Journal of Turkish Science Education, 2024, *21*(1), 1-21.
DOI no: 10.36681/tused.2024.001

Early childhood preservice teachers' knowledge of micro-organisms and cystitis

Arritokieta Ortuzar-Iragorri[1], Araitz Uskola[2], Teresa Zamalloa[3]

[1]*Sports and Education Faculty, University of the Basque Country (UPV/EHU), Spain, arritxu.ortuzar@ehu.eus, Corresponding author, ORCID ID: 0000-0003-1051-7524*
[2]*Bilbao Faculty of Education, University of the Basque Country (UPV/EHU), Spain, ORCID ID: 0000-0003-0621-3085*
[3]*Bilbao Faculty of Education, University of the Basque Country (UPV/EHU), Spain, ORCID ID: 0000-0001-8050-496X*

ABSTRACT
Health literacy should be developed from early ages, but students, including preservice teachers, hold misconceptions about micro-organisms. The objective of this study was to analyse the knowledge that a sample of 102 Early Childhood Preservice Teachers (PST) had about micro-organisms and about cystitis. The PSTs performed a series of activities that included an inquiry-based laboratory activity. Their knowledge about micro-organisms was assessed by pre- and post-questionnaires, and about cystitis, by analysing the responses to an open-ended pretest, the inquiry reports and the performance of the PSTs when changing nappies on dolls. Results show a better understanding about the micro-organisms at the end of the study. In the case of cystitis, in the pretest PSTs did not identify bacteria as agents, but they did after the inquiry activity, and they also mentioned the proliferation of bacteria. Nevertheless, only 32% of PSTs changed nappies coherently with the knowledge.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
21.04.2023
Accepted:
18.12.2023

KEYWORDS:
Caretaking; diaper, microorganisms.

To cite this article: Ortuzar-Iragorri, A., Uskola, A., & Zamalloa, T. (2024). Early childhood preservice teachers' knowledge of micro-organisms and cystitis. *Journal of Turkish Science Education, 21*(1), 1-21. DOI: 10.36681/tused.2024.001

Introduction

In the developed world, a large number of children spend a considerable part of their time under the tutelage of their Early Childhood Teachers. To assume the great responsibility of caring for the physical and mental well-being of their pupils, educators must be able to recognise infectious diseases and to know and apply basic hygienic measures to prevent injuries and illnesses (Chalas et al., 2014; Slabe et al. 2016). Moreover, similar to the Turkish Early Childhood Education (ECE) curriculum, which aims to improve the well-being of Turkish citizens by validating their personality and traits in a healthy way (Aktürk et al., 2017), the Spanish ECE curriculum aims at the integral formation of their pupils, contributing to the full development of their personality and preparing them for the full exercise of human rights (Royal Decree 95/2022).

It establishes that one of the duties of ECE teachers is to provide children with routines that favour the development of positive attitudes towards their emotional and physical well-being, which includes hygiene and safety habits (Royal Decree 95/2022). The childhood and youth stages are considered highly suitable for the acquisition of individual and collective responsibilities related to health since it is then that pupils are more receptive to learning and acquire key habits for health (Catalán et al., 2019). There are multiple articles that deal, for example, with the teaching of washing hands or cleaning teeth in ECE (Blanco-López et al. 2015; Franco- Mariscal et al., 2014; García-Barros et al., 2020; Marcos-Merino et al. 2019).

Future ECE educators must therefore be trained to acquire scientific knowledge about hygiene measures and healthy habits and to know how to promote them among their pupils, this necessarily includes knowing about microorganisms. In this sense, it must be borne in mind that future teachers usually hold various alternative conceptions regarding micro-organisms (Marcos-Merino & Esteban-Gallego, 2017). For instance, they may be unaware of the diversity of microorganisms and presume that all of them are bacteria. They may also presume antibiotics to be a common remedy to treat all diseases caused by micro-organisms (Teodoro & Chambel, 2013). In a recent study (Robredo & Torres, 2021) such a misconception regarding antibiotics was also detected among Spanish Secondary School pupils. They also thought that antibiotics were useful against diseases caused by viruses. Consequently, the authors of this work recommended a less theoretical curriculum, but which is more focused on practical cases that instils attitudes towards the responsible use of antibiotics and favours education on their importance in the prevention and treatment of infectious diseases.

Besides these described misconceptions, Marcos-Merino et al. (2019) explained that students may hold negative emotions towards microbiology. Thus, Marcos-Merino et al. (2019) designed and implemented a series of activities for Primary Education Degree students that involved experimental activities as positive emotion raisers (Hofstein & Lunetta, 2004). This consisted of growing micro-organisms from the surroundings and from their hands (before and after washing them) in petri dishes. This is similar to what López (2015) had proposed some years before in his inquiry-based science teaching sequence for Secondary Education to observe antibiotic action and bacterial resistance. Also, that very same year, Mafra et al. (2015) published their findings regarding the positive effect of growing dental plaque before and after teeth cleaning on the dental hygiene habits of primary school pupils. Later, other authors (Puig et al., 2020) have also suggested growing bacteria from pupils' hands in petri dishes at primary school level (Primary Education). At Secondary School level (Secondary Education), Garcia-Barros et al. (2020) suggested growing pupils' mouth bacteria in a carbohydrate-rich medium for the pupils to conceptualise their mouth as an ecosystem.

If the ultimate goal of scientific education is to help learners to become scientifically literate individuals with the skills to critically analyse and change society (Longbottom & Butler, 1999), then they will have to be able to transfer the scientific knowledge acquired in the university to other scenarios. For this to happen, the topic selected to be studied in the classroom must be significant for the learners and facilitate the learning of relevant scientific knowledge that can be transferred to other contexts (Pipitone et al., 2013). According to Jiménez-Aleixandre (2010), to raise interest in science and put them in challenging situations, such scenarios should reflect authentic problems or activities. In such a way, learners will be required to seek adequate and relevant knowledge to identify, understand and deal with such situations (Bolivar, 2010; Sanmartí et al., 2011) and in this way experience the interdisciplinary character of science and its relevance in their life (Mandler et al., 2012). Karakas (2022) found that up-to-date socio-scientific issues which were based on real examples were effective in the improvement of the attitude of Primary School teacher candidates towards the course on life science teaching they attended.

Science is a way of knowing the world (National Academies of Sciences, Engineering and Medicine [NASEEM], 2016) and the need for scientific literacy for the population is often justified

with reference to enabling individuals to make decisions regarding health (Esquivel, 2019; Shen, 1975). Someone who is scientifically literate will be able to take better care of those in their charge for they will be able to make more solid decisions regarding actions such as nutritional measures, drug administration, etc. In this sense, care provision may be an appropriate scenario for the science education Early Childhood PSTs are subjected to. Additionally, its inclusion in the ECE Degree classroom is justified for further reasons; it is a way to prepare teachers for their future work in the early childhood field (Beck, 2010) and attenuate the sensation of being "lost at sea" (Kauffman et al., 2002) of novice teachers. Also, it satisfies the demand of most of the Early Childhood, Primary and Secondary Education teachers who refer to the need for more training in health matters (Díaz & Arias, 2018). This is especially true for ECE, since care-related issues have usually not been considered as part of the professional repertoire of teachers (Van Laere, 2017).

Aznar and Puig (2014) reported that Spanish Secondary School textbooks frequently mentioned infectious illnesses but did not deal with specific diseases. They also reported finding a small number of articles in science teaching about the difficulties of Secondary School pupils to understand aspects related to infectious diseases and infection processes. They suggested that the textbooks incorporated tasks that presented real and specific dilemmas which required decision-making by pupils and the development of critical thinking. Later, the same authors (Aznar & Puig, 2016) published their research on the conceptions and models about tuberculosis held by future Primary Education teachers. They found that most participants had difficulties with fundamental concepts, including identifying how the disease is transmitted, the location of the infection, and linkages between the components of the immune response.

There is some literature on students' knowledge on micro-organisms in Primary and Secondary Education stages previous to university, yet, it is scarce (Simard, 2023). There is also some literature on pre-schoolers' knowledge about micro-organisms (i.e. López-Luengo et al., 2023; Martinerie et al., 2021), and on how to teach about microorganisms in Early Childhood Education. Such is the case, for example, for the E-bug International Project (UK Health Security Agency, 2022), López-Luengo et al. (2021) and Ruiz-Gallardo and Paños (2018) who compared a theoretical and a practical strategy to teach about micro-organisms in ECE. However, the literature on what the Early Childhood PSTs, who are going to teach the pre-schoolers about micro-organisms, hygiene habits and so on is scarce, and so is the literature on how they can learn about them. This work refers precisely to such a question. It is an initial approach to a proposal of a series of activities which aims to improve the knowledge on microorganisms and cystitis of Early Childhood PSTs. Ultimately, this will favour their professional performance when taking care of their future pupils and when teaching them how to take care of themselves. The research questions (RQ) are the following:

RQ1. What knowledge of microorganisms do the Early Childhood PSTs acquire via the suggested activities?

RQ2. Using a cystitis context, what knowledge about such infection do the Early Childhood PSTs acquire?

Methods

Sample

The sample constituted 102 PSTs of the Bachelor´s degree of ECE, who took part in all or some of the activities described in Table 1 during the academic year 2021-2022. The PSTs were chosen for convenience, as Authors 1 and 2 were the teachers at group A and B respectively. 31 PSTs of the 4th year course subject "Activities, Instruments and Resources for Teaching Science" (Group A) in the first semester of academic year 2021-2022 and 71 PSTs of the 3rd year course subject "Experimental Sciences in Early Childhood classroom" (Group B) in the second semester participated. PSTs' age range was 20-23 years, in group A 77% of the PSTs were female and in

Group B 90%of them were female. PSTs were named as A1-31 and B1-71 for Groups A and B respectively.

The PSTs had not received previous formation about microorganisms during the ECE Grade.

Comparisons of the results obtained for the groups were made through the Chi-squared test (SPSS-version 27), a significance level of p 0.010 was considered (Kim, 2017). Only the questions or aspects where the performance of both groups was similar after the intervention, and thus showed no significant difference, were considered in this work for the impact of the similar aspects for both groups, i.e. activity sequence, rather than the differences, i.e. teacher´s performance, was the object of study in this work.

Research Tools and Procedures

To address RQ1, a questionnaire on micro-organisms (MQ) composed of questions used in previous studies was responded by PSTs twice, at the beginning of the sequence (MQpre) and at the end (MQpost).

The questions used are detailed in Appendix 1. The questions I such questionnaire were based on previous studies by Bandiera (2007), Molina et al. (2021) and Robredo and Torres (2021), and their objective was to address students´ knowledge about microorganisms, that is, the ubiquity of microorganisms (MQ1, MQ2), the relation between microorganisms and illness (MQ2, MQ3, MQ5, MQ6), the benefits of microorganisms (MQ2, MQ4), prevention (MQ7) and mitigation measures (MQ8). It was answered by 96 PSTs (26 from Group A and 70 from Group B) before the activity sequence and by 44 PSTs after it (21 from Group A and 23 from Group B). MQ4 was not administered to Group B because of a technical error.

Each response was given a mark, as described in Appendix 1. The possible maximum mark was 1 for the correct answer for each question, except MQ7 and MQ8 that had a maximum of 2 as the correct answer must mention two concepts. A mark of half the maximum was given when the answer was not incorrect but was incomplete. A mark of 0 was given to incorrect answers. Appendix 1 shows an example of answers of PSTs that were given each of the possible marks for each question.

The results obtained in this questionnaire by the whole group were relativized regarding the maximum total score that all the participants could have obtained.

To answer RQ2, three tools were used: the questionnaire on cystitis which was designed and distributed to assess the initial knowledge the PSTs had on cystitis; the written report the PSTs produced; and the performance of Group B PSTs when changing nappies on baby-like dolls. The tools and procedures followed to analyse the data are described below.

Questionnaire on Cystitis (CQ)

Four questions were included about what cystitis is, the factors that produce it, the infectious agent that generates it and its symptoms (Table 1). Ideal answers are included in Appendix 2.

Table 1

Questions of the questionnaire on cystitis (CQ) for the Early Childhood PSTs of the Faculty of Education of Bilbao

Number	Question
CQ1	What is cystitis?
CQ2	Why do you think someone develops cystitis?

CQ3	Why does cystitis happen? What infectious agent generates it?
CQ4	What are the symptoms?

72 Early Childhood PSTs (27 PSTs from Group A and 45 from Group B) responded.

The responses obtained for all questions were read as a whole for each PST and were analysed based on the consideration of various aspects related to the infection, such as the organs affected (Anatomy), the agent involved (Agent), the description of the process (Process) and the Symptoms. Table 2 shows the coding of the responses for each aspect. When possible, an illustrative example of a PST is shown. Responses for Anatomy were coded as 0, 1 or 2, the maximum corresponding to mentioning the immune system and the urinary tract. The same codes were used for Agent and Symptoms. In the case of Agent, the maximum corresponded to specifying that bacteria cause cystitis. The best answers for Symptoms related them to immunological responses. One more code was set for Process, as there were PSTs that only mentioned infection (level 1), others the entering of the bacteria (level 2), but others came to refer to the reproduction of bacteria (level 3).

Table 2

Answer categorisation of the CQ for the Early Childhood PSTs of the Faculty of Education of Bilbao

Aspect	Level	Answer categorisation and example
Anatomy	0	No answer or does not know, or organs outside the urinary tract are mentioned (i.e. "…pain in the vagina", PST A6).
	1	Some part of the urinary tract is mentioned (i.e "kidney pain", PST A8).
	2	The inmune system is mentioned as well as the urinary tract
Agent	0	No answer, does not know (nobody), or activity (i.e." due to sexual intercourse", B67) or non-living agent (i.e. "cold", PST A6; "humidity", PST B32…) are mentioned
	1	The word "microorganism" is mentioned
	2	Bacteria are mentioned (i.e. "I believe a certain type of bacteria generates cystitis…", PST A26)
Process	0	No answer or does not know (PST A15)
	1	Infection is mentioned (i.e. "[Cystitis] is a urine infection", A7)
	2	Bacterial colonisation is mentioned (i.e. "it happens when bacteria enter the body", PST B40)
	3	Bacterial proliferation is mentioned (i.e. "A urinary tract infection occurs when bacteria from outside the body enter the urinary tract through the urethra and begin to multiply", PST B68)
Symptoms	0	No answer or does not know (PST A19)
	1	Mentioning of any symptom (i.e." a strong urge to pee", PST B6)
	2	Mentioning of any symptom related to the immunological process (i.e. "a fever in serious cases", PST A16)

Reports

98 people arranged in 25 groups and wrote 25 reports. They were assessed regarding the extent to which they explained that cystitis is an infection frequently caused by the *E. coli* bacteria proliferation, which they had observed.

Nappy Change

The performance of the Group B PSTs when changing diapers on baby-like dolls was recorded on video and evaluated to assess knowledge on cystitis in a transfer context. The aspects analysed were: the direction in which they cleaned the genitals, perineal and anal area of the baby-like dolls (backwards or forwards) and whether they used or not a clean area of cloth or tissue every time they touched the doll. Cleaning the dolls backwards (towards the anus) and using clean tissues was considered to show an adequate transfer.

Twenty four percent of the videos were viewed in pairs by the authors of this work. They evaluated the correct/incorrect cleaning of the dolls by the PSTs and agreed in 89% of the cases. The cases that were not clear were reviewed and evaluated by the three researchers until a consensus was reached. The conversations of the triads when explaining their actions were also studied. It was analysed whether they mentioned infection and whether they referred to the presence of agents that may generate it.

Activity Sequence

Activity sequences are important pedagogical devices for experimental science teaching with a constructivist approach (Jorba & Sanmartí, 1996). Science education pursues the promotion of scientific competence (Organisation for Economic Co-operation and Development [OECD], 2013), especially with regard to contextualisation in genuine circumstances that have a bearing on learners' personal, social, or future professional life (Jiménez-Aleixandre, 2010).

