific physics content. Then, they should be knowledgeable about the specificity of the content, the objectives of the physics curriculum, and the teaching strategy that can enhance learning of specific content. Thus, special attention goes to three components of PCK among the five proposed by Magnusson et al. (1999): PCK/students' understanding, PCK/curriculum, and PCK/teaching strategies. Two of these categories (PCK/understanding and PCK/strategies) that Shulman called the knowledge base for PCK (Shulman, 1987). In addition, the corresponding TPCK related to these three categories are TPCK/ISTE, TPCK/CUTE, and TPCK/SUTE. The third component about students' understanding, thinking, and learning with technology consists of knowledge about students' learning difficulties in using technology. However, this component is not explored in this study because it is not related to any of its objectives.

Thus, professional knowledge was divided into two categories: PCK and TPCK. In turn, teachers' PCK was divided into sub-categories, which are the strategies of teaching (coded by PCK/S), the students' understanding (coded by PCK/U), and the curricula and curriculum materials (coded by PCK/C). TPCK was also divided into two sub-categories about teaching strategies using technology (coded TPCK/ST) and curriculum materials using technology (coded TPCK/CT), as shown in Figure 3.

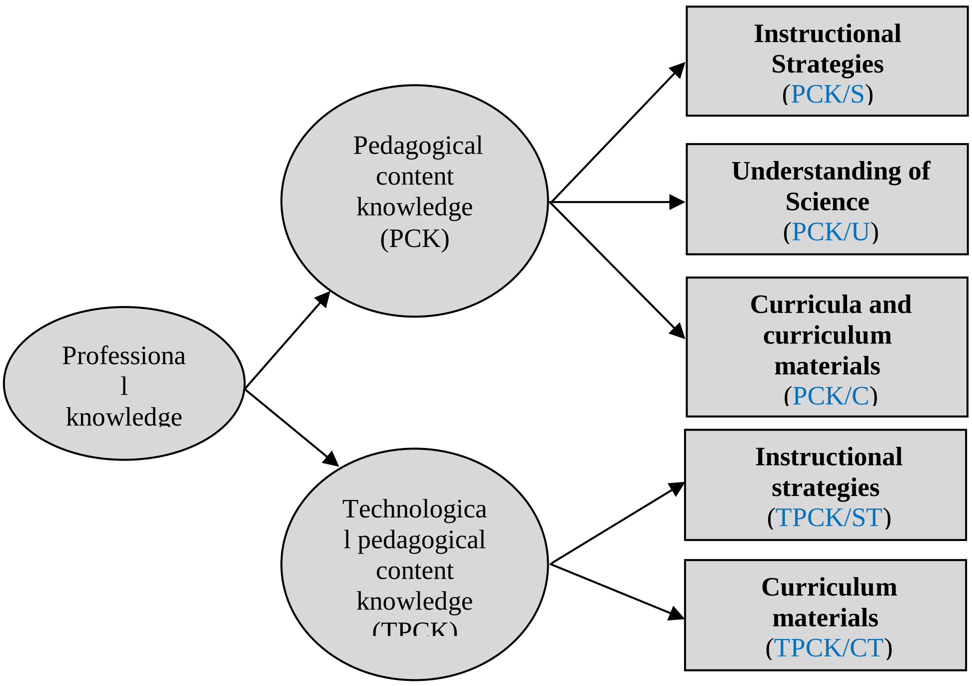

Figure 3. Categories and sub-categories of the theme "professional knowledge, K."

Figure 3 shows the system of teachers' professional knowledge (K) inspired by the model of PCK developed by Magnusson (1999) and that of TPCK developed by Mishra and Koehler (2006). From these two models, five components of knowledge were identified as crucial for this study: PCK/U, PCK/S, PCK/C, TPCK/ST, and TPCK/CT. In this study, the differentiation between PCK/S and TPCK/ST is not primordial since the main objective is to study the inferred knowledge behind the selection and integration of educational resources. Thus, these two sub-categories will be combined into one only named the total package of pedagogical and technological knowledge related to the instructional strategy with or without using technology denoted by TPACK/S. Consequently, the total package of pedagogical and technological knowledge related to the curriculum material with or without using technology is denoted by TPACK/C.