The activities in such sequences can generally be classified in four categories: exploratory activities; activities for the introduction of concepts or procedures, which help learners to identify new points of view in relation to the topic; knowledge structuring activities, in which the learners outline what they have learned; and application activities that, in general, are considered necessary by constructivist teaching models for successful Science and Mathematics teaching (Jorba & Sanmartí, 1996). The activities usually take place in time in the order displayed and they correspond to stages 1. Exploration, 2. Introduction to knowledge, 3. Structuring and 4. Application.

In the present work, the activities (Table 3) were set up around the topic of cystitis. Urinary tract infections, such as cystitis, are one of the most common bacterial infections in paediatrics. They affect from 5 to 11% of the child population and it is the most frequent reason for consultation in hospital services in some countries (Moriyón et al., 2013). Thus, it is a familiar problem that may motivate the students (Eugenio-Gozalbo & Ortega-Cubero, 2022) and thus, in this sense, it seems to be an appropriate choice for teaching about micro-organisms. In their work about the tuberculosis infection model, Aznar and Puig (2014) describe that those who had suffered from the disease showed a deeper knowledge of it. Cystitis can be a consequence of poor hygiene, as, in children, it is generally caused by the *Escherichia coli* (*E. coli*) bacteria of intestinal origin that are in the perineal area and enter the urinary tract through the urethra). It has the potential to produce long-term morbidity (Cisneros, 2015). Table 3 shows the stages of the learning sequence, the activities performed by PSTs and the research question with which each activity was linked.

Table 3

Teaching Sequence Including: Learning Stage, Chronology in Weeks, Objectives and Tasks

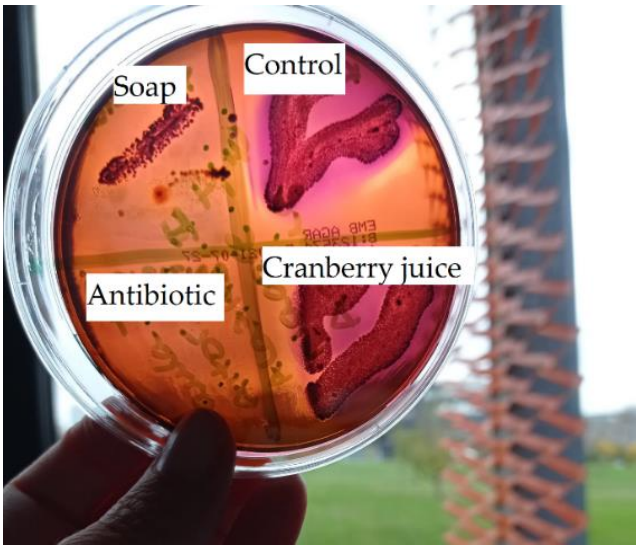
Learning stage	Week	Objective	Task	RQ addressed
Stage 1: Exploration	1	Show knowledge	1. Questionnaire about cystitis	RQ2
	3	Show knowledge	2. Questionnaire about microorganisms	RQ1
Stage 2: Introduction to knowledge	10	Gather information about the questions in the questionnaires, focusing on the bacterium *E. coli*	3. Gather information	
		Design an experiment to try to test different hypothesis regarding *E. coli* growing	4. Set hypotheses on the information collected and design an experiment	
Stage 3: Structuring	11	Grow *E. coli* in petri dishes under different circumstances	5. Experiment execution	
	12	Communicate and contrast the results obtained by the different groups	6. Meeting to contrast results	
Stage 4: Application	13	Write a report	7. Writing a report	RQ2
	14	Show knowledge	8. Questionnaire about micro-organisms	RQ1
	15	Express knowledge by simulating nappy changing	9. Diaper change	RQ2

To express knowledge, the PSTs answered questions on microorganisms (Appendix 1) and on cystitis (Table 1). Then, a similar approach to that used in inquiry practices was implemented (Caamaño, 2012). As reported by Cimer (2007), activities that encourage students` inquiry and cooperative learning favour effective teaching. Thus, after the initial questionnaire about microorganisms, the PSTs were asked to gather in groups of three or four and search for information regarding the issues raised by the questions in both questionnaires, focusing on the bacterium *E. coli*. After that, they were asked to design an experiment to try to test in which conditions *E. coli* would grow. For that purpose, they had to consider the resources available in the laboratory of the Faculty of Education of Bilbao. These were the following: sunlit and dark areas, a refrigerator, a stove with a thermostat, petri dishes with *E. coli* selective media, different substances such as the antibiotics ciprofloxacin and amoxicillin, the antifungal miconazole, and any other that they might bring in themselves (blueberry juice, hydro alcoholic hand gel to the lab. We were thus not assuming they had prior knowledge of lab procedures, as we have previously explained, they just brought or used the products they thought about when they formulated their hypotheses The PSTs had to design different situations, predict where *E.* coli

would grow and explain the reason. Once in the lab, each group of PSTs sowed the *E. coli* bacterium in petri dishes and subjected them to different incubation conditions for 24 h. The bacteria were sourced in the excrement of a pet belonging to a member of the group. Then, the groups of PSTs collected their petri dishes, observed them (Figure 1), met to communicate and contrast the results obtained by the different groups, tried to respond to the hypotheses initially raised and produced a report on the experiment that structurally resembled a scientific paper (Theoretical framework; Objectives; Materials and methods; Results; Conclusions; References).

Figure 1

Example of Eschericia Coli Cultivation in a Petri Dish under Different Treatments. In This Case, Clockwise: Without Any Additive (Control), With Cranberry Juice, With Antibiotic (Ciprofloxacin) and With Hand Soap, Respectively



Finally, a questionnaire on micro-organisms was administered again (Table 2). Transference is an essential cognitive process in education which consists in the ability to apply what has been learned in a specific context to a new situation (Voss, 1987). According to Schönborm and Bögelholz (2009), students demonstrate understanding (a major goal both for educators and students), when, to meet the demands of a new situation, they can connect existing knowledge with new knowledge during the transference. Thus, a situation where PSTs had to simulate changing nappies on baby-like dolls was set up so that the PSTs transferred what they had previously learned about the causes for cystitis. During the last week of the semester, 58 Group B PSTs were taken to a kindergarten-like room in the Faculty of Education of Bilbao where they were asked to simulate changing diapers on dolls (Figure 2). They entered the room in groups of three, but each PST had a doll. The teacher then asked for an explanation of their actions. For Group A PSTs this activity could not be carried out.

Findings and Discussion

Knowledge about Micro-organisms (RQ1)

The Chi-square test was used to compare the results obtained by Groups A and B in the responses to the questionnaire about microorganisms (Table 5). Differences were detected for MQ5 after the implementation of the didactic sequence, thus this question was discarded.

Figure 2 shows the total number of points obtained by the PSTs who answered the questionnaire relative to the maximum they could have obtained. The PSTs initially obtained an average score of 54% (Figure 2). They showed an initial knowledge level that corresponded to a mark of 80% for questions MQ1-MQ3 that dealt with the ubiquity of microorganisms and their beneficial nature. Comparatively, the last questions (MQ4, MQ6-MQ8), about the existence of beneficial organisms, whether all diseases are caused by microorganisms, and the ways to prevent and treat such diseases, reached scores beneath the average, which ranged from 31% to 41% (Figure 2). The poor result obtained at MQ4 might derive from the wide-spread thought that microorganisms are all potentially pathogenic, highly infectious, and dangerous (Simard, 2023):

Table 5

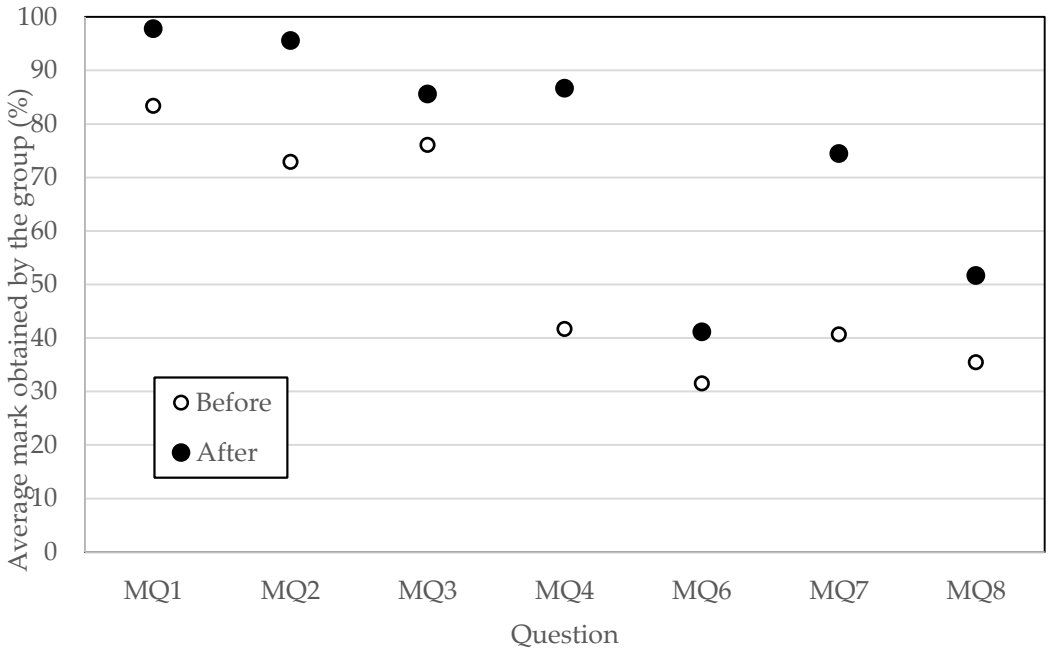
Descriptive statistics of the MQ Questions, χ2 Results and p-Values in Comparisons of Groups A and B.

Timing of the questionnaire	Question	χ^2	p
Before the activity sequence	MQ1	2.822	0.244
	MQ2	5.926	0.115
	MQ3	2.854	0.415
	MQ5	6.130	0.190
	MQ6	5.695	0.223
	MQ7	5.737	0.123
	MQ8	13.474	0.019
After the activity sequence	MQ1	0.026	0.872
	MQ2	1.318	0.517
	MQ3	8.673	0.013
	MQ4	2.230	0.325
	MQ5	14.387	0.002*
	MQ6	4.571	0.102
	MQ7	5.355	0.069
	MQ8	4.888	0.185

Note: *Significant at 0.01 probability level

Figure 2

Responses to the MQ Questionnaire before and After the Series of Activities



Except for questions MQ3 and MQ6, which according to the Chi-square test did not significatively improve after the didactic sequence (Table 6), the responses improved by at least a 10% after the didactic sequence.

Regarding question MQ4, on whether there are beneficial micro-organisms, some of the PSTs understood that this referred to micro-organisms in the human body. In spite of the question being aligned with the recommendation given by Simard (2023) that the centre of the microorganism discourse should better be shifted away from the human being so as to dispel misconceptions, it was the PSTs who brought it back to humans. Also, in line with the idea detected by Bandiera (2007), referring to the fact that microorganisms present in a healthy body are mainly related to protection and defence rather than other functions, four people gave the following answers (which were considered correct): "yes, they help us to be healthy" (PST A14), "yes, beneficial microorganisms help us stay healthy and overcome diseases" (PST A30), "yes, they help take care of our body" (PST B36). However, there were cases in which, by extrapolation of such a conception, the PSTs asserted that antibodies are microorganisms. This can be seen, for example, in the following answers (which were considered incorrect): "yes, for example if there is a virus in our body, they [antibodies] stand up to it" (PST A8) and "yes, defences can be microorganisms" (PST A15). After the series of activities, through which the PSTs had had to establish the functions of *E. coli* in the digestive system and cystitis infection due to the *E.coli* colonisation and proliferation in the urinary tract, the two PSTs who initially answered these questions incorrectly, respectively switched their answers to the following, considered as correct: "yes [..], for example microorganisms in the gut are very important to digest food" (A8) and "yes, when they are in the right place" (A15). Similar to the positive impact reported by Ruiz-Gallardo and Paños (2018) after a practical intervention for Primary School children that involved microorganism cultivation, the knowledge of the PSTs significantly increased not only for question MQ4, but also for MQ1, MQ2, MQ7 and MQ8. This is especially true for questions 4 and 7 respectively where the mark raised from around 40% to beyond 70%, which was the initial score for questions 1, 2, and 3 had initially scored. The answers to question 8 improved the least (10%), and marks for questions MQ6 and MQ8 remained the lowest (Figure 2).

Table 6

Descriptive Statistics of the Questions, X2 Results and p-Values in Comparisons between Before and After the Questionnaire

Question	χ^2	p
MQ1	11.92	0.003*
MQ2	14.603	<0.001*
MQ3	3.249	0.197
MQ4	16.816	<0.01*
MQ6	3.390	0.335
MQ7	21,127	<0.01*
MQ8	50.577	<0.01*

Note: *Significant at 0.01 probability level

Regarding question MQ6, about whether all diseases were caused by microorganisms, three types of erroneous or partially incorrect answers were given before the activity sequence: i) those in which the answer was completely wrong or the person asked stated that they did not know the answer (34% of the incorrect or partially incorrect answers); ii) those in which the person asked answered correctly that not all illnesses are caused by microorganisms, but illustrated their answer with no example or an erroneous one. For example, "No, for example congenital or chronic diseases" (PST A1), ignoring the fact that both congenital and chronic diseases can include diseases caused by microorganisms such as congenital toxoplasmosis and chronic gastritis. iii) those who responded correctly but stated that virus-caused illnesses such as the common flu were not caused by microorganisms since viruses were not microorganisms.

The first and second types of answers indicate the existence of difficulties in understanding terms about the characteristics of the diseases, this is related to the limited medical literacy of society (Falcón & Luna, 2012). The third type of response presumably refers to the lack of knowledge concerning the diversity of microorganisms and to the assimilation of the concept of microorganism to that of bacteria (Marcos-Merino et al., 2019). In this regard, Jones and Rua (2006) also indicated in their work that the lack of clear concepts in this area contributed to misconceptions similar to those described in this work.

It is noteworthy that those people who responded with two words for medications to question MQ8 (8 people out of 96 wrote "medicines and antibiotics") where the word "medication", since it was accompanied by the word "antibiotics", presumably meant "other medications that are not antibiotics", did not answer with a type iii response to question MQ6. That is, there may be a relationship between the integration of the concept of microorganism to that of bacteria and the misuse of antibiotics since, as Robredo and Torres (2021) state, knowing the differences between microorganisms is necessary for understanding that the mechanism of attack and destruction of these infective agents is different and thus may need different treatments.

After the implementation of the didactic sequence, which included the search for information in the literature, the rate attained by the group for questions 4-8, which initially showed a knowledge below the average (54%), improved the least for questions MQ6 and MQ8 (Figure 2). This might be taken as a sign for the previously suggested relation between the assimilation of the concept of microorganisms to that of bacteria and the misuse of antibiotics, as the poor results obtained for question 6 might have had dragged down those of question MQ8, where different treatments for infections caused by different microorganisms had to be specified. Some members of the sample gave answers to question MQ6 in which they implied that they did

not consider viruses to be microorganisms and were like the following: "No, in addition to diseases caused by microorganisms, there are others, such as those caused by virus" (PST A10). As previously pointed out, the cause for such answers presumably lies in the lack of clear concepts in this area (Jones & Rua, 2006). In fact, there are different definitions of microorganisms in the literature that exclude viruses, as clearly indicated by the cancer dictionary of the US National Institutes of Health (NIH) (n.d.) for the term "microorganism": "[…] viruses […] are sometimes classified as microorganisms". For instance, at the web of the Centre or Geobiology (2010) viruses are excluded from the microorganism definition while at the online educational science resource e-bug (UK Health Security Agency, 2022) they are included. Another possible source of confusion in this regard is assimilating the terms microbe and microorganism as synonyms which, according to the glossary of the European Society for Neurogastroenterology and Motility [ESNM] (n.d), is not recommended. However, the definition of Royal Academy of the Spanish Language (2022), for instance, equates both terms and thus defines the word microorganism/ microbe as a "unicellular organism only visible under a microscope". If the PSTs link this information with the information that viruses are acellular (Sevillano & Eraso, 2013), they will exclude them from the microorganisms. Or if they assume that all microorganisms are alive (because they are microbes), this may lead to a concatenation of ideas such as the one illustrated with the following example of a PST's response "No. Viruses are not living things and therefore diseases transmitted by viruses are not caused by microorganisms" (PST A2). That is to say, although the person who answered in this way did not subscribe to the aforementioned belief that viruses are living beings (Marcos-Merino & Esteban-Gallego, 2017), they indicated that they do think that all microorganisms are living beings, and that since viruses are not, they do not belong to the microorganism category. In fact, discrepancies among the scientific community about whether viruses are alive or not can also be found in the literature (Koonin & Starokadomskyy, 2016).

After the activity sequence, the marks for question MQ7 about ways to avoid microorganisms entering your body (Table 2) increased by a 34% as more PSTs correctly answered the question, usually by specifying two different hygiene measures amongst which hand washing was frequent.

It should also be noticed that in question MQ1, after the implementation of the didactic sequence, 98% of respondents correctly indicated that microorganisms are ubiquitous, but some of them also clarified that they cannot be seen except under a microscope. For example, a response in this sense was the following: "Yes. They are everywhere but we can only see them with a microscope" (PST A29), an answer that reflects a previous conception described by Marcos-Merino and Esteban-Gallego (2017). As in the work by Robredo and Torres (2021) in this work similar responses have been admitted as correct. Yet, it was surprising to find no further explanations about the fact that microorganisms can be seen with the naked eye when many of them gather, i.e. we can see the colonies – microbes *en masse* – but not the individual organisms, despite the PSTs having cultivated *E coli* and observing its colonies in petri dishes.

Knowledge about Cystitis (RQ2)

To evaluate the results obtained in both groups, the Chi-square test was used to compare the results obtained by Groups A and B. No differences were detected, as shown in Table 7.

Table 7

Descriptive Statistics of the Questions, X^2 Results and p-Values in Comparisons of Groups A and B

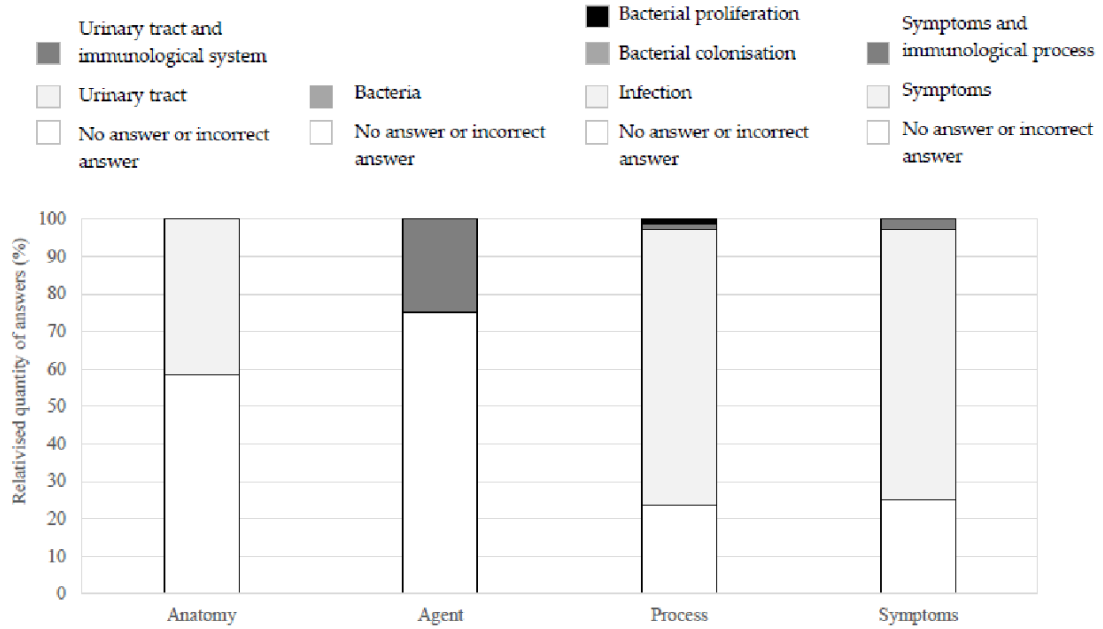
Question	$\chi 2$	p
1	0.747	0.388
2	0.140	0.708
3	1.299	0.729
4	1.169	0.919

In Figure 3, the results regarding the initial questionnaire about cystitis for the whole group of 72 people are shown. More than half of the questioned failed to describe where in the human anatomy cystitis takes place, and the agent that causes it (58% and 75% respectively). In contrast, these frequencies decreased to approximately 25% both for the aspects regarding the infection process and the symptoms of cystitis.

As mentioned, 58% of the questioned failed to define what cystitis is or placed it outside the urinary tract, i.e. in the vagina (12% of the answers considered incorrect) (Figure 3). As Aznar and Puig (2014) detected for tuberculosis in the lungs, the PSTs had difficulties in locating the cystitis infection in the bladder. This may be due to ignorance about human anatomy, particularly feminine anatomy (Pozo et al., 2014; Van Moorst et al., 2012), since some of the PSTs placed the infection in the vagina rather than in the urinary tract. It is also noticeable that 38% of the PSTs whose answers were considered incorrect, responded that cystitis is a "urine infection" which, in Spanish, (the language our PSTs speak), is the usual informal expression for cystitis. In the answers where the words "tract" or "apparatus" were omitted, it is not clear whether this omission was conscious or not. This raises the question of whether the PSTs manifested their thoughts via a metonymy by placing the infection in the urine rather than the surrounding organs as way of expressing themselves, or whether they have a mistaken conceptualisation of the illness.

Figure 3

Responses to the CQ questionnaire



Four people noted that they had suffered from cystitis although they were not asked about this, and a fifth person mentioned that a cousin had had it. Such responses show that cystitis is a familiar problem and one which may motivate PSTs.

Regarding the reasons why someone develops cystitis, (the agent), cold was the most cited reason (74% of the PSTs), while humidity and hygiene were mentioned by 33% of the PSTs and sexual intercourse by 26% of them. Among those who mentioned poor hygiene, 33% identified a bacterium as being the cause for cystitis. Of these, one person (PST B67) who described suffering from recurrent cystitis and identified a bacterium as its causing agent commented: "I've always been told to clean my vulva meticulously, wash it with water only, dry thoroughly, pee after sex, eat red fruits, etc.", thus implying that poor hygiene can be a cause for cystitis.

Approximately 75% of the answers to questions 3 and 4 were correct. In question 3, 74% of the answers referred to an infection when explaining what cystitis was. More detailed answers that entangled bacterial colonisation and proliferation (1.4%) were less numerous. Thus, processes such as bacterial colonisation or proliferation or/and immunological responses, which, for instance, occupy an important space in the infection model suggested by Aznar and Puig (2016), were, at this stage, viewed from afar. Similarly, in question 4, most PSTs (72%) correctly described an urge to urinate and a burning sensation among the symptoms rather than doing so in relation to the immunological processes (1.4%).

No report failed to describe that cystitis was most frequently caused by *E. coli* bacteria from the digestive apparatus. Furthermore, 52% of the reports described that the infection was caused by an *E. coli* proliferation in the urinary tract. In addition, in two reports the recommendation was given that the area should be cleaned backwards (towards the anus) and 28% of the reports described that the urethra is shorter in women and that is why female cystitis is more common.

This might reflect the fact that the PSTs' knowledge of the anatomy and the agents has increased, especially when compared to their results in the previous questionnaire. It also

satisfies the concepts of entrance and proliferation of the infecting agent in a specific organ considered in the Aznar and Puig (2016) infection model. Furthermore, 28% of the reports offered information about the anatomical differences between women and men (women´s shorter urethra) that relate to cystitis being more frequent in women.

It was found that only 32% of the PSTs changed nappies correctly in the sense that they cleaned the baby's nappy area backwards and did not reuse the same tissue or part of the tissue or cloth to clean the doll. After the performance, the PSTs were asked what they thought the objective of the performance was. They usually answered that it was connected to hygiene. When their answer was confirmed, they were further asked in what direction children should be cleaned. Some (10% of the groups) described that boys and girls were to be cleaned differently. However, 55% of them correctly answered that cleaning should be in a backwards direction so as not to spread excrement into the genitalia; sometimes they realised that they had not carried out the cleaning appropriately and corrected themselves. Furthermore, in 14 out of 20 groups, the word "infection" was then used spontaneously in the context of it being avoided by correct cleaning. Only in 9 out of 20 groups were either bacteria or *E. coli* spontaneously mentioned.

Conclusion and Implications

Regarding micro-organisms, the PSTs showed a high initial knowledge on their ubiquity, their presence in a healthy body and the existence of harmful microorganisms. However, they exhibited difficulties when questioned about the existence of beneficial micro-organisms, (which were sometimes confused with antibodies), medical terminology for the description of diseases, and the prevention and treatment of infections.

After the activity sequence, which included the collection of information about cystitis, the formulation of hypotheses about it, and the design and implementation of an experiment to test these, PST knowledge of every issue about microorganisms improved to at least 75% on the scale used. The only exception to this involved the questions that referred to the existence of beneficial microorganisms and the treatment of their infections. This is presumably because of the discrepancy in the scientific literature as to what microorganisms and/or viruses are.

In order to improve the suggested didactic sequence, following Karaarslan-Semiz *et al*. 's (2023) suggestion on equipping teachers in a way that they can access and interpret information about COVID-19 or other similar socioscientific issues in a timely and correct way, we propose to inform PSTs about the existence of the mentioned discrepancies regarding virus in the scientific community, but not encourage them to search for information on microorganisms and/or viruses on the Internet. Instead of this, we would provide them with a definition of both. Secondly, we suggest that knowledge about the correct use and misuse of antibiotics to treat infections caused by microorganisms and/or viruses is also provided by the teacher.

Regarding cystitis, even though initially most of the PSTs knew how to correctly define it as an infection and list some of its symptoms, they showed difficulties in locating it in the bladder, in some cases denoting their ignorance regarding the female sexual anatomy. Also, cold and other factors were more often signalled as the cause for cystitis than bacteria. The laboratory reports show that such difficulties with the location of the infection and the cause for cystitis were apparently overcome but then, when the transference session was carried out, it was observed that the PSTs did not perform coherently. Here, we would propose a further improvement: in the future, a modelling sequence would be implemented, including the construction of a 3D model of the human body, in which the PSTs represent the macroscopic and microscopic elements and processes that take part in the infection. Building 3D models may facilitate the visualisation of the system itself and may lead to a better understanding of both the location of the infection and the processes underlying the cystitis.

This study is, to our knowledge, one of the few focused on Early Childhood PSTs' knowledge on microorganisms, as well as on suggesting a series of activities to teach about

microorganisms in ECE degree. Thus, the results obtained are considered in light of its exploratory nature and it is reckoned that more data needs to be collected on the issue, both at the University of the Basque Country and other universities. To that end, the authors of this work will implement again the revised versions of the activity sequence described here that will comprehend, as explained, the following: (1) the teachers will provide the Early Childhood PSTs with information about microorganisms rather than letting them search for it on the web so as to avoid confusion derived from lack of scientific consensus about the issue, and (2) the students will build 3D anatomic models that will later be used for diaper-change so as to promote the comprehension of the infection causes and process. Also, to further ensure safety in ongoing work, non-toxigenic commercial *E. coli* samples will be used.

Acknowledgements

This research was developed within KOMATZI (GIU21/031) research group, funded by the University of the Basque Country UPV/EHU.

References

Aktürk, A. A., Demircan, H. Ö., Şenyurt, E., & Çetin, M. (2017). Turkish early childhood education curriculum from the perspective of STEM education: A document analysis. *Journal of Turkish Science Education, 14*(4), 16-34. DOI: 10.12973/tused.10210a)

Aznar, V., & Puig, B. (2014). ¿Cómo se presentan las enfermedades infecciosas en los libros de texto*?. Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, *11*(2), 135-144. DOI: 10498/15971

Aznar, V., & Puig, B. (2016). Concepciones y modelos del profesorado de primaria en formación acerca de la tuberculosis. *Enseñanza de las ciencias: revista de investigación y experiencias didácticas, 34*(1), 33-52. DOI: 10.5565/rev/ensciencias.1670

Bandiera, M. (2007). Micro-organisms: Everyday knowledge predates and contrasts with school knowledge. In R. Pintó, &D. Couso (Eds), *Contributions from science education research* (pp. 213-224). Springer. https://link.springer.com/chapter/10.1007/978-1-4020-5032-9_16

Beck, L.M.P. (2010) *More than "just" changing diapers: The experiences of preservice early childhood teachers in infant field placements.* [PhD Thesis, Teachers College,].

Blanco-López, A., Franco-MariscaL, A. J., & España, E. (2015). A competence-based approach to the design of a teaching sequence about oral and dental health and hygiene: a case study. *Journal of Biological Education*, *50*(2), 196-206. DOI: 10.1080/00219266.2015.1058838

Bolívar, A. (2010). *Competencias básicas y currículo*. Editorial Síntesis.

Caamaño, A. (2012). ¿Cómo introducir la indagación en el aula? Los trabajos prácticos investigativos. *Alambique, 70*, 83-91.

Catalán, V. G., Fernández, A. G., Ortega, M. T., Mocholí, C. S., & García-Berlanga, O. M. (2019) Alfabetización en salud a través de las competencias. *Enseñanza de las ciencias, 37*(2), 107-126. DOI: 10.5565/rev/ensciencias.2628

Center for Geobiology (2010). *What are microorganisms?* University of Bergen. https://www.uib.no/en/geobio/56846/what-are-microorganisms

Chałas, R., Maksymiuk, P., & Fajgier, T. (2014). The evaluation of kindergarten teachers' preparation to promote oral health among children. *Polish Journal of Public Health, 124*(1), 33-37. DOI: 10.2478/pjph-2014-0007

Cimer, A. (2007). Effective teaching in science: A review of literature. *Journal of Turkish Science Education*, *4*(1), 20-44. https://www.tused.org/index.php/tused/article/view/657

Cisneros-Mallcco, M. (2015). Infección urinaria en niños. *Revista de la Facultad de Medicina Humana*, *15*(3), 40-50. https://revistas.urp.edu.pe/index.php/RFMH/article/view/682/649

Díaz, H., & Arias, M.M. (2018) Necesidad percibida del profesorado de Educación Infantil, Primaria y Secundaria sobre formación en salud e implantación de la figura de la enfermera escolar. *Metas de enfermería*, *21*(9), 5-12

Esquivel, T. (2019). Propuesta educativa para la alfabetización científica sobre salud en bachillerato. *Didácticas Específicas*, *20*, 7-24. DOI: 10.15366/didacticas2019.20.001

Eugenio-Gozalbo, M., & Ortega-Cubero, I. (2022). Drawing our garden's insects: a didactic sequence to improve pre-service teachers' knowledge and appreciation of insect diversity. *Journal of Biological Education*, 1-18. DOI: 10.1080/00219266.2022.2081243

European Society for Neurogastroenterology and Motility. (No data). *Glossary: Microorganisms*. https://www.gutmicrobiotaforhealth.com/glossary/microorganisms.

Falcón, M., & Luna, A. (2012). Alfabetización en salud: concepto y dimensiones. Proyecto europeo de alfabetización en salud. *Revista de Comunicación y Salud*, *2*(2), 91-98. https://dialnet.unirioja.es/servlet/articulo?codigo=4500264

Franco-Mariscal, A.J., Blanco-López, A., & España-Ramos, E. (2014). El desarrollo de la competencia científica en una unidad didáctica sobre la salud bucodental. Diseño y análisis de tareas. *Enseñanza de las Ciencias*, *32*(3), 649-667. 10.5565/rev/ensciencias.1346

Garcia-Barros, S., Rivadulla-López, J. C., & Fuentes-Silveira, M. J. (2020). Los microorganismos en nuestra boca, ¿están vivos? *Alambique, 99*, 11-17

Goldstone, R. L., & Day, S. B. (2012). Introduction to «new conceptualizations of transfer of learning». *Educational Psychologist, 47*(3), 149-152. DOI: 10.1080/00461520.2012.695710.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science education, 88*(1), 28-54. DOI: 10.1002/sce.10106

Jiménez-Aleixandre, M.P. (2010). *10 Ideas Clave.Competencias en argumentación y uso de pruebas*. Graó.