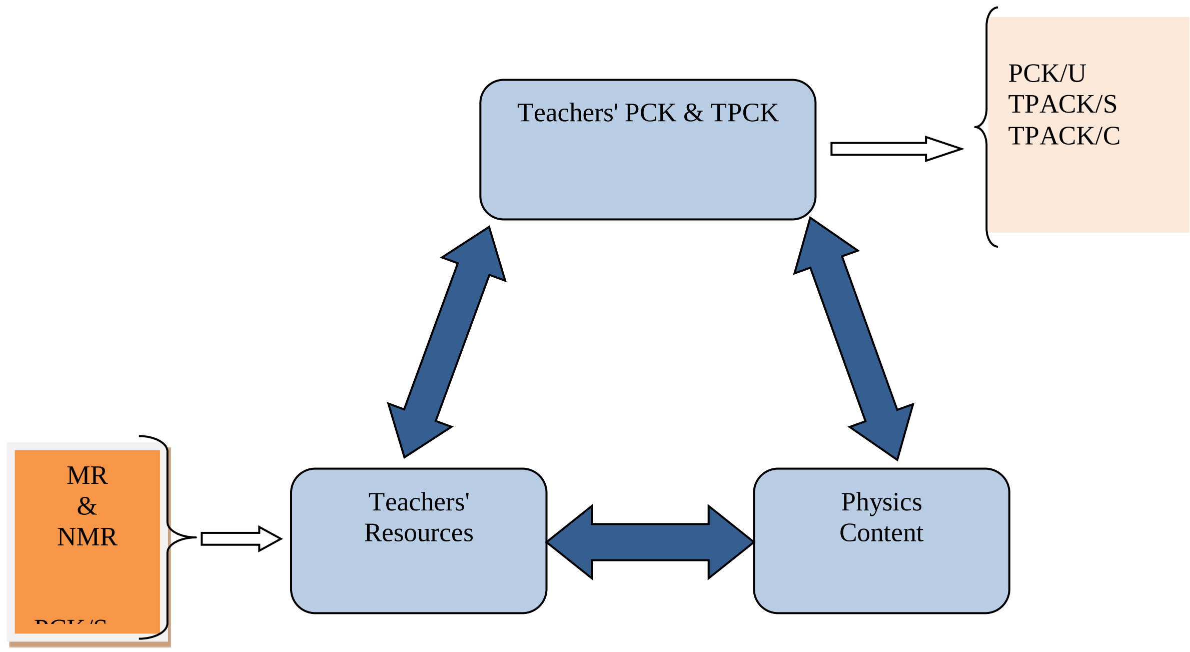

Figure 4. Schematic representation for the theoretical framework

In summary, this study focused on the secondary physics teachers' professional knowledge (K) through their *pedagogical content knowledge* (PCK) and their *technological pedagogical content knowledge* (TPCK) that drives their choices for the educational resources and its integration into their professional work. To explore this knowledge and the selected resources, the researchers referred to the concept of PCK (Magnusson, 1999) and TPCK (Mishra & Koehler, 2006) in addition to the categorization of resources developed by Chazbeck *et al.* (2018). Figure 4 presents the three parts characterizing the theoretical framework of this research, which are interrelated: the resources, teachers' PCK and TPCK, and the content included. The analysis of the content included in the usage of a resource characterized the objective of the use of the resource as an interaction with the professional knowledge of the teachers (PCK and TPCK).

Method

Research Design

This research is designed to investigate secondary physics teachers' technological pedagogical content knowledge (TPACK). More precisely, it permits the researcher to explore the systems of teachers' professional knowledge that drive their work on the educational resources in their teaching in general and particularly for teaching electricity. The setting and the participants of the research were selected purposefully.

Participants

The participants were four secondary physics teachers at Lebanese private and public schools. These teachers were selected based on some specific criteria related to their teaching experience, their proficiency in using educational technology, and their school settings. The four teachers selected for in-depth investigation were given the pseudonyms Albert, George, Pascal, and Curie. Two of them are beginning teachers; they have less than ten years of teaching experience, and the two other participants are in mid-career, having more than 15 years of teaching experience.

The four teachers worked in different schools with different levels of equipment. They had different profiles, but they all believed in the importance of educational technology to enhance students' understanding, and they all taught secondary classes. Table 1 shows a comparison between the different profiles and work environments of the selected participants.

Table 1. Teachers participating in the research

Name*	Diploma	Teaching experience	School' setting
Pascal	BS+TD	Eight years	Poor
Curie	BS+TD	Seven years	Average
Albert	BS	18 years	Good
George	BS	22 years	Average

* Pseudonyms

Data Collection Tools

The data was collected purposefully through semi-structured interviews and classroom observations. The interviews and the classroom observations helped the researchers to investigate the intended and operational practice of secondary physics teachers in general and the use of educational resources in particular. All the interviews and the observations were recorded or videotaped, then were all transcribed and checked again by the participant to ensure the exactitude of the collected data.

In this study, semi-observation is employed where the observer does not use a particular instrument, such as a checklist. The purpose of the classroom observations was to observe the teaching activity and the integrated educational resources in the setting (Patton, 1990b). Video recordings of observed sessions enabled the partial reconstruction of the studied situation and allowed the viewing and reviewing of videotapes. Additionally, it allowed them to observe verbal and non-verbal interactions between students and teachers (teacher-student, student-student). In order to clarify the overall picture of the teaching-learning process, notes and reflections were taken excessively during classroom observations. The researcher observed the activities (Fraenkel & Wallen, 2000) but did not take part in them. Thus, he is said to be the data-collection instrument (Johnson & Christensen, 2008). The length of the observations varied depending on the teaching time observed.

Despite knowing they were being observed, the research participants did not know the purpose of the observations. By using the interview guide approach (Patton, 1990a), the interviews were conducted to explore teachers' opinions and practices about their teaching and how their experiences might inform their current practices. In the data analysis, the forms of PCK used by teachers were extracted from their teaching content and strategies. Researchers also investigated how teachers perceive the teaching and learning process by conducting informal conversations and interviews with them. Analyzing the data using thematic analysis was conducted (Boyatzis, 1998).

Method of Data Analysis

The analysis of the data collected from the interviews and classroom observations was conducted on the basis of criteria inspired by the theoretical framework of this study. The interviews and the videos were first transcribed, and then the discourse was segmented into meaningful analytical units before being coded and categorized into themes. The themes were coded using descriptive words in relation to the objectives of the research (Johnson & Christensen). The main themes in this research in relation to the purpose are the educational resources and teachers' professional knowledge. The resources were categorized into their types: material and non-material resources coded by MR and NMR (Chazbeck et al., 2018).

The material resources included documents, books, copybooks, lab tools, real-life tools, videos, CDs, software, images, etc.) whereas the non-material resources, also called Evoked resources (ER), were examples of natural phenomena, features, or any material situation related to the taught subject that teachers could use it in their professional work. Concerning the second theme, this research aimed to study teachers’ professional knowledge (coded by K) behind the use of diverse resources. In this research, this theme covered teachers' knowledge about the general pedagogy, the subject matter, the curricula, the instructional strategies, the students' difficulties, the educational supports, and the educational technology. This knowledge could be viewed as the total package of knowledge (TPACK) called the technological pedagogical content knowledge (Mishra & Koehler, 2006). This knowledge is categorized into three main categories: knowledge about students' understanding (PCK/U), knowledge about curriculum including technology (TPACK/C), and knowledge about instructional strategies including technology (TPACK/S).

The criteria of analysis of the declarative and operational knowledge in terms of teachers' TPACK are inspired by Cross (2009) and the model of Magnusson (1999). The inferred TPACK/C is divided into three main categories: knowledge about the different resources that can be selected and integrated into teaching, knowledge about educational technology, knowledge about the objectives of the physics curriculum, and knowledge about the other interrelated curricula. The criteria to infer PCK/U covers the mathematics students' difficulties in solving problems, difficulties in learning scientific concepts, and students' difficulties in the application of scientific concepts in real life. However, the criteria to infer TPACK/S are related to the main characteristics of instructional strategies applied to present physics content.

In order to study the main system of knowledge affecting the selection and the integration of educational resources, a comparison between the inferred PCK and TPACK about students' understanding, curriculum, and instructional strategies is made. This helps the researcher to understand which system of knowledge drives the didactical decision of the teacher concerning the relevant resource to present specific content in an understandable way. Moreover, the comparison between the inferred PCK and TPACK from the declarative data (interviews) and operational data (practice) permits the researcher to study the role of the context of the teaching/learning process on the teachers and their pedagogical decisions.

Results and Discussion

In this section, the researcher presents the findings from the analysis of the interviews and the classroom observations in terms of teachers' TPACK behind the selection and the integration of pedagogical resources. Moreover, the analysis aimed to study the difference between the intended practice (declarative knowledge from the interviews) and the actual practice (operational knowledge from the classroom observation) in terms of teacher's TPACK. The analysis of data collected from the interviews and the classroom observation in terms of teachers' TPACK behind the selection and the integration of pedagogical resources corresponds to three main categories of knowledge related to students' understanding (PCK/U), the curriculum material (TPACK/C) and instructional strategies with or without using technology (TPACK/S).

Table 2. List of most common inferred teachers' TPACK/C

Categories	TPACK/C
Knowledge about NMR and MR	1. Teachers know the objects from real life, and students' pre-knowledge permits them to introduce and define an electric generator and receiver. Explain or clarify a law. 2. Teachers know relevant examples from students' everyday real life (battery, motor, electro-dynamic flashlight..., etc.) that they can evoke to illustrate the principle of conservation of energy relative to generators and receivers. 3. Teachers know that there are visual educational aids (e.g., videos, software, phone applications...) that they can use for specific physics content (e.g., electricity, radioactivity, astronomy...).
Knowledge about different curricula	1. Teachers know what students have as pre-knowledge from previous classes about the unit of electricity in general. 2. Teachers know different physics books of different levels and from different educational systems that they can use in relation to specific content.
Knowledge about the objectives of the curriculum	1. Teachers know the objectives of the Lebanese physics curriculum of teaching the chapter on generators and receivers in grade ten. Find exercises and problems. 2. Teachers know the curriculum of chemistry in grade nine related to electric generators and receivers and can serve them to illustrate the principle of conversion of energy.