Jones, M. G., & Rua, M. J. (2006). Conceptions of germs: Expert to novice understandings of microorganisms. *The Electronic Journal for Research in Science & Mathematis Education*, *10*(3), 1-40. https://ejrsme.icrsme.com/article/view/7741

Jorba, J., & Sanmartí, N. (1996). *Enseñar, aprender y evaluar: un proceso de regulación continua. Propuesta didáctica para las áreas de ciencias de la naturaleza y las matemáticas*. Ministerio de Educación y Cultura. https://dialnet.unirioja.es/servlet/libro?codigo=186191.

Karakaş, H. (2022). Socioscientific Issues-Based Discussions on Increase of Attitudes of Primary School Teacher Candidates Towards the Life Science Teaching. *Journal of Turkish Science Education*, *19*(1), 17-36. https://www.tused.org/index.php/tused/article/view/1450

Karaarslan Semiz, G., Çakır Yıldırım, B., Tuncay Yüksel, B., Ozturk, N., & Irmak, M. (2023). What can be learned from pre-service teachers' intentions to vaccinate against COVID-19 and relevant factors for future crises? A cross-sectional survey research. *Journal of Turkish Science Education*, 20(3), 567-586. https://www.tused.org/index.php/tused/article/view/2549

Kauffman, D., Johnson, S. M., Kardos, S. M., Liu, E., & Peske, H. G. (2002). "Lost at sea": New teachers' experiences with curriculum and assessment. *Teachers College Record: The Voice of Scolarship in Education, 104*, 273–300. https://www.academia.edu/9191102/Lost_at_Sea_New_Teachers_Experiences_with_Curriculum_and_Assessment

Kim, H.Y. (2017). Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative Dentistry & Endodontics, 42*(2), 152-155. DOI: 10.5395/rde.2017.42.2.152

Koonin, E. V., & Starokadomskyy, P. (2016). Are viruses alive? The replicator paradigm sheds decisive light on an old but misguided question. *Studies in history and philosophy of science part C: Studies in history and philosophy of biological and biomedical sciences, 59*, 125-134. DOI: 10.1016/j.shpsc.2016.02.016

Longbottom, J. E., & Butler, P. H. (1999). Why teach science? Setting rational goals for science education, *Science. Education*, *83*(4), 473-492. DOI: 10.1002/(SICI)1098-237X

López, J. A. (2015). *En la guerra de las bacterias el antibiótico es el rey: una propuesta de indagación para la enseñanza de la microbiología en 2º curso de Bachillerato*. [Master Thesis. University of Granada].

López-Luengo, M. A., González Díaz, E., Paños, E., & Ruiz-Gallardo, J. R. (2021). Microorganismos y hábitos de higiene. ¿Se aprende más en la Educación Infantil mediante fichas? *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 18*(2), 2302-1-2302-19. https://revistas.uca.es/index.php/eureka/article/view/5833

López-Luengo, M. A., Paños, E., & Ruiz-Gallardo, J. R. (2023). El alumnado de educación infantil ya sabe lo que es un virus. *Enseñanza de las Ciencias. Revista de investigación y experiencias didácticas, 41*(2), 5-24. https://ensciencias.uab.cat/article/view/v41-n2-lopez-panos-ruiz

Mafra, P., Lima, N., & Carvalho, G. S. (2015). Experimental activities in primary school to learn about microbes in an oral health education context, *Journal of Biological Education*, *49*(2), 190-203. DOI: 10.1080/00219266.2014.923485

Mandler, D., Mamlok-Naaman, R., Blonder, R., Yayon, M., & Hofstein. A. (2012). High-school chemistry teaching through environmentally oriented curricula, *Chemistry Education Research and Practice, 13*, 80–92. DOI:10.1039/C1RP90071D

Marcos-Merino, J. M., & Esteban-Gallego, M. R. (2017). Concepciones alternativas sobre Biología Celular y Microbiología de los maestros en formación: implicaciones de su presencia. C*ampo Abierto, 36*(2), 167-179. DOI: 10.17398/0213-9529.36.2.167

Marcos-Merino, J. M., Esteban Gallego, M. R., & Gómez Ochoa de Alda, J. (2019). Formando a futuros maestros para abordar los microorganismos mediante actividades prácticas. Papel de las emociones y valoraciones de los estudiantes. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias,, 16*(1), 1602-2-1602-18. DOI: 10.25267/Rev_Eureka_ensen_divulg_cienc.2019.v16.i1.1602

Martinerie, L., Bernoux, D., Giovannini-Chami, L., & Fabre, A. (2021). Children's drawings of coronavirus. *Pediatrics, 148*(1), 1-10. https://pubmed.ncbi.nlm.nih.gov/34074701/

Molina, J., Paños, E., & Ruiz-Gallardo, J.R. (2021). Microorganismos y hábitos de higiene. Estudio longitudinal en los cursos iniciales de Educación Primaria. *Eureka, 18*(2), 1-19. DOI: 10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i2.2201

Moriyón, J., De Molero, N., Coronel, V., Ariza, A., Arias, A., & Orta, N. (2013). Infección urinaria en pediatría. Definición, Epidemiologia, Patogenia, Diagnóstico. *Archivos Venezolanos de Pueruclтura y Pediatría*, *74*(1), 23-38. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0004-06492011000100006&lng=es&tlng=es

NASEEM National Academies of Sciences, Engineering, and Medicine (2016). *Science Literacy: Concepts, Contexts, and Consequences*. The National Academies Press. https://nap.nationalacademies.org/catalog/23595/science-literacy-concepts-contexts-and-consequences

National Institutes of Health. (No data). *NCI Dictionary of Cancer Terms: Microorganism*. https://www.cancer.gov/publications/dictionaries/cancer-terms/def/microorganism

Organisation for Economic Co-operation and Development [OECD]. (2013). *PISA 2012, Assessment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy*, OECD Publishing. https://www.oecd.org/pisa/pisaproducts/PISA%202012%20framework%20e-book_final.pdf.

Pipitone, C., Couso, D., & Sanmartí, N. (2013). Ciencias para el mundo contemporáneo: diferentes maneras de ver y entender una asignatura. *Enseñanza de las ciencias*, *Extra*, 2800-2805. https://raco.cat/index.php/Ensenanza/article/view/308072/398063

Pozo, A., Cubero, J., & Ruiz, C. (2014). Elaboración de cuestionarios para la detección de conocimientos previos en Educación para la Salud, Sexualidad y Nutrición de un grupo de estudiantes de secundaria de un Centro Penitenciario Español. *Campo Abierto*, *33*, 43-64. https://dialnet.unirioja.es/servlet/articulo?codigo=5250167

Puig, B., Castiñeiras, D., & Maceira, J. J. P. (2020). ¿Tratamientos convencionales o terapias alternativas?. *Alambique*, *99*, 43-48.

Robredo, B., & Torres, C. (2021). ¿Es consciente el alumnado de secundaria de la patogenicidad de los microorganismos y de la problemática sobre la resistencia a los antibióticos? *Eureka*, *18*(3), 3301-2-3301-19. DOI: 10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i3.3301

Royal Academy of Spanish Language (2022). *Microorganismo.* https://dle.rae.es/microorganismo.

Royal Decree 95/2022 of february the first, which establishes the Early Childhood Education curriculum. *Boletín Oficial del Estado, 28,* of 2022 february the second, 14561 -14595. https://www.boe.es/boe/dias/2022/02/02/pdfs/BOE-A-2022-1654.pdf

Ruiz-Gallardo, J. R., & Paños, E. (2018). Primary school students' conceptions about microorganisms. Influence of theoretical and practical methodologies on learning. *Research in Science & Technological Education*, *36*(2), 165-184. https://www.tandfonline.com/doi/epdf/10.1080/02635143.2017.1386646?needAccess=true

Sanmartí, N., Burgoa, B., & Nuño, T. (2011). ¿Por qué el alumnado tiene dificultades para utilizar sus conocimientos escolares en situaciones cotidianas?, *Alambique, 67*, 62-68.

Schönborn, K. J. & Bögeholz, S.(2009). Knowledge Transfer in biology and Translation Across External Representations: Experts View and Challenges for Learning, *International Journal of Science and Mathematics Education, 7*(5), 931-955. DOI: 10.1007/s10763-009-9153-3

Sevillano, E. & Eraso, E. (2013). *Tema 1. Introducción a la Microbiología Oral*. https://ocw.ehu.eus/pluginfile.php/44848/mod_resource/content/1/Material_de_estudio/Tema_1._Introduccion_a_la_microbiologia_oral.pdf

Shen, B.S.P. (1975) Scientific literacy and the public understanding of science. In S.B. Day (Ed.), *Communication of Scientific Information* (pp. 44-52). Karger.

Simard, C. (2023). Microorganism education: misconceptions and obstacles. *Journal of Biological Education, 57* (2), 308-316.

Slabe, D., Fink, R., Dolenc, E., & Kvas, A (2016). Knowledge of health principles among professionals in Slovenian kindergartens. *Slovenian Journal of Public Health, 55*(3), 185-194. DOI:10.1515/sjph-2016-0024

Teodoro, A. & Chambel, L. (2013) The role of teachers in students' education for antibiotic use. In A. Méndez-Vilas. (Ed.), *Microbial pathogens and strategies for combating them: science, technology and educations* (pp. 1957-1968). Formatex Research Center. https://www.researchgate.net/publication/259383893_The_role_of_teachers_in_students%27_education_for_antibiotic_use

UK Health Security Agency (2022). *KS2: Introduction to Microbes*. https://www.e-bug.eu/ks2-intro-to-microbes

Van Laere, K. (2017). *Conceptualisations of care and education in early childhood education and care*. [PhD Thesis, University of Ghent].

Van Moorst, B. R., van Lunsen, R. H., van Dijken, D. K., & Salvatore, C. M. (2012). Backgrounds of women applying for hymen reconstruction, the effects of counselling on myths and misunderstandings about virginity, and the results of hymen reconstruction. *The European Journal of Contraception & Reproductive Health Care, 17*(2), 93-105. DOI: 10.3109/13625187.2011.649866

Voss, J. F. (1987). Learning and transfer in subject-matter learning: A problem-solving model. *International Journal of Educational Research*, *11*(6), 607-622. DOI: 10.1016/0883-0355(87)90005-X

Vygotsky, L S. (1972). *Thought and language*. M.I.T. Press.

Appendix 1

Questions Included in the Questionnaire about Microorganisms, Marking, and Answer Examples with the Corresponding PST´s Code

Number	Question	Marks (points)	Example of answers of PSTs
MQ1	Are there microorganisms around us? Explain your answer	0	I don´t know (B32).
		0.5	Yes (B48).
		1	Yes. Microorganisms are everywhere (B3).
MQ2	Are there microorganisms in your body when you are healthy? Explain your answer	0	There are not. Microorganisms make us sick (B42)
		0.5	Yes, but I cannot explain my answer (B33).
		1	Yes, all over it (B11).
MQ3	Are there pathogenic microorganisms? Explain your answer.	0	I don´t know, but I guess there are (B44)
		0.5	I believe so (B34).
		1	Yes, for example some bacteria may be pernicious for us and cause infections (A31).
MQ4	Are there beneficial microorganisms? Explain your answer	0	I don´t know (B32)
		0.5	Yes (A19).
		1	Yes, there are. For example, in yoghurts or in decomposing bodies (A31).
MQ5	Are there microorganisms in your body when you are sick?	0	I don´t know (A11)
		0.5	Yes, I don´t know where (A19)
		1	Yes. The flu, for instance, in such case, microorganisms are mainly in the respiratory system (A27)

MQ6	"All illnesses are due to microorganisms". Is this true? If your answer is negative, give an example	0	I don´t know (B39)
		0.5	No, it isn´t. Other particles can also cause illness (B4)
		1	No, for instance a heart attack (B50)
MQ7	Mention at least two measures to prevent microorganisms from entering your body	0	No answer (A27)
		1	Hand washing. I don't know any other (B40)
		2	Face masks, screens (B50)
MQ8	Mention at least two measures to eliminate microorganisms from your body	0	I don´t know (B5)
		1	Medicines. I don't know any else (B40)
		2	Penicillin and amoxicillin (B12)

*Note: MQ1, MQ3, MQ4 adapted from Molina et al. (2021); MQ2, MQ5, MQ8 adapted from Bandiera (2007); MQ6 adapted from Robredo and Torres (2021).*The answers were obtained before the activity sequence.*

Appendix 2

Ideal Answers to Questionnaire about Cystitis

Number	Question	Ideal response
CQ1	What is cystitis?	Cystitis is inflammation of the bladder, usually caused by a bladder infection.
CQ2	Why do you think someone develops cystitis?	Because the openings to the urethra, vagina and anus are close together, and bacteria can get into the bladder easily. Sexual practices. Bad hygiene.
CQ3	Why does cystitis happen? What infectious agent generates it?	The commonest cause is bacteria entering the bladder through the urethra. Most cases of cystitis are caused by a type of Escherichia coli (*E. coli*) bacteria
CQ4	What are the symptoms?	Pain or burning when you pee. Needing to pee more often and urgently than normal. Presence of blood in urine. Low fever.

Journal of Turkish Science Education, 2024, *21*(1), 22-43.
DOI no: 10.36681/tused.2024.002

Implementation of sustainable development goals in higher education modalities: Literature review

Ragil Meita Alfathy[1], Sulistyo Saputro[2], Sarwanto Sarwanto[3], Murni Ramli[4]

[1]*Universitas Sebelas Maret, Indonesia, meita.alfathy@gmail.com, Corresponding author, ORCID ID: 0000-0003-3232-5734*
[2]*Universitas Sebelas Maret, Indonesia, ORCID ID: 0000-0002-5613-9496*
[3]*Universitas Sebelas Maret, Indonesia, ORCID ID: 0000-0002-9602-5776*
[4]*Universitas Sebelas Maret, Indonesia, ORCID ID: 0000-0003-4242-9190*

ABSTRACT
A systematic mapping review of the implementation of the Sustainable Development Goals (SDGs) in higher education has been carried out. Forty-six articles published from 2018 to 2022 were identified using the Systematic Literature Review. The purpose of this literature review was to derive a research framework that effectively raise awareness of SDGs from the realm of higher education and show SDGs research opportunities that have not been widely implemented. Research findings in the implementation of SDGs innovation in higher education have a trend in the categories of learning, stakeholders (institutions), teaching and approach. Based on the five modalities of higher education, the category is spread over the aspects of education (79%) and knowledge production (10%). The other three aspects such as public debate, provision of public services and embodiment only have quantities below 5%. Innovations include the development of SDGs-based courses by integrating aspects of knowledge production and provision of public services into one learning goal through the Project-based Learning Model. Mapping of the implementation of the SDGs in higher education provides information that supports researchers, educators and policy-making institutions interested in educational innovation. The results of the analysis show that the integration of these aspects can not only increase the understanding of higher education graduates regarding the SDGs but also increase public awareness regarding the SDGs through the provision of public services by universities.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
13.10.2022
Accepted:
31.07.2023

KEYWORDS:
Courses, higher education, innovation, SDGs.