Table 2 shows the most common TPACK/C inferred from the individual analysis of the four case studies. It reveals that teachers are knowledgeable about the vertical curriculum and its objectives, in addition to the availability of materials and non-material resources (MR and NMR) related to specific physics content and its application in real life. Furthermore, it also shows that teachers are knowledgeable about technology and its integration in the field of education and its importance for some specific content.

The cross-case analysis in terms of TPACK/C shows that teachers who are knowledgeable about the applications of many physics principles in real life refer mainly to the evoked resources and the real-life objects to introduce many physics content. Moreover, their knowledge about the availability of some simulation software or videos permits them to illustrate some particular physics content (astronomy, radioactivity, etc.) and to help students overcome their learning difficulties. However, George, who did not use any object or visual resources and who has more teaching experience than the other three cases, showed more proliferation in SMK (subject matter knowledge) in his teaching. He was the only one who could explain that there is no distinction between the theoretical and experimental value of the open circuit voltage. Moreover, he explicitly presented some extra knowledge in relation to the taught chapter that could enhance students' understanding.

On the other hand, all the teachers were knowledgeable about the curriculum objectives, and they followed the same divisions stated by the official textbook. Therefore, teachers' knowledge about the available materials in their work environment and their relevance for specific content, in addition to their knowledge concerning the interrelated curricula, affect the selection of the pedagogical resources. Thus, TPACK/C forms one of the basic knowledge behind the selection of specific resources and their implementation in a specific strategy to present specific content.

The knowledge of teachers about the sources of difficulties that students struggle with during their learning process is studied through teachers' PCK/U. The analysis in terms of PCK/U inferred from the interviews showed that the four teachers knew a set of students' learning difficulties related to various physics content. Table 3 shows the most common teachers' PCK/U inferred from the declarative data of the four case studies. These difficulties correspond to different topics in physics, such as the period of oscillations of a pendulum, the time dilation in relativity, the nuclear reaction, the potential difference, the current and the short circuit, the principle of conservation of energy, the term confusion, the electromotive force, and the back electromotive force.

Table 3. List of the most frequent PCK/U inferred from teachers' declarations in the interviews

PCK/U
Students have difficulty understanding that the period of oscillations of a simple pendulum is independent of its mass and its amplitude.
Students have difficulty understanding the principle of conservation of energy.
Due to its abstract nature, the electric current formed a source of difficulty for the students in learning electricity.
Students have difficulty understanding the concept of time dilation in relativity.
Students have difficulty understanding the equivalence of many electric generators.
Students have difficulty identifying series resistors, in particular when they are geometrically parallel in the circuit.
Students have difficulty understanding the meaning of an electromotive force for an electric generator and the back electromotive force for an electric receiver.
Students have difficulty understanding that an electric short circuit puts two or many electric points on the same electric potential.

According to teachers' declarations in the interviews, teacher's knowledge about the sources of learning difficulties came from teachers' professional knowledge and their experience as teachers and as students. Therefore, to help students overcome their learning difficulties or to remove students' misconceptions, they mobilize many types of educational resources. Table 4 shows the most common educational resources selected by the teachers to enhance students' understanding of specific content. Thus, one of the factors that affect the selection of educational resources is the professional knowledge of teachers about the sources of difficulties that students struggle with. Then, PCK/U forms one of the basic knowledge that teachers mobilize behind the selection of resources from one side, and it affects teachers' TPACK/C from the other side.

Table 4. Some educational resources that teachers select in relation to PCK/U

MR and NMR related to PCK/U.
Making experiment using concrete materials help students understand that the period of oscillation of a simple pendulum is independent of its mass.
Using real objects from everyday life, i.e., a battery, a motor, an electrodynamics flashlight, etc., illustrates the principle of conservation of energy in electricity.
Using a video showing a historical experiment of Einstein permits students to understand time dilation.
Using real resistors connected in series but geometrically parallel in the circuit permits students to identify series and parallel resistors.
Using many batteries connecting differently and using a voltmeter clarifies the concept of the equivalence of many electric generators.
Referring to the evoked resources, such as the motor of a domestic water pump, helps students to overcome their difficulty about the meaning of the back electromotive force of a receiver.
Simulation or virtual lab is a way to show how the nucleons go out from the nucleus during nuclear fission.
The projection of a video showing the free fall of a parachute explains the influence of a frictional force (air resistance) on the motion.
Using simulation programs like Phet helps students to understand nuclear fission and fusion in radioactivity.
Using a phone application (i.e., Solar Walk) shows the rotation of the solar system and its period of revolution.

However, the analysis of data in terms of educational resources showed that virtual laboratories and simulations are chosen mainly for astronomy, relativity, and radioactivity. However, when there is a lack of equipment, this type of resource replaces the use of concrete materials in real laboratories for electricity, mechanics, and other topics. Otherwise, teachers declared that real laboratories form the most common way to help students understand physics in a good way and remove their misconceptions. Therefore, teachers' PCK/U led them to find specific support and specific strategies to overcome students' learning difficulties in teaching specific physics content. Thus, many of the teachers' TPACK/S was based on their PCK/U, and then many resources were mobilized to this aim.

The analysis of data collected from the interviews and the classroom observations in terms of TPACK/S showed that teachers referred mainly to the in-door lab and Socratics' questioning as instructional strategies in teaching physics in general and to the classroom technology (videos, simulations, software, etc.) specifically for the inapplicable experiments in the school lab, such as the nuclear reactions and the observation of the solar system. Therefore, the inferred TPACK/S showed an advantage for the virtual experimentation against the real one for particular topics. Furthermore, due to a lack of materials, visual resources were also used to replace real experiments and to show some scientific laws. The analysis in terms of instructional strategies also shows when the equipment cannot cover all students' needs to do the experiment individually; teachers conducted the experiment by themselves. However, Albert believes that doing experiments by himself, where the role of students is limited to observation and answering the questions asked by the teacher, is time-saving.

The analysis of the classroom in terms of TPACK/S also showed that teachers selected different types of resources and integrated them into specific strategies to present specific content. For example, Albert, who is in his mid-career and teaching in an equipped school, applied in his teaching approach the "indoor lab" strategy most of the time, and he used for this aim the real object resources to perform experiments about all the main ideas of the chapter. However, Curie and Pascal, who are beginners (having less than ten years of teaching experience) and teaching in poorly equipped schools, applied classroom technology as an instructional strategy in their teaching in general and electricity in particular.

In addition to the visual resources (simulations, software, etc.), Pascal used examples from real life as non-material resources to present the different ideas of the chapter. George, who has more teaching experience (more than 20 years of teaching experience) and works in a non-equipped school, uses the traditional way in his teaching in general by using his drawings, demonstrations, and examples from everyday life. Table 5 presents examples of teachers' TPACK/S inferred behind the integration of different resources in the classroom to present the same content.

Table 5. List of some teachers' TPACK/S inferred behind the integrated resources to present Ohm's law

Teacher	TPACK/S
Albert	The experimental activity using concrete materials is a way to determine the (I-V) characteristics and to show Ohm's law relative to electric generators.
Curie	Betta uses classroom technology by referring to some software, i.e., the Edulab software, the Crocodile, and the Multisim, to show laws in electricity.
Curie & Pascal	Using the Multisim is a way that allows the teacher to determine the (I-V) characteristics of an electric generator and to show Ohm's law.
George	Referring to the examples from real life and then to the theoretical demonstration supported by the graphs is a way that permits us to determine the (I-V) characteristics and to show Ohm's law relative to electric generators.

It shows additionally that some of the selected specific visual resources depend on the specificity of the content itself while others replaced the lack of materials. The four case studies believed in the role of the experiment and the use of the real object, but the lack of materials and equipment in schools controlled the selection of the resources. However, Curie, who believed that the virtual laboratory is safer, easier to manage, more accurate, and saves time in comparison with the real laboratory, referred to visual resources in his teaching. Therefore, the availability of material and technologies in the teacher's work environment (school setting), teachers' pedagogical knowledge, and the specificity of the content included were determinants for the chosen teaching activity.

Thus, in order to select and integrate specific resources that are suitable to specific physics contents, teachers should be knowledgeable about the curriculum, students' learning difficulties, the availability of educational aids, the subject matter knowledge (SMK), and the objectives of related curricula. These factors were studied in this research by teachers' PCK/U and TPACK/C. Therefore, teachers' knowledge about specific instructional strategy (TPACK/S) that can be selected relies strongly on this knowledge (PCK/U & TPACK/C).

The "Nested Knowledge Systems"

The individual and the cross-analysis of the four case studies in terms of teachers' knowledge about students' understanding, instructional strategies, and curriculum materials behind the use of educational resources and the comparison between the intended and the operational practice were the main objectives of this study. The analysis of collected data from the interviews and the classroom observations shows that teachers are knowledgeable about the curricula and the educational resources (MR and NMR) in addition to the use of technology.