To cite this article: Alfathy, R.M., Saputro, S., Sarwanto, S., & Ramli, M. (2024). Implementation of sustainable development goals in higher education modalities: Literature review. *Journal of Turkish Science Education, 21*(1), 22-43. DOI: 10.36681/tused.2024.002

Introduction

The rapid advancement of information, communication technology and the increasingly complex future challenges mark a new era referred to by some as the era of the industrial revolution 4.0 (Lim, 2019). In this era, information technology has become a companion to human life. This has real consequences and impacts on various areas of life. In the field of education, government must educate the nation's successors based on the need to meet future needs through the use of technology. Higher education in particular has a role in producing human resources who are innovative and have

superior competencies both in soft skills and hard skills (21st-century skills) to be able to face various challenges, ranging from of poverty, gender equality, climate change, inequality and financial inequality (Oral & Erkilic, 2022), in line with the sustainable development programme of the United Nation (UN) for the 2030 agenda which aims to end poverty and inequality along with improving health, education and spurring economic growth.

Sustainable development is development that meets the needs of the industrial revolution era 4.0 without compromising the ability of future generations to meet their own needs (UN Secretary General, 2019). Sustainable Development Goals (SDGs) are global development targets that aim to sustainably increase the economic welfare of the community, maintain the sustainability of people's social life, preserve environmental quality, and ensure justice and the implementation of good governance. They are designed to maintain an improvement in the quality of life from one generation to the next. The SDGs are a refinement of the more comprehensive Millennium Development Goals (MDGs) by involving more countries, both developed and developing, expanding funding sources, and emphasising human rights through the involvement of community organisations and the media, philanthropy and business actors, as well as academics and experts.

In September 2015, UN declared 17 Sustainable Development Goals (SDGs) with 169 targets referring to the 2030 Agenda. These goals include: (1) No Poverty; (2) No Hunger; (3) Healthy and Prosperous Life; (4) Quality Education; (5) Gender Equality; (6) Clean Water and Proper Sanitation; (7) Clean and Affordable Energy; (8) Decent Work and Economic Growth; (9) Industry, Innovation and Infrastructure; (10) Reducing Gaps; (11) Sustainable Cities and Settlements; (12) Responsible Consumption and Production; (13) Climate Change Management; (14) Ocean Ecosystems; (15) Land Ecosystems; (16) Peace, Justice and Strong Institutions; and (17) Partnerships to Achieve Goals (UN General Assembly, 2015).

Efforts to achieve the SDGs' targets become a global development priority, which requires a synergy of planning policies at the national level and at the provincial and district/city levels. SDG targets in Indonesia are in line with the 2015-2019 National Medium-Term Development Plan (RPJMN) and 2020-2024 RPJMN in the form of programmes, activities and measurable indicators as well as indications of financial support (BAPPENAS, 2020).

In 2019, the results of United Nations investigation showed that public awareness of the SDGs and the 2030 Agenda was low (UN Secretary General, 2019). Based on the results of the 2019 Sustainable Development Goals Summit, it was held that the government could not carry out the sustainable development programme alone to achieve the 2030 Agenda, thus requiring various groups including civil society, the scientific community, and others to work together to reach sustainable development for the success of the 2030 Agenda (UN Secretary General, 2019). Public awareness of SDGs is a prerequisite for formulating policy preferences and putting pressure on policy makers (Otto et al., 2019). The public sector is expected to improve its performance based on the targets of the SDGs (Figueira et al., 2018).

Meeting the 2030 Agenda targets, in addition to investing in advanced technology as needed in the industrial revolution 4.0 era, the creation and dissemination of knowledge on sustainable development is seen as important through higher education and research institutions in various fields and disciplines (Tchamyou, 2020). Based on this, it is important to know what roles higher education can play in the feasibility and implementation of SDGs that can carry out as drivers of SDGs in the field of education. This is done to effectively raise awareness of the SDGs and equalize SDG feasibility and SDG implementation in all aspects of higher education partnerships. The contribution of higher education institution partnerships to the SDGs is also referred to as higher education modalities (McCowan, 2019). The partnership field consists of five areas or aspects, namely education, knowledge production, public debate, public service provision, and embodiment.

There have been numerous studies related to sustainable development goals. A search using the Scopus database with the keywords "sustainable AND development AND goals" in the past five years (2018-2022) yielded 36,954 documents. Meanwhile, a search using the keywords "sustainable AND development AND goals AND higher AND education" in the Scopus database in the past five

years resulted in 1,423 documents. Further exploration using the keywords "integration AND sustainable AND development AND goals AND higher AND education" in the Scopus database in the past five years produced 278 documents. The keyword search "modalities AND higher AND education AND sustainable AND development AND goals" in the Scopus database in the past five years yielded only 4 documents. Many studies have been conducted using these four combinations of keywords. However, a study that combines all four keywords has not been conducted yet. The search using the keywords "implementation AND sustainable AND development AND goals AND higher AND education AND modalities" in the Scopus database in the past five years resulted in only 1 document. The title of that document is "Challenge based learning: Innovative Pedagogy for Sustainability Through E-learning in Higher Education" (Castro et al., 2020). However, this study does not directly demonstrate the implementation of SDGs in the aspects of higher education modalities.

Therefore, we intend to identify previous research related to the trend or dominance of SDGs research themes and the forms of implementation that have been carried out by universities based on aspects of higher education modalities. The aim is to provide an overview of research frameworks that effectively raise awareness of SDGs from the realm of higher education and show SDGs research opportunities that have not been widely implemented. This is done to provide information that supports researchers, educators, and policy-making institutions interested in educational innovation. To conduct this research, we posed the following research questions: 1) which areas of higher education did the sustainable development goals study focus on? 2) how is the distribution of Sustainable Development Goals studies in higher education based on Higher Education Modalities; and 3) how is the implementation of Sustainable Development Goals in higher education?

Methods

A Systematic Literature Review method is used in this article to identify, evaluate and interpret the availability of research relevant to the research question (Calderón & Ruiz, 2015; Kitchenham et al., 2009). The purpose of this study is to provide an overview of an effective research framework to raise awareness of SDG from the realm of higher education and point out SDGs research opportunities that have not been widely implemented, by identifying previous studies related to the trend or dominance of SDGs research themes and forms of implementation that have been carried out by universities based on aspects of higher education modalities. In the next sections, we present the main stages of the research process according to Petersen's guidelines, namely: (1) defining research question, (2) conducting searches, (3) selecting articles, (4) data extraction, (5) analysing and classifying schemas, and (6) validity evaluation (Petersen et al., 2015).

Stage 1 - Defining Research Questions

The objective of this study is to provide an overview of an effective research framework for raising awareness of the SDGs from the higher education domain and show the distribution of SDGs implementation research based on aspects of higher education modalities. This leads to the research question (RQ) shown in table 1.

Table 1

Research Question

Codes	Question
RQ1	Which areas of higher education did the sustainable development goals study focus on?
RQ2	How is the distribution of Sustainable Development Goals studies in higher education based on Higher Education Modalities?
RQ3	How is the implementation of Sustainable Development Goals in Higher Education?

Stage 2 - Conducting Searches

Kitchenham & Charters (2009) introduced PICO (Population, Intervention, Comparison and Outcome) as a tool designed for the identification of keywords and the creation of search strings based on research questions (Kitchenham et al., 2009).

- Population: it may refer to specific role, category, an application area or an industry group. In our context, the population are systematic mapping/scoping studies about SDGs.
- Intervention: it refers to a methodology, tool, technology or procedure. In the context of this study, we do not have a clear intervention to be investigated.
- Comparison: in this study we compare the different processes of conducting the implementation of SDGs by means of identifying the different strategies that have been used by author in higher education.
- Outcome: it refers to the outcomes that author measure to assess the effectiveness of an intervention. In this study, no measurable outcomes were considered, as we did not focus only on empirical studies.

Table 2 shows the identified keywords, i.e. Sustainable Development Goals, higher education, undergraduate, and university grouped into sets and their synonyms considered to formulate the search string.

Table 2

Search string of this research

Set 1	Scoping the search for population	Set 2	Search terms related to the process of classification and categorization
(1.1)	"Sustainable Development Goals" OR	(2.1)	"Higher education" OR
(1.2)	"SDGs"	(2.2)	"Undergraduate" OR
		(2.3)	"University"

The word "Sustainable Development Goals" or "SDGs" was entered to delimit the search area. The word "Higher education" is used to filter articles at the level of higher education. The words "Undergraduate" and "University" eventually became synonyms of "Higher education" due to several similarities in the data. Mendeley, a reference management tool, was used to remove duplication and to manage a large number of references.

Stage 3 - Selecting Articles

We exclude articles by considering their titles and abstracts, and also through a thorough examination of the full text and quality assessment. Additionally, studies were incorporated through backward snowball sampling. The first author applied inclusion and exclusion criteria to titles and abstracts, introducing a potential reliability threat to the mapping study, as each article was reviewed by a single author. To mitigate this threat, the second, third and fourth author conducted an evaluation of the final set of articles included, as explained later. The inclusion criteria specified for titles and abstracts were as follows:

- Studies present the result of Sustainable Development Goals study.
- Studies are in the field of higher education level.
- Studies were published online in the time frame 2018 to 2022.
- Studies that were catalogued as articles (classified as "articles" or "articles in print" by the same database).

The exclusion criteria specified for titles and abstracts were as follows:

- Studies not accessible in full-text.

- Studies not presented in English.
- Studies using research methods such as opinion surveys.
- Studies involving samples of students who are not from the Faculty of Education or the Faculty of Science.
- Books and Gray Literature.

During full-text reading it became obvious that further articles should be removed as they were not in the scope based on the inclusion and exclusion criteria. There were 67 studies deemed relevant during inclusion and exclusion based on title and abstract. The second, third and fourth authors reviewed all included studies during quality assessment and full-text reading, leading to 21 excluded studies, which had been included previously. A total of 46 studies proceeded to enter the data extraction stage.

Stage 4 - Data Extraction

To extract data from the identified primary studies, we created a template outlined in Table 3. The template comprises data items and their corresponding values. In the data extraction form, 46 articles are presented with identification keys A1 to A46.

Table 3

Data Extraction Form

Data Item	Value	RQ
Study ID	Identification key	
Article Title	Name of the article	
Author Name	Set of names of the authors	
Year of Publication	Calendar year	
Research purpose	What goals they set and in what areas they conduct the study	RQ1
Intervention	What intervention were used in order to introduce the SDGs	RQ3
Aspect in higher education modalities	Congruence between how they achieved their research targets and the definition of aspects of higher education modalities. (Fill in the name of the appropriate aspect, including: Education, Knowledge, Production, Public Debate, or Embodiment).	RQ2

The first author conducted the extraction, and the second, third, and fourth author subsequently reviewed it by cross-referencing the information in the extraction form with statements in each paper, ensuring accuracy. This practice of having a second author verify the extraction is a standard procedure in systematic reviews within the social sciences (Petticrew & Roberts, 2008).

Step 5 - Analysing and Classifying Schemas

The extracted research purpose and intervention were grouped and themed by the first author during analysis using the NVivo application. The NVivo application output indicates that only 21 articles are valid for forming study area themes, and this theme is necessary to answer the RQ1 (see Table 4).

The congruence of the papers included in each aspect of higher education modality was then calculated to answer RQ2 (see Fig. 1). Classification was based on the conformity of the intervention to the following definitions of each aspect of higher education modality (McCowan, 2019):

- Education: promotion of sustainable development knowledge, skills and values to design the latest ideas on sustainable development education and global citizenship education.
- Knowledge production: conduct basic and applied research as a function of Higher Education Institutions, e.g. climate change research, the impacts arising from it, and possible mitigation factors.
- Public debate: higher education institutions' contributions to community deliberation, providing spaces for deliberation to take place and raising public awareness of critical national/global issues.
- Provision of public service: the creation of facilities (e.g. Internet, recreational areas, educational areas, sports halls) and services (e.g. health and legal services) in Higher Education Institutions for the service of the local community.
- Embodiment: form of SDGs practice policies in higher education institutions to encourage positive changes within the higher education institution community and outside of the institution, e.g. implementing gender equality in the internal processes and structures of higher education institutions, and preserving the environment around higher education institutions in relation to resource use, carbon footprint, and local emissions.

Based on the aspect in higher education modalities (education, knowledge production, public debate, public service provision, and embodiment), their themes were identified (see Table 5). The aspect for the process were known a priori and were based on McCowan's (2019) theory of higher education modalities. Themes were identified to see what interventions they have put in place to introduce the SDGs in order to foster SDG awareness and answer RQ3 (see Fig. 2).

Stage 6 - Validity Evaluation

Systematic literature review is a vital part of qualitative research. Validity and reliability in qualitative studies are achieved through triangulation of diverse data sources, enhancing research accuracy. Source triangulation, as employed in this study, strengthens evidence from various individuals in describing qualitative research themes. Creswell emphasises that researchers meticulously examine each information source, ensuring accuracy and credibility by drawing from multiple individual sources (minimum 2) to support themes (Creswell, 2009). Ultimately, findings or themes in this research are deemed valid and reliable when backed by at least 2 supporting studies or articles. The accuracy of the findings has been examined by all research members. This method is called member checking. Aspects that were assessed include whether the article is suitable for developing the categorisation theme, whether the description is comprehensive and realistic, whether the categorisation theme is accurate to be included, and whether the interpretation is fair and representative (Creswell, 2009).

Findings

Study Areas (RQ1)

The study areas covered are classified based on the structure of the NVivo output. The output results were then made into themes. The first author added theme areas such as approach, development, stakeholders, teaching, and learning to cover the study area generated by NVivo. Table 4 shows the mapping articles per study area category. It can be seen that all activities are well represented, while the emphasis is on approach, development, stakeholders, teaching, and learning.

Table 4

Study Areas Covered in SDGs Studies at Higher Education

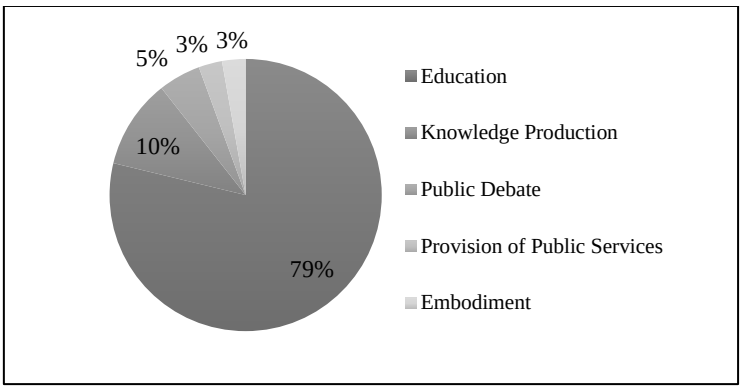
Theme	Study areas	Review citation
Approach	Interdisciplinary approaches	(Michalopoupou et al., 2019)
	Multidisciplinary approach	(Álvarez et al., 2021)
	Pedagogical approach	(Alm et al., 2021)
	Systemic approach	(Camacho et al., 2019; Pallant et al., 2020)
Development	Bilateral education agreements	(Zguir et al., 2021)
	Biological education area	(Lucas, 2018)
	Education system	(Alexio, et al., 2021; Ambariyanto & Utama, 2020; Clark et al., 2020; Hansen et al., 2021; Heleta & Bagus, 2020)
	Pre-service teacher education programs	(Chisingui & Costa, 2020; Tan, 2019)
Stakeholders	Education institution	(Aleixo et al., 2021; Alm et al., 2021; Ambariyanto & Utama, 2020; Hansen et al., 2021; Kioupi & Voulvoulis, 2020)
	Institution curricula	(Pallant et al., 2020; Rajabifard et al., 2021)
	Institution strategy	(Rajabifard et al., 2021)
Teaching	Inductive teaching methods	(Prince & Felder, 2018)
	Initial teacher education	(Chisingui & Costa, 2020; Cryne, 2018; Tan, 2019)
	Just-in-time teaching	(Prince & Felder, 2018)
Learning	Learning models	(Prince & Felder, 2018)
	Learning functions	(Ramaswamy et al., 2021)
	Learning method	(Bolmsten & Kitada, 2020)
	Learning objectives	(Dlouha et al.,2019)
	Learning outcomes	(Rajabifard et al., 2021; Kioupi & Voulvoulis, 2020)
	Learning point	(Álvarez et al., 2021)

Frequency of Publication (RQ2)

The interventions discussed are classified based on the aspect definitions of higher education modalities. The definition was described earlier in the methods section. Figure 1 shows the number of mapping articles per aspect category.