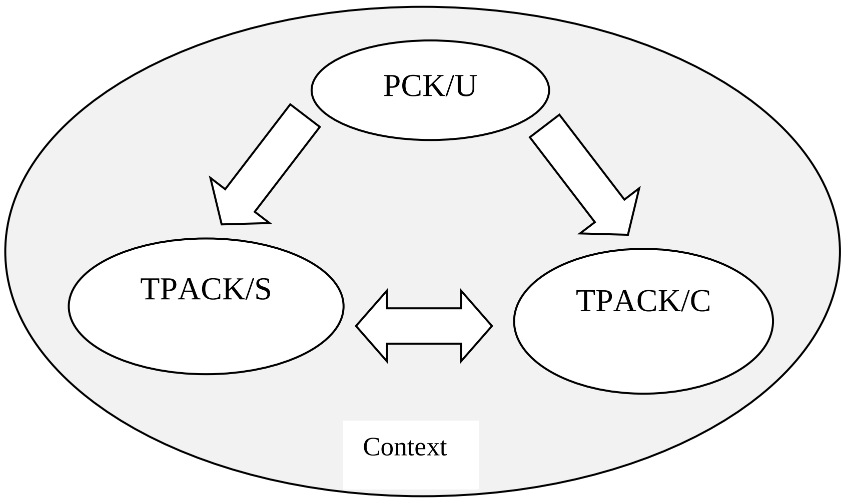

Figure 5. The nested system of teachers' professional knowledge behind the selection and integration of resources

Furthermore, teachers are also knowledgeable about the sources of difficulties that students struggle with in general and in the observed chapter in particular. Moreover, teachers are knowledgeable about different instructional strategies that they may apply to present specific content in a comprehensive way and to enhance students' understanding. Thus, for this aim, they mobilize different types of educational resources and implement them in a specific strategy to facilitate the process of learning specific content and to prevent or remove students’ misconceptions. Therefore, teachers’ PCK/U has a great effect on teachers' knowledge about the curriculum material and the instructional strategies. Thus, there is no one system of teachers' knowledge that drives the selection and the integration of educational resources in a relevant strategy to specific content, but interrelated systems of knowledge do.

Consequently, figure 5 shows a system of nested teachers' knowledge behind the selection and integration of different resources. Teacher's PCK/U, TPACK/S, and TPACK/C could be viewed as one whole system where different types of knowledge are interrelated. This study calls these consistent knowledge systems "nested knowledge systems." This system corresponds to teachers' knowledge about teaching and learning science as well as about the curricula, the curriculum materials, and the educational aids that can support teachers’ practice. The "nested knowledge systems" determines teachers' didactical decisions in general and influence the selection and the integration of educational resources to present specific content in a specific context.

Comparison between Intended and Operational Teachers’ Practice in terms of TPACK

One of the objectives of this research is to study the difference between declarative data (from the interviews) and operational data (from the classroom' practice) in terms of PCK and TPCK and between the stated resources and the integrated ones. This could help to understand how the teacher mobilized his professional knowledge in his work environment (equipment, students, content, etc.). The main findings about teaching strategies showed that they all give great importance to the indoor lab instructional strategy, but due to lack of school equipment and poor laboratories, the examples from real life and the software formed the main resources for their documentation work, especially for Pascal and Curie. However, George's PCK/S shows consistency between declarative data and the real practice only about the use of evoked resources, while no other type of resources appears in his practice. Teachers' declarations in the interviews about their teaching in general and teaching electricity in particular and the observation of their classroom did not show any specification concerning the instructional strategies. More particular, there is consistency between teachers' declarations and their practice about how to introduce a new concept and how to show the law relative to it.

The comparison between the inferred TPACK about the curriculum materials shows that there is coherence between declarative data and real practice. However, the four cases are all knowledgeable about the curriculum objectives, the different curricula, and the curriculum, in addition to their knowledge about the available technology that can be used in their teaching practice.

Concerning the inferred teachers' PCK/U, it shows inconsistency between the declarative data in the interviews and the real practice from classroom observations for three of the teachers (Curie et al.). In the classroom, students struggled with learning difficulties, which were slightly different from those stated by the teachers in the interviews. Albert was the only one to show consistency between declarative data and real practice in terms of PCK/U. However, George showed inconsistency between declarative data and real practice in terms of PCK/U, but on the other side, the analysis shows that he is knowledgeable about the applications of physics in everyday life and their relation with the taught subject. It also showed that he is knowledgeable about the subject matter and about the objectives of the curriculum. Furthermore, he knew how to clarify some confusing ideas that were not presented explicitly in the official book and could form a source of students' learning difficulty or even a misconception. Only Pascal's PCK/U about *term confusion* figured in the declarative data as well as the real classroom practice. Thus, the analysis of the classroom practice shows inconsistency in general between PCK/U inferred from the interviews and those inferred from the class observations. This inconsistency could be explained by the fact that the PCK/U changes with the context or the situation of learning in class according to the students' capacities and students' questions. This means PCK/U is strongly affected by the context of the teaching-learning process and its particularity. Thus, the context of the class is a determinant of the PCK/U.

In conclusion, the main findings related to the research questions can be summarized by the following points:

- Time constraints, school equipment, content specificity, and teachers' knowledge affect the selection of resources.
- Teachers' TPACK could be captured using interviews and classroom observations.

- Studying teachers' PCK about students' understanding showed the misconceptions that students and teachers have about learning different physics topics. Moreover, it also showed that misconceptions are persistent and highly resistant to change.
- The interaction between the available resources and the teacher's knowledge showed that TPACK/C and PCK/U are determinants for TPACK/S.
- Teachers with more experience developed better PCK, particularly about the content.
- Teacher's professional knowledge, particularly the teacher's PCK, is one of the main factors that affect teacher practice and his documentary work on the available resources.
- Teacher's PCK/U, TPACK/S, and TPACK/C could be viewed as a whole, while one knowledge system was highly related to another. This study calls these consistent knowledge systems "*nested knowledge systems*," which is responsible for teachers' didactical decisions.

Discussion of the Results

According to Gueudet and Trouche (2009), the documentation work about teaching resources is affected by teachers' professional knowledge in a specific context. In this study, teachers' professional knowledge was explored through some components of PCK and TPCK seen as relevant for the documentary work of the teachers. To infer this knowledge-namely, PCK/U, TPACK/S, and TPACK/C- data were gathered through interviews and classroom observations. This methodology was consistent with many researchers who used interviews (Fernández-Balboa & Stiehl, 1995; Koballa et al., 1999), classroom observations (van Driel, Verloop, & de Vos, 1998), and a combination of methods using the interviews and the classroom observations (Bellamy, 1990; Sanders et al., 1993).

The individual analysis of the four case studies about PCK/U showed that the participants were knowledgeable about a lot of students' learning difficulties related to different physics topics in general. In teaching electricity, they stated some misconceptions related to many ideas, such as the potential difference, the current, the resistance, the generation of electricity, the open circuit voltage, the short circuit, the misuse of some scientific words, etc. At this level, the literature review showed that many researchers had studied students' misconceptions of electricity (Dupin & Johsua, 1986; Guillaud & Robardet, 1997; Michelet, 2006; Osborne, 1983; Osborne et al., 1985), and they showed many models of them. These models were: "the unipolar or sink model," "the clashing currents model," "The weakening current model," "The shared current model," "the statement model," "the local reasoning model," "the short circuit model," "the battery as a current source," "battery and resistive Superposition principle," "topology," "term confusion," "rule application error" (Kapartzians, 2010). Some of the students' misconceptions stated by the teachers showed consistency with the literature review, such as "the weakening current model," "the battery as current source," and "the term confusion ."The analysis of classroom observation shows that the open circuit voltage across a device forms one of the students’ misconceptions. Indeed, the analysis of the discourse of the teacher revealed that this misconception came from the teacher's misconception about this notion. When misconceptions are embedded, they are persistent and highly resistant to change (Clement, 1987). This could explain the inconsistency with the literature review about this misconception. To remove misconceptions, the teachers claimed that they used some available resources in the elaboration of their teaching activities. Therefore, teachers should be knowledgeable about the available materials adequate to an idea in order to integrate it in a convenient strategy and present this idea. Thus, based on the students' understanding, the teacher mobilized his knowledge about the content, the resources, and the strategies of teaching to present specific content. This is consistent with one previous study, which revealed that the resources and the strategies of teaching, in addition to the knowledge about the content and students' understanding, formed the main components of the PCK (Bertram, 2010).

The knowledge of the teacher about content is characterized by PCK/C. The individual case analysis showed that George, who had a long teaching experience and a specialization in Electronics, was more knowledgeable about the content than the other participants were. On the other hand, Curie and Pascal, who had formation in education, used better visual resources in their teaching. Then PCK evolved with the years of experience and training at different levels, such as the content, the strategies, the use of technology, students' understanding, etc. This is consistent with many previous researchers (Baxter & Lederman, 1999; Gess-Newsome, 1999; Grossman, 1990; Magnusson et al., 1999; Sarkim, 2004; Van Driel et al.,2001) who also revealed that PCK develops through teaching experience.

A teacher's professional knowledge determines his or her view about the teaching/learning process. The teacher's TPACK/S characterized his way of teaching and the use of resources and technology to present subject material in a comprehensive way. This is consistent with Chen and Wei (2015), who revealed that the adaptation of the curriculum materials in practice depended on seven factors: the teacher's PCK, Teaching resources, belief about science, time constraints, and others. Therefore, he dealt with science by referring to facts and observations; this form or strategy of teaching is a form of demonstration in physics education (Dupin & Johsua, 1993). The availability of teaching resources in the teacher work environment was studied in this research through the teacher's TPACK/C. Hence, this research showed that the interrelation between these systems of teachers' professional knowledge directed the professional work of the secondary physics teachers behind the selection and integration of educational resources. This is in line with Chen and Wei (2015), who found that the more significant factor behind the professional work of chemistry teachers to adapt their curriculum materials to their practice was the teacher's PCK.