Figure 1

Frequency of Publications Based on Aspects of Higher Education Modalities



Publications related to the education aspect dominate the distribution. This tendency arises as a result of the important role and sense of responsibility of higher education in the sustainability of the SDGs, namely increasing awareness of the SDGs through education (Crespo et al., 2017).

Intervention (RQ3)

Analysis of publications related to the implementation or intervention of SDGs in higher education will be discussed based on the five modalities of higher education by McCowan (McCowan, 2019). The intervention data from the data extraction (see Table 3) were classified into themes of each aspect within the corresponding higher education modality. This was done to provide a clearer framework for the form of interventions that can be carried out in each aspect of higher education modalities. The findings complement Mc Cowan's theory of higher education modalities, which was not previously explained in detail.

We collected research data for RQ3 after reading each publication thoroughly. We organized the identified intervention data in the form of keywords that represented them and placed them in a table with the name of the activity (e.g. see table 5). Similar activities were brought together to build intervention themes with appropriate names. The themes were matched with the definition of each aspect of higher education modality to see which aspect they belonged to.

Education Aspect

Nine themes of Sustainable Development Goal interventions in higher education based on education aspect have been found. Table 5 shows the intervention activities represented by the themes under the education aspect.

Table 5

Intervention Activities Represented by the Themes Under the Education Aspect.

Activities	Theme
Co-creation approach, crosscutting approach, Impact-oriented approach, Integrated approach, Learning approaches, Methodology approach, Inductive approach, Two-phase approach	Approach
Integrative competence development, Sustainability competences, Transversal competences	Competence
Compulsory course, Course component, Course content (broad topics	Course

Activities	Theme
integrating climate change topics, topic investigation), Course inventory, Course objectives	
Character (SDGs awareness) education, Climate change education, Education institutions compromise, Education systems, Experiential education, International education policies, Quality education.	Holistic Education
SDGs-based academic institutions, introduction of SDGs at all levels of the institution, Institution's vision and mission	Institutions
Developed knowledge, Instructional knowledge, Knowledge areas, Normative knowledge, Scientific knowledge, Sustainability knowledge	Knowledge
Autonomous learning, Blended learning, Creative learning environment, Learning cycle, Learning landscapes, Learning methodology, Learning objectives, Learning process, Learning room, Learning methods, Learning trip	Learning
Introduction to teaching fundamentals, Teaching methods, Lesson plan (LSP), Pre-service teachers, Student-centered teaching, Teaching materials, Teaching sustainability	Teaching

Based on the intervention data, the SDGs intervention under the education aspect is generally carried out through: early introduction of SDGs to first semester students, including SDGs material in special courses (Chaleta et al., 2021; Willats et al., 2018), conducting work-based learning or projects related to SDGs (Álvarez et al., 2021; Fuertes-Camacho et al., 2019), creation of teaching modules/materials on SDGs (Crespo et al., 2017), curriculum development and evaluation (Pallant et al., 2020; Rajabifard et al., 2021) and scientific publications related to each pillar of SDGs: social, economic, legal and environmental.

Knowledge Production Aspect

Change, Project, Engineering are intervention themes found under the knowledge production aspect. Table 6 shows the intervention activities represented by the themes under the knowledge production aspect.

Table 6

Intervention Activities Represented by the Themes Under the Knowledge Production Aspect

Activities	Theme
Behavioural change, Climate change education, Integrating climate change topics, Sound climate science instruction, Substantial change	Change
Academic projects, Ecological projects, Engineering projects, Road infrastructure projects	Project
Innovative engineering	Engineering

Some interventions that higher education institutions can do based on the definition of knowledge production aspects include: researching climate change (change theme), the impacts arising from it (project theme), and possible mitigation factors (engineering theme).

Public Debate Aspect

The aspect of public debate has been stated as higher education's contribution to society including providing a forum for deliberation, information dissemination efforts to raise public

awareness on critical issues. Table 7 shows the 2 themes of SDGs intervention in higher education that were found in the public debate aspect.

Table 7

Intervention Activities Represented by the Themes Under the Public Debate Aspect

Activities	Theme
Audience barriers, Potential target audience, Wide audience	Audience
Environmental impact, Macro-level impact, Real-life impact, Update the impact review	Impact

The audience area discusses possible targets to be invited to work together to achieve the successful implementation of the SDGs. Meanwhile, the Impact theme is a theme that covers the causal effects of SDGs implementation on the environment outside higher education institutions.

Provision of Public Services Aspect

The theme of SDGs intervention in higher education found in the aspect of public service provision is called the dimensional services theme. Table 8 shows the types of intervention activities carried out under the dimension theme.

Table 8

Intervention Activities Represented by the Themes Under the Provision of Public Services Aspect

Activities	Theme
Economic dimension, health dimension, personal dimension, and social dimension	Dimensional services

This aspect is known to have not been studied in many publications published between 2018 and 2022.

Embodiment Aspect

Table 9 shows the intervention activities conducted under the advocacy theme. In the embodiment aspect, only one activity was found, namely SDGs advocacy. The activity discusses how all faculty members have the responsibility to introduce SDGs perspectives and ideas to students and the surrounding community.

Table 9

Intervention Activities Represented by the Themes Under the Embodiment Aspect

Activities	Theme
SDGs advocacy	Advocacy

This aspect is known to be under-researched, similar to the Provision of Public Services aspect.

Discussion

This discussion outlines the findings by grouping the identified area studies and interventions according to the similarity of their underlying theoretical frameworks. Five overarching aspects of higher education modalities are discussed, with particular reference to the field of SDGs in higher education, as it is one of the focuses of this systematic literature review. We then examined the positioning of the area study themes we found against the aspects of higher education modalities. The discussion continued by articulating the findings with a detailed description of the activities that have been undertaken on each aspect of the higher education modality. We conclude the discussion with a consideration of implications for future studies on the implementation of SDGs integration in higher education, noting the gaps in the current literature.

Publication Theme of Sustainable Development Goals in Higher Education

After examining the research objectives and interventions at the data extraction stage, it can be seen that there are connections and similarities among the various approaches identified in Table 4. It is clear that there are five overarching study area themes: approach, development, stakeholders, teaching, and learning. These approaches are not mutually exclusive and many papers fall into more than one theme study area. In the following we will provide a broad explanation of the five themes according to the way they are used in this SLR article.

The results of data extraction found 5 articles that have a similar area of study framework. Two articles from Pallant et al. (2020) and Camacho et al. (2019) are about applying a systemic approach to the curriculum, where all departments in a Higher Education are required to take courses related to SDGs. Three other articles have a focus area study on interdisciplinary or multidisciplinary approaches based on pedagogical approach thinking on courses that adopt SDGs as an overarching framework (Alm et al., 2021; Álvarez et al., 2021; Michalopoulou et al., 2019). The basis for the theme building of these area studies is the similarity in the framework of the approach taken. In the context of education, the term "approach" refers to the approach or method used to design, develop, and implement educational programs (in this case, SDGs education programs). Examples of approaches commonly used in education include interdisciplinary approaches, multidisciplinary approaches, pedagogical approaches, systemic approaches, thematic approaches, discipline-specific approaches, and others.

Seven publications from the data extraction were found not to fit into the study area approach themes. One article (Zguir et al., 2021) discusses higher education in low-income countries overcoming existing limitations to still implement the SDGs in higher education with the development of inclusive socio-economic bilateral cooperation. Five articles focus on education system development by mapping institutional needs for the future sustainability of SDGs in higher education (Aleixo et al., 2021; Ambariyanto & Utama, 2020; Clark et al., 2020; Hansen et al., 2021; Heleta & Bagus, 2021). One article (Lucas, 2018) has a study area of SDGs integrated biology education curriculum development by conducting an evaluation (assessment) study, a research study based on program usage, and discussing the implications of the existence of the curriculum. Two other articles (Chisingui & Costa, 2020; Tan, 2019) were identified as having a study focus area related to the development of an SDGs-aware pre-service teacher education program through piloting the program in ways that can be measured, reported, and incorporated into all education faculty curricula efficiently. It appears that the 7 publications have a common research framework related to processes and efforts that aim to improve the abilities, knowledge, skills, and potential of individuals or groups towards the sustainability of the SDGs. The research objectives of the seven publications are known in general to strengthen higher education institutions by developing SDGs-related programs at the inter-faculty and inter-institutional levels. Based on this, a study area theme called development was built to cover these 7 publications.

Four articles (Aleixo et al., 2020; Alm et al., 2021; Ambariyanto & Utama, 2020; Hansen et al., 2021) that were previously identified in the theme study area development, were decided to be included in the same study area as the publication from Kioupi & Voulvoulis (2020) after checking by the second, third, and fourth authors. These publications also address stakeholder-related study areas that review the alignment of desired learning outcomes with enabling conditions for a vision of sustainability based on the Sustainable Development Goals (SDGs). For example, in the publication of Aleixo et al. (2020) there are keywords in the sentence "an analysis of the perception of sustainable development carried out by higher education institutions", and in the publications of Alm et al. (2021), Ambariyanto & Utama (2020), Hansen et al. (2021) there are identified similarities in the way of achieving goals related to follow-up analysis conducted on stakeholders in higher education institutions to explore interdisciplinary curricula or pedagogical approaches that are suitable for advancing knowledge and understanding of sustainable development goals. In the publication of Kioupi & Voulvoulis (2020), there is a key sentence that describes a study related to an assessment framework for educational institutions to evaluate the strategies for contributing educational programs to sustainability carried out by stakeholders. Based on this, five articles have similar study areas related to education institutions. Further identification results on the extraction data also found that 2 publications (Pallant et al., 2020; Rajabifard et al., 2021) conducted research on stakeholders who reviewed the alignment of SDGs-based learning outcomes at the university curriculum level (general basic courses that must be taken for all first-year students), not only that in the Rajabifard et al. (2021) publication, it was also identified that they also analysed the strategies carried out by stakeholders to implement the university's vision and mission that were directed at the SDGs. The three study areas (education institution, institution curricula, and institution strategy) have similar goals and ways to achieve these goals, namely by conducting research on stakeholders. This is the basis for the formation of a new study area theme called stakeholders to cover these seven publications (Aleixo et al., 2020; Alm et al., 2021; Ambariyanto & Utama, 2020; Hansen et al., 2021; Kioupi & Voulvoulis, 2020; Pallant et al., 2020; Rajabifard et al., 2021).

A new area study was built by the first author after identifying publications from Prince & Felder (2018), which achieved the research objectives (introducing SDGs) with the application of Inductive teaching methods and Just-in-time teaching (instructors respond to students' specific needs and facilitate concept understanding more effectively). Another area of study called initial teacher education builds on the identification of publications from Chisingui & Costa (2020) and Crayne (2018). The two publications examined the experiences of college graduates from education faculties and pre-service teachers (final-year students who are interning as teachers) to find out how they promote the 2030 Agenda. Another article categorized under the study area initial teacher education is a publication that applies Shulman's pedagogical concepts in a micro-teaching class that education students take before their internship (Tan, 2019). The study areas of inductive teaching methods, just in time teaching and initial teacher education are classified in a new study area theme, called teaching. A total of 4 publications were in the teaching theme (Chisingui & Costa, 2020; Crayne, 2018; Prince & Felder, 2018; Tan, 2019). The theme was built on the basis of the similarity of study areas that examined the effectiveness and application of teaching methods (in higher education) by emphasizing students' multidimensional thinking skills to deepen their understanding of SDGs.

The discovery of a new study area was identified from the publication of Ramaswamy et al. (2021), namely the study area of learning functions. This publication integrates sustainable development goals (SDGs) into learning functions (Ramaswamy et al., 2021). Another new study area discovery is the learning method from the publication of Bolmsten & Kitada (2020), which focuses the research area on agile social learning methods to achieve the research goal of forming a community of professional people to have an interest in SDGs and develop sustainable solutions in their origin organizations. Another discovery is the learning objectives area study from the publication of Dlouha et al. (2019). The focus of Dlouha's study area is the analysis of learning objectives to assess the personal competency dimensions (addressing individual values, attitudes, and life experiences) and systemic dimensions (cognitive) of students, as an impact of implementing an SDGs-based approach.

The three publications (Bolmsten & Kitada, 2020; Dlouhá et al., 2019; Ramaswamy et al., 2021), are categorized under the same area study theme, and named learning. The theme of the learning study area was built on the basis of the similarity of the study area of using learning methods in higher education to build sustainable development capacity in the institutional community (university) to the community level. In the member checking session, the second, third and fourth authors agreed to include 4 publications (Álvarez et al., 2021; Kioupi & Voulvoulis, 2020; Prince & Felder, 2018; Rajabifard et al., 2021) to the learning study area theme because they were identified as having study areas that could also be covered by this theme. Prince & Felder (2018) also conducted research related to learning, namely analysing the virtues of a multidisciplinary approach with active learning models (inquiry-based learning, problem-based learning, project-based learning, teaching-based learning) for SDGs-based learning. Meanwhile, Álvarez et al. (2021) tested the effectiveness of the application of learning in higher education that incorporates the points of sustainable development goals (in the form of learning points) in the classroom. Finally, Rajabifard et al. (2021) and Kioupi & Voulvoulis (2020) analysed the impact of stakeholder policies on the success of SDGs-based learning in their higher education institutions. Based on this, there are 7 publications under the theme of learning studies (Álvarez et al., 2021; Bolmsten & Kitada, 2020; Dlouhá et al., 2019; Kioupi & Voulvoulis, 2020; Prince & Felder, 2018; Rajabifard et al., 2021; Ramaswamy et al., 2021).

The identification and classification we have done gives the scope of each study area theme as follows:

- Approach refers to the study area of introducing SDGs in Higher Education Institutions using a model approach, theme approach, specific disciplinary approach or even a specific curriculum to advance knowledge and understanding of sustainable development goals (SDGs) in higher education.
- Development is a study area of bilateral relationship ideas to support the implementation of sustainable development goals (SDGs) through various educational programs for higher education.
- Stakeholders is a study area related to the perception of sustainable development organized by Higher Education Institutions related to vertical integration (from the scope of the institutional community then expanding nationally) of sustainable development goals and assessment of the contribution of their education programs to the SDGs. This is done by reviewing the alignment of desired learning outcomes, with enabling conditions for a vision of sustainability based on the SDGs.
- Teaching is an area study that covers experiential and pedagogical testing of education study program students to pre-service teachers (final year students who intern as teachers) related to teaching techniques to introduce SDGs for students.
- Learning is an area study on the implementation of effective learning methods to improve student competencies in higher education related to the SDGs in the affective, cognitive, and psychomotor dimensions.

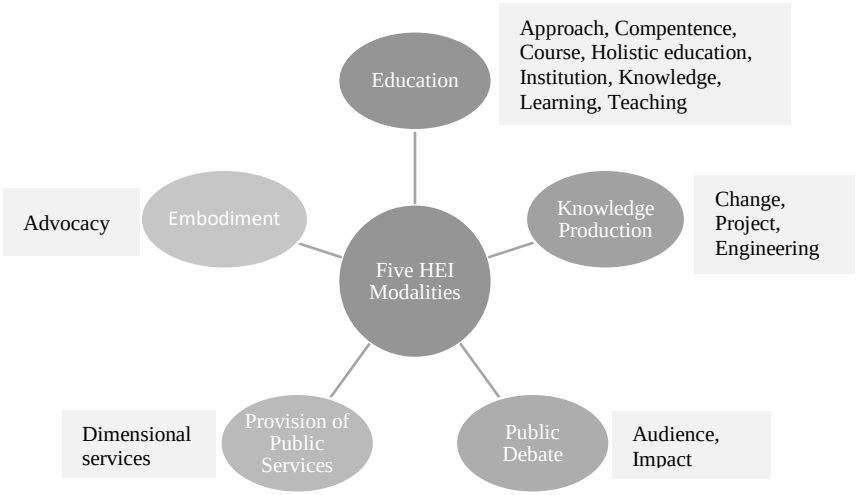
Framework for Raising SDG Awareness Based on Higher Education Modalities

Implementation of the SDGs in higher education is an effort to implement or carry out the Sustainable Development Goals (SDGs) in the higher education environment. The implementation of SDGs in higher education involves various interventions made by higher education institutions to ensure that the principles and goals of sustainable development are reflected in their policies, programs and activities. Publications related to SDGs implementation in higher education have been identified and categorized based on aspects of higher education modalities. The interventions written in the publications show the trend of research related to SDGs in higher education based on higher education modalities. On the other hand, we used the classification results of these interventions to refine McCowan's (2018) theory of higher education modalities. McCowan's theory only provides definitions for each aspect of higher education modalities or aspects of higher education institutions'

partnership contributions to the SDGs. In this study, we provide an overarching framework for how these aspects are actually carried out by constructing corresponding intervention themes. Figure 2 shows the improvements we made to McCowan's theory. The words in the box are intervention themes that we added to Mc Cowan's theory on the implementation of higher education modalities. Through this refinement, Mc Cowan's theory of higher education modalities, which previously provided explanations or predictions about how and why a phenomenon occurs, can now be practically used as a framework or conceptual structure or systematic thinking used to structure and organize ideas or concepts in a research or project.

Figure 2

Higher Education Modality Framework



In the next session we explain each of the themes in higher education modality framework as follows:

Education Aspect

Approach Theme: Approach is an intervention theme related to the development of active learning models that have been followed by a co-creation approach. The framework offered from this theme is the development of a model to facilitate students and college staff to learn about the challenges of global issues and how to overcome them. The characteristics of this theme are built from the identification of existing publication interventions in the 2018-2020 range, including: Longoria et al. (2021) and Aartz et al. (2020), who analysed the success of developing a model for SDGs-based learning through a co-creation approach for a balanced elaboration of knowledge, skills, attitudes and global citizenship. Other examples of interventions are those of Alm et al. (2021), Camacho et al. (2019) and Dlouha et al. (2019) that promote project methods in multidisciplinary and transdisciplinary teams to improve SDGs competencies related to SDGs knowledge, psychomotor, attitudes and values.

Competence Theme: This theme is built on the basis of identifying interventions in a sample of publications, including: Chang & Lien (2020) and Dlouha et al. (2019). Competence theme is how general education plays an important role in supporting the need to provide normative knowledge, transversal competencies, integrative competencies into courses, to compensate for the lack of holistic understanding and systems thinking when SDGs are integrated into the overall university curriculum. Transversal competencies, known as cross-disciplinary skills or cross-functional skills, refer to skills and knowledge that can be applied across different contexts or fields.

Meanwhile, integrative competencies refer to an individual's ability to combine or integrate knowledge, skills and resources from different sources or disciplines to achieve a more holistic or comprehensive goal or solution (Dlouhá et al., 2019).

Course Theme: The course theme is an intervention in the form of curriculum extension to introduce SDGs to students. This intervention creates a compulsory course that includes understanding the SDGs in a context-adaptive framework. Examples of existing publications on this theme are those of Tandon & Pandey (2019), Tan (2019) and Chang & Lien (2020). We identified important information in the intervention data related to the implementation of the new research framework in the intervention course theme, namely: (1) the SDGs course inventory should offer useful information for academic administration to better understand the interdisciplinary capacity and internal collaboration opportunities in the university; (2) SDGs-based classes can serve as a platform to develop innovative and interdisciplinary programs through multi-university collaboration, where faculty can engage in the same SDGs through different approaches; and (3) the integration of SDGs points should be clearly aligned with the expertise of specific departments in the university.

Holistic Education Theme: Publications related to holistic education focus more on policy interventions and international educational entities as well as historical calls that paved the way for the emergence of the concept of SDGs integration in higher education as a result of the international adoption of the UN 2030 sustainable development agenda. Examples of activities we identified are mobilizing students to take action to support SDGs (Fekih Zguir et al., 2021), designing sustainable development education to form sustainable citizens at the university level (Ambariyanto & Utama, 2020), support for SDGs-related work and capacity building (Žalėnienė & Pereira, 2021). Sustainable citizen refers to individuals who are committed to contributing to the sustainability or sustainability of the environment and society and they endeavour to choose a way of life that supports sustainability goals (Ambariyanto & Utama, 2020).

Institution Theme: The institutional intervention theme is a theme that we developed based on interventions in the activities of managers of academic institutions to serve as a protocol for assessing the sustainability dimension. The aim is to promote behavioural change within the university community towards sustainable development at the individual, organizational and institutional levels. One example of a publication that discusses this intervention is Hübscher et al. (2022), where he conducts SDGs-based academic institutions by analysing institutional policies to motivate students through meaningful campus agendas with the SDGs as guiding principles. The majority of institutional intervention themes are built from the activity of analysing the perception of the impact of SDGs-based policies on students, because students are considered as agents of sustainability change that have the potential to generate SDG-related impacts externally, from student organizations to institutions (Hübscher et al., 2022).

Knowledge Theme: The knowledge intervention theme is one that builds on the commonality of SDGs knowledge transfer activities to the course reflected in the course syllabus. In the process of transferring SDGs knowledge, four publications (Antó et al., 2021; Manolis & Manoli, 2021; Pallant et al., 2020; Shabalala & Ngcwangu, 2021) used in-class projects to enable them to measure students' knowledge and psychomotor skills.

Learning Theme: The Learning intervention theme leads to the intervention of new learning techniques or ways to improve students and staff learning about the challenges of global issues by bringing concrete issues into the subject and how to address them. Activities in learning interventions emphasize improving SDGs knowledge, problem-solving skills, SDGs-aware attitudes and global citizenship through. Examples of these interventions include implementing active learning methods

(Aarts et al., 2020; Bolmsten & Kitada, 2020), implementing Co-Curricular, which is a learning process where students can choose to engage in paid or unpaid internship activities, conduct research with faculty members through independent study, participate in study abroad or work as volunteers in their communities (Pallant et al., 2020). We conclude from the few existing publications on this theme, that the function of these interventions is to: present challenges for students to broaden their learning (Holmberg & Larsson, 2018) and behavioural based on assumptions of professional attitudes, values, and dispositions (Álvarez et al., 2021; Tan, 2019).

Teaching Theme: The teaching intervention theme refers to the management of SDGs basic teaching development with adaptive techniques in the context of introducing SDGs to education faculty (faculties that produce bachelor's degrees in education) students. Publications under this theme emphasize that teachers can play an important role in education towards a more sustainable world, and to achieve this, teacher education institutions (faculties of education) must explicitly integrate the SDGs into the vision and mission of their faculties (Chisingui & Costa, 2020). Examples of activities covered by teaching interventions are: 1) improvement of education faculty students' competencies related to SDGs with an integrated approach of knowledge, procedures, attitudes, and values through the promotion of the project method in multidisciplinary and transdisciplinary teams (Fuertes-Camacho et al., 2019); 2) Interactive and collaborative activities that invite education faculty students to acquire, align, and demonstrate the V3SK framework, namely the three components of values (i.e. learner-centered values, teacher identity values, service to the profession and community values), skills, and knowledge of the SDGs (Tan, 2019); 3) Creating SDGs-based education fundamentals teaching materials created by lecturers or academic staff members (Willats et al., 2018).

Knowledge Production Aspect

Change Theme: The theme of change is a theme that covers the intervention activities of assessing the real-life impact of students in encouraging behavioural changes towards sustainable development at the individual, organizational, and institutional levels structurally, emotionally and culturally. These activities are carried out because in general, students have a low level of awareness regarding SDGs and global issues, especially climate change. Some of the publications identified as conducting this intervention are Demaidi & Al-Sahili (2021), Cryne (2018), Hübscher et al. (2022), and Prasad (2022). These four publications provide examples of interventions that offer undergraduate students the opportunity to learn more about climate change by integrating climate change topics into the higher education curriculum (Crayne, 2018; Demaidi & Al-Sahili, 2021; Hübscher et al., 2022; Prasad, 2022).

Project Theme: Theme projects are intervention activities that propose research in the form of projects, which are incorporated into the classroom. Examples of project titles that we have identified are Ecological Projects (Manolis & Manoli, 2021), Becoming an Agent of Change (Pallant et al., 2020), Road infrastructure projects (Álvarez et al., 2021). Based on this theme, we recognize the synchronization between the educational and knowledge production aspects of the higher education modality. The elaboration of projects in classroom activities can open new areas of publication in SDGs research in Higher Education.

Engineering Theme: The engineering theme is an advanced intervention activity of the project theme, which substantially evaluates students' skills during the completion of the project. In an educational context, engineering refers to student practices related to designing, building, developing, and maintaining products, systems, structures, or processes. Engineering in the context of SDGs-based projects involves applying scientific knowledge, mathematics, and practical skills to create innovative solutions to problems (Fuertes-Camacho et al., 2019; Shabalala & Ngcwangu, 2021).

Public Debate Aspect

Audience Theme: The audience theme is a theme that covers intervention activities carried out in higher education institutions to become community partners in promoting agents of change. One example we provide from the identification of the Hübscher et al. (2022) publication, is to establish a social marketing program that evaluates the audience (community) as a potential target, sets goals based on audience behaviour, surveys barriers, benefits, motivators, competition, and other things that affect the SDGs campaign at the local and national levels.

Impact Theme: The theme of impact refers to intervention activities that assess the impact of SDGs campaign programs of higher education institutions, to serve as reference material for a very wide audience across internal and external universities. For example, the assessment results of Social marketing programs show the potential to increase the impact of universities at a higher level when they successfully overcome audience barriers in carefully designed campaigns that build on benefits and motivations (Hübscher et al., 2022).

Provision of Public Services Aspect

Dimensional Services Theme: The dimension service theme has a type of SDGs intervention in setting indicators that allow academic institution managers as a protocol to assess the sustainability attitude of the community in the economic dimension, health dimension, personal dimension (values, emotions, and motivation) and social dimension. Examples of activities carried out are: 1) inviting the university community to consider environmental, technical, and social dimensions in formulating solutions to global issues in the SDGs campaign (Abad-Segura & González-Zamar, 2021; Crespo et al., 2017); 2) determine a policy that considers biodiversity issues, which then expands to include socio-cultural, ethical, behavioural, governance, and health dimensions (Kioupi & Voulvoulis, 2020).

Embodiment Aspect

Advocacy Theme: The SDGs Intervention activity on the advocacy theme is an activity that highlights how the SDGs can serve as a platform to develop innovative and interdisciplinary programs through multi-university collaboration, where each faculty member can engage with the same SDGs through different approaches. In the previous themes, the SDGs appeared as if they were part of the course content or pedagogy, but they are not. Therefore, faculty members who are not lecturers can take responsibility for introducing SDGs perspectives and ideas to the internal and external communities of the Institution at their own pace (Chang & Lien, 2020; Tandon & Pandey, 2021). Based on this, it is important to fulfil research distribution in this aspect.

Frequency of Studies on Sustainable Development Goals in terms of Higher Education Modalities

The high frequency in the education aspect is understood as the awareness of higher education to focus on improving the quality of graduates so that they have good personal and systemic competence dimensions towards the SDGs (Dlouhá et al., 2019) and are able to face global issues such as poverty, equality gender, climate change, inequality and social disparity (Berchin et al., 2021; Heleta & Bagus, 2021; Žalėnienė & Pereira, 2021).

Basically, the educational aspect of higher education is considered a focal point to spread knowledge and research inspiration to the younger generation (Manolis & Manoli, 2021). They are key

agents in educating future leaders who contribute to the successful implementation of the Sustainable Development Goals (SDGs) promoted by the United Nations. In addition, the academic community, including students, are the closest community to the general public because they can channel knowledge such as the introduction of the Sustainable Development Goals through programs owned by higher education.

We realise that various contributions outside the institution can be made only if the prerequisites for understanding and ownership of sustainable development awareness are owned by the academic community, including students who are in higher education. So that the largest distribution is in the education aspect where researchers focus on addressing the gap in increasing awareness of the SDGs through creative, practical and interesting ways among university students. Based on this, it is important to conduct research related to aspects of other modalities to provide new innovations in the world of education through new discoveries or a combination of several aspects with the same goal. We suggest a combination of various modalities as stated in the previous statement, namely between education, knowledge production, and public service provision in one goal as alternative research.

Conclusion and Implications

Systematic mapping of SDGs implementation in higher education aims to obtain a theoretical framework that can reveal the concepts of SDGs implementation that are relevant to research cases in higher education. Approach, Education, Stakeholders, Teaching and Learning are the findings of the publication theme of Sustainable Development Goals in higher education in the range of 2018 to 2022. Based on the analysis of the distribution classification of SDGs publications at higher education based on the modalities of higher education, the education aspect has the highest distribution quantity, namely 79%. Followed by knowledge production, public debate, provision of public services and implementation of public services with the percentages, respectively, namely 10%, 5%, 3% and 3%.

Integration is carried out in the education aspect, including in the areas of Approach, Competence, Course, Education, Institutions, Knowledge, Learning, and Teaching. Aspects of knowledge production are areas of change (including behavioural contexts, topics, curricular), projects (Ecological Projects, Becoming an Agent of Change, Road infrastructure projects) and engineering. Aspects Public debate is classified into two areas, namely audience and impact. In the provision of public services and the embodiment, there is only one area, successively dimensional services and advocacy. Based on this, it appears that it is important to fulfil the distribution of research in these two aspects. We suggest combining various aspects of the modalities as previously stated, namely between education, knowledge production and the provision of public services in a goal as an alternative for future research. This concept can not only increase the understanding of graduates of higher education related to the SDGs but also increase public awareness regarding the SDGs through the provision of public services and the implementation of public services by higher education institution.

Acknowledgements

We would like to express our gratitude for the funding provided by The Ministry of Education, Culture, Research, and Technology of Indonesia through The Dissertation Basic Research Program in 2023, under contract number 1280.1/UN27.22/PT.01.03/2023, chaired by Prof. Sulistyo Saputro, M.Si., Ph.D.

References

Aarts, H., Greijn, H., Mohamedbhai, G., & Jowi, J. O. (2020). *The SDGs and African Higher Education*. Springer International Publishing. https://doi.org/10.1007/978-3-030-14857-7_22

Abad-Segura, E., & González-Zamar, M. D. (2021). Sustainable economic development in higher education institutions: A global analysis within the SDGs framework. *Journal of Cleaner Production*, *294*(1). https://doi.org/10.1016/j.jclepro.2021.126133

Aleixo, A. M., Azeiteiro, U. M., & Leal, S. (2020). Are the sustainable development goals being implemented in the Portuguese higher education formative offer? *International Journal of Sustainability in Higher Education*, *21*(2), 336–352. https://doi.org/10.1108/IJSHE-04-2019-0150

Aleixo, A. M., Leal, S., & Azeiteiro, U. M. (2021). Higher education students' perceptions of sustainable development in Portugal. *Journal of Cleaner Production*, *327*(1), 1–15. https://doi.org/10.1016/j.jclepro.2021.129429

Alm, K., Melén, M., & Aggestam-Pontoppidan, C. (2021). Advancing SDG competencies in higher education: exploring an interdisciplinary pedagogical approach. *International Journal of Sustainability in Higher Education*, *22*(6), 1450–1466. https://doi.org/10.1108/IJSHE-10-2020-0417

Álvarez, I., Etxeberria, P., Alberdi, E., Pérez-Acebo, H., Eguia, I., & García, M. J. (2021). Sustainable civil engineering: Incorporating sustainable development goals in higher education curricula. *Sustainability (Switzerland)*, *13*(16), 1–16. https://doi.org/10.3390/su13168967

Ambariyanto, A., & Utama, Y. J. (2020). Educating Higher Education Institutions to Support SDGs: Indonesian Case. *E3S Web of Conferences*, *202*, 1–5. https://doi.org/10.1051/e3sconf/202020202015

Antó, J. M., Martí, J. L., Casals, J., Bou-Habib, P., Casal, P., Fleurbaey, M., Frumkin, H., Jiménez-Morales, M., Jordana, J., Lancelotti, C., Llavador, H., Mélon, L., Solé, R., Subirada, F., & Williams, A. (2021). The planetary wellbeing initiative: Pursuing the sustainable development goals in higher education. *Sustainability (Switzerland)*, *13*(6), 1–11. https://doi.org/10.3390/su13063372

BAPPENAS. (2020). *Pedoman Teknis Penyusunan Rencana Aksi Tujuan Pembangunan Berkelanjutan (TPB)/ Sustainable Development Goals (SDGs)*. Kementerian Perencanaan Pembangunan Nasional Republik Indonesia/Badan Perencanaan Pembangunan Nasional.