As a result, the model illustrated by Figure 5 formed the core of the teacher's PCK and TPCK (adopted from the model of Magnusson (1999) and Mishra & Kohler (2006) from the teacher's professional knowledge that affects the selection of the modification and the integration of resources in the elaboration of the teaching activity. This model of nested knowledge systems is similar to that found by Tsaii (2002) concerning teachers' beliefs about teaching science, learning science, and the nature of science. Beliefs and knowledge were seen as equivalent (Kagan, 1990) and critical to studying teachers' practices. Furthermore, science students' views about the nature of science were nested with their perceptions of learning environments in science (Tsai, 2000). In another way, the nested knowledge systems formed a part of the teacher's professional knowledge responsible for the phenomena of "instrumentation" and "instrumentalization" adopted by Gueudet and Trouche (2008) and formed the core of their representation of a documentational genesis (or instrumental genesis) and didactical decisions maker.

Conclusion

The investigation work in this study concerning the professional knowledge of secondary physics teachers, which they mobilize to select and integrate educational resources, had many findings. In their teaching practice, teachers referred to all types of material and non-material available resources. School setting, time constraints, the specificity of the content, and teachers' professional knowledge are the main factors that affect the didactical decision of teachers about educational resources. The comparison between the intended and the operational practice in terms of TPACK shows that there is inconsistency in PCK/U where the context reshapes this knowledge. Moreover, the investigation of teachers' PCK/U shows that when misconception is formed, it resists change and has a great effect on teachers' TPACK/C and TPACK/S. Therefore, a new model of knowledge system is generated from this study that combines together many components of teachers' technological and pedagogical content knowledge called a *nested knowledge system* (figure 5). This model of knowledge is shown to be the main responsible for different didactical decisions of teachers in general and behind the use of different educational resources in particular.

Limitations of the Study

The current study presents some limitations. One of the limitations is the number of cases studied where four teachers were selected for this research, where they all work in the same region in Lebanon (for the feasibility of the study). Thus, and like most of the case study research, this type presents a lack of generalization. Another limitation of this study is that the analysis referred only to the verbal discourses of the teachers and students and neglected students' physical actions and reactions in the classroom, which could be helpful in inferring TPACK, which may affect the results of this study. Moreover, other components of TPACK/C, TPACK/S, and PCK/U could have an influence on the teachers' documentary work and practices and, afterward, the selection and integration of the resources. Additionally, other research can test teachers' knowledge of other disciplines, i.e., chemistry, biology, etc.

Implications and Recommendations

In light of the findings of this study, several implications could be applied at many levels. Since educational research appreciated the role of real experimentation as an effective way of teaching to help students acquire science knowledge and skills (ACS, 2011; Mallory, 2012; NSTA, 2007), and since most of the teachers (the participants) believed in the importance of the experimental activities and suffered from the lack of materials and schools' equipment in addition to the time consumed to search for other resources, the Ministry of Education should provide schools with the minimum of needed materials to perform hands-on experiments for small groups. Moreover, with the progression of technology in the field of education and the development of ICT, policymakers and curriculum developers should modify the curriculum and provide schools and students with simulation software to perform virtual experiments. Furthermore, they should elaborate teachers' training sessions concerning teachers' adaptation of the curriculum materials using virtual laboratories and simulations to form student-centered activities instead of teacher or content-centered ones. The findings of this study showed that physics teachers used ICT to replace the lack of materials. According to the literature, the virtual laboratory is adequate and efficient when teaching issues at the microscopic scale (Perkins et al., 2006).

The most common definition of PCK was the minimum knowledge required by the teacher to transform disciplinary materials into teachable materials in a specific context. Therefore, teacher education programs should focus on developing pre-service teachers' PCK and TPCK. Consequently, a teaching diploma should become a necessity for pre-service teachers to start teaching. Etkina (2010) showed that high school physics teacher preparation programs focused on three aspects of Physics teachers' knowledge: Knowledge of physics, knowledge of pedagogy, and knowledge of how to teach physics (PCK).

Despite the limitation of this study, future studies/interventions could arise from the discussion of the results of this study. The interaction among the theoretical framework in this study: the documentation approach (Gueudet & Trouche, 2009a), the PCK (Magnusson, 1999), and the TPCK (Mishra & Kohler, 2006) provided a new model of the "nested knowledge systems." Future researchers can utilize this model to study teachers' professional knowledge behind their documentary work in other disciplines. This study showed that the selection of resources is content-dependent. Thus, other research could test this result by choosing Physics topics other than electricity to explore if the selection and the integration of resources change.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

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