Berchin, I. I., de Aguiar Dutra, A. R., & Guerra, J. B. S. O. de A. (2021). How do higher education institutions promote sustainable development? A literature review. *Sustainable Development*, *29*(6), 1204–1222. https://doi.org/10.1002/sd.2219

Bolmsten, J., & Kitada, M. (2020). Agile social learning – capacity-building for sustainable development in higher education. *International Journal of Sustainability in Higher Education*, *21*(7), 1563–1586. https://doi.org/10.1108/IJSHE-07-2019-0212

Calderón, A., & Ruiz, M. (2015). A systematic literature review on serious games evaluation: An application to software project management. *Computers and Education*, *87*(1), 396–422. https://doi.org/10.1016/j.compedu.2015.07.011

Castro, M. P., Zermeño, G., & Marcela, G. (2020). Challenge based learning: Innovative pedagogy for sustainability through e-learning in higher education. *Sustainability (Switzerland)*, *12*(10), 1–15. https://doi.org/10.3390/SU12104063

Chaleta, E., Saraiva, M., Leal, F., Fialho, I., & Borralho, A. (2021). Higher education and sustainable development goals (SDGs)—potential contribution of the undergraduate courses of the school of social sciences of the university of Évora. *Sustainability (Switzerland)*, *13*(4), 1–10. https://doi.org/10.3390/su13041828

Chang, Y. C., & Lien, H. L. (2020). Mapping course sustainability by embedding the SDGS inventory into the university curriculum: A case study from national university of Kaohsiung in Taiwan. *Sustainability (Switzerland)*, *12*(10), 1–21. https://doi.org/10.3390/su12104274

Chisingui, A. V., & Costa, N. (2020). Teacher education and sustainable development goals: A case study with future biology teachers in an angolan higher education institution. *Sustainability (Switzerland)*, *12*(8), 1–14. https://doi.org/10.3390/SU12083344

Clark, I., Nae, N., & Arimoto, M. (2020). Education for Sustainable Development and the "Whole Person" Curriculum in Japan. In *Oxford Research Encyclopedia of Education* (pp. 1–32). Oxford University Press. https://doi.org/10.1093/acrefore/9780190264093.013.935

Crayne, J. A. (2018). *Teaching Climate Change: Pressures and Practice in The Middle School Science Classroom*. University of Oregon.

Crespo, B., Míguez-álvarez, C., Arce, M. E., Cuevas, M., & Míguez, J. L. (2017). The sustainable development goals: An experience on higher education. *Sustainability (Switzerland)*, *9*(8). https://doi.org/10.3390/su9081353

Creswell, J. W. (2009). *Research desıgn qualitative, quantitative, and mixed methods approaches*. SAGE Publications. https://doi.org/10.2307/1523157

Demaidi, M. N., & Al-Sahili, K. (2021). Integrating SDGs in higher education—case of climate change awareness and gender equality in a developing country according to rmei-target strategy. *Sustainability (Switzerland)*, *13*(6). https://doi.org/10.3390/su13063101

Dlouhá, J., Heras, R., Mulà, I., Salgado, F. P., & Henderson, L. (2019). Competences to address SDGs in higher education-a reflection on the equilibrium between systemic and personal approaches to achieve transformative action. *Sustainability (Switzerland)*, *11*(13). https://doi.org/10.3390/su11133664

Fekih Zguir, M., Dubis, S., & Koç, M. (2021). Embedding Education for Sustainable Development (ESD) and SDGs values in curriculum: A comparative review on Qatar, Singapore and New Zealand. *Journal of Cleaner Production*, *319*(August), 128534. https://doi.org/10.1016/j.jclepro.2021.128534

Figueira, I., Domingues, A. R., Caeiro, S., Painho, M., Antunes, P., Santos, R., Videira, N., Walker, R. M., Huisingh, D., & Ramos, T. B. (2018). Sustainability policies and practices in public sector organisations: The case of the Portuguese Central Public Administration. *Journal of Cleaner Production*, *202*(1), 616–630. https://doi.org/10.1016/j.jclepro.2018.07.244

Fuertes-Camacho, M. T., Graell-Martín, M., Fuentes-Loss, M., & Balaguer-Fàbregas, M. C. (2019). Integrating sustainability into higher education curricula through the project method, a global learning strategy. *Sustainability (Switzerland)*, *11*(3). https://doi.org/10.3390/su11030767

Hansen, B., Stiling, P., & Uy, W. F. (2021). Innovations and challenges in SDG integration and reporting in higher education: a case study from the University of South Florida. *International Journal of Sustainability in Higher Education*, *22*(5), 1002–1021. https://doi.org/10.1108/IJSHE-08-2020-0310

Heleta, S., & Bagus, T. (2021). Sustainable development goals and higher education: leaving many behind. *Higher Education*, *81*(1), 163–177. https://doi.org/10.1007/s10734-020-00573-8

Holmberg, J., & Larsson, J. (2018). A sustainability lighthouse-supporting transition leadership and conversations on desirable futures. *Sustainability (Switzerland)*, *10*(11). https://doi.org/10.3390/su10113842

Hübscher, C., Hensel-Börner, S., & Henseler, J. (2022). Social marketing and higher education: partnering to achieve sustainable development goals. *Journal of Social Marketing*, *12*(1), 76–104. https://doi.org/10.1108/JSOCM-10-2020-0214

Kioupi, V., & Voulvoulis, N. (2020). Sustainable development goals (SDGs): Assessing the contribution of higher education programmes. *Sustainability (Switzerland)*, *12*(17). https://doi.org/10.3390/SU12176701

Kitchenham, B., Pearl Brereton, O., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering - A systematic literature review. *Information and Software Technology*, *51*(1), 7–15. https://doi.org/10.1016/j.infsof.2008.09.009

Lim, T. W. (2019). *Industrial Revolution 4.0, Tech Giants, and Digitized Societies* (1st ed.). Palgrave Macmillan Singapore. https://doi.org/10.1007/978-981-13-7470-8

Lucas, A. M. (2018). The development of a curriculum monopoly in australian secondary schools: Biological science: The web of life 2 research and comment. *Journal of Biological Education*, *14*(2), 167–174. https://doi.org/10.1080/00219266.1980.10668984

Manolis, E. N., & Manoli, E. N. (2021). Raising awareness of the Sustainable Development Goals through Ecological Projects in Higher Education. *Journal of Cleaner Production*, *279*(1). https://doi.org/10.1016/j.jclepro.2020.123614

McCowan, T. (2019). *Higher Education for and Beyond the Sustainable Development Goals*. Palgrave Studies in Global Higher Education. https://en.unesco.org/themes/higher-education/sdgs%0Ahttp://library.lol/main/C330C34C497268D525AAC5638BD60C09

Michalopoulou, E., Shallcross, D. E., Atkins, E., Tierney, A., Norman, N. C., Preist, C., O'Doherty, S., Saunders, R., Birkett, A., Willmore, C., & Ninos, I. (2019). The End of Simple Problems: Repositioning Chemistry in Higher Education and Society Using a Systems Thinking Approach and the United Nations' Sustainable Development Goals as a Framework. *Journal of Chemical Education*, *96*(12), 2825–2835. https://doi.org/10.1021/acs.jchemed.9b00270

Oral, I., & Erkilic, M. (2022). Investigating the 21st -Century Skills of Undergraduate Students: Physics Success, Attitude, and Perception. *Journal of Turkish Science Education*, *19*(1), 284–301. https://doi.org/10.36681/tused.2022.1122

Otto, I. M., Kim, K. M., Dubrovsky, N., & Lucht, W. (2019). Shift the focus from the super-poor to the super-rich. *Nature Climate Change*, *9*(2), 82–84. https://doi.org/10.1038/s41558-019-0402-3

Pallant, E., Choate, B., & Haywood, B. (2020). How Do You Teach Undergraduate University Students to Contribute to UN SDGs 2030? In *World Sustainability Series* (pp. 69–85). Springer. https://doi.org/10.1007/978-3-030-15604-6_5

Petersen, K., Vakkalanka, S., & Kuzniarz, L. (2015). Guidelines for conducting systematic mapping studies in software engineering: An update. *Information and Software Technology*, *64*, 1–18. https://doi.org/10.1016/j.infsof.2015.03.007

Petticrew, M., & Roberts, H. (2008). *Systematic Reviews in the Social Sciences: A Practical Guide.* John Wiley & Sons. https://doi.org/10.1002/9780470754887

Prasad, R. R. (2022). Mitigating Climate Change: A Study of the University of the South Pacific and the State University of Malang. *Journal of Turkish Science Education*, *19*(1), 111–128. https://doi.org/10.36681/tused.2022.113

Prince, M. J., & Felder, R. M. (2018). The Many Faces of Inductive Teaching and Learning. *Journal of College Science Teaching*, *36*(5), 14–20. https://www.researchgate.net/publication/239773785

Rajabifard, A., Kahalimoghadam, M., Lumantarna, E., Herath, N., Hui, F. K. P., & Assarkhaniki, Z. (2021). Applying SDGs as a systematic approach for incorporating sustainability in higher education. *International Journal of Sustainability in Higher Education*, *22*(6), 1266–1284. https://doi.org/10.1108/IJSHE-10-2020-0418

Ramaswamy, M., Marciniuk, D. D., Csonka, V., Colò, L., & Saso, L. (2021). Reimagining Internationalization in Higher Education Through the United Nations Sustainable Development Goals for the Betterment of Society. *Journal of Studies in International Education*, *25*(4), 388–406. https://doi.org/10.1177/10283153211031046

Shabalala, L. P., & Ngcwangu, S. (2021). Accelerating the implementation of SDG 4: stakeholder perceptions towards initiation of sustainable community engagement projects by higher education institutions. *International Journal of Sustainability in Higher Education*, *22*(7), 1573–1591. https://doi.org/10.1108/IJSHE-04-2020-0123

Tan, C. (2019). A Signature Pedagogy for Initial Teacher Education in Singapore. *New Educator*, *15*(3), 226–245. https://doi.org/10.1080/1547688X.2019.1626670

Tandon, R., & Pandey, P. (2021). Disciplines, Professions and the Sustainable Development Goals (SDGs): Challenges in Higher Education in India. In *Implementing the 2030 Agenda at Higher Education Institutions: Challenges and Responses* (pp. 47–53). Global University Network for Innovation. http://mospi.nic.in/sites/default/files/National_Indicator_Framework_

Tchamyou, V. S. (2020). Education, Lifelong learning, Inequality and Financial access: Evidence from African countries. *Journal of the Academy of Social Sciences*, *15*(1), 7–25. https://doi.org/https://doi.org/10.1080/21582041.2018.1433314

UN General Assembly. (2015). *Global Sustainable Development Report 2015 Edition Advance*.

UN Secretary General. (2019). *Report of the Secretary-General on SDG Progress 2019 Special Edition*.

Willats, J., Erlandsson, L., Molthan-Hill, P., Dharmasasmita, A., & Simmons, E. (2018). A university wide approach to embedding the sustainable development goals in the curriculum—a case study from the nottingham trent university's Green academy. In *World Sustainability Series* (pp. 63–78). Springer. https://doi.org/10.1007/978-3-319-70281-0_5

Žalėnienė, I., & Pereira, P. (2021). Higher Education For Sustainability: A Global Perspective. *Geography and Sustainability*, *2*(2), 99–106. https://doi.org/10.1016/j.geosus.2021.05.001

Zguir, M. F., Dubis, S., & Koç, M. (2021). Embedding Education for Sustainable Development (ESD) and SDGs values in curriculum: A comparative review on Qatar, Singapore and New Zealand. *Journal of Cleaner Production*, *319*(August). https://doi.org/10.1016/j.jclepro.2021.128534

Journal of Turkish Science Education, 2024, *21*(1), 44-60.
DOI no: 10.36681/tused.2024.003

Exploring Iranian pre-service teachers' conceptual understanding of chemical equilibrium

Mahshid Golestaneh[1*], Seyed Mohsen Mousavi[2]

[1]*Department of Chemistry Education, Farhangian University, Iran, m.golestaneh@cfu.ac.ir, Corresponding author, ORCID ID: 0000-0001-6182-2495*
[2]*Department of Chemistry Education, Farhangian University, Iran, ORCID ID: 0000-0001-6182-2495*

ABSTRACT
This study aimed to develop a two-tier test to identify misconceptions of pre-service teachers about chemical equilibrium. The sample was made up of 135 pre-service chemistry teachers at Farhangian University in Iran (70 female and 65 male) who were spending the final semester of the eighth semester of the teacher training programme. After analysing the distribution pattern of the participants' answers in the first and second tiers, fifteen misconceptions were identified. A new misconception was identified for the first time, which we called the common ion effect which was held by about 50% of participants. Gender was a significant factor in the rate of misconceptions, with male pre-service teachers having fewer rate misconceptions compared with females. The results showed that when the first tier or the second tier was considered alone, female participants performed better, but when both tiers were combined, the performance of males was better. However, males had a weaker performance in three questions related to the approach to equilibrium in this situation. These findings will help educators plan their instruction by knowing pre-service teachers' preconceptions about chemical equilibrium.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 07.10.2022
Accepted: 05.05.2023

KEYWORDS: Pre-service teachers, chemical equilibrium, misconception, gender.

To cite this article: Golestaneh, M., & Mousavi, S. M. (2024). Exploring Iranian pre-service teachers' conceptual understanding of chemical equilibrium. *Journal of Turkish Science Education, 21*(1), 44-60. DOI: 10.36681/tused.2024.003

Introduction

Chemistry concepts are generated, expressed, taught, and communicated at three levels of representation: macroscopic, microscopic and symbolic. (Johnstone, 2000). The macroscopic level refers to the chemical processes most commonly seen with our senses. Microscopic refers to phenomena at the particle level (Talanquar, 2010), including the movement of electrons during bond breaking and bond-forming. We cannot observe any chemical changes that occur at this level. As a result, students find it hard to describe chemical phenomena at the microscopic level and tend to attribute the microscopic properties of matter to its macroscopic particles. (Ben-Zvi et al., 1988). Symbolic representations contain chemical symbols, equations, formulas, diagrams, models and animations (Siswaningsih et al., 2019). The ability to master the three levels of chemical representation makes chemistry so hard for students to learn. Therefore, learners often have difficulties explaining chemical phenomena with reference to these abstractions (Nur Akın & Uzuntiryaki-Kondakci, 2018; Yakmaci-Guzel, 2013). Submicroscopic and symbolic representations are abstract and cannot be

experienced, so students have difficulty understanding these representations (Chandrasgaran et al., 2007; Griffiths & Preston, 1992). Students often have limited conceptual knowledge and little visual-spatial ability and cannot translate one representation into another (Keig & Rubba, 1993). For better conceptual understanding, it is important to help students see the connections between submicroscopic, symbolic and macroscopic representations (Gable, 1999).

The main goal of learning and teaching methods is to achieve meaningful learning (Üce & Ceyhan, 2019). Ausubel (2012) stated that to achieve meaningful learning, students need to make connections between new ideas, concepts and information, and prior knowledge they also need to make a linkage between concepts that are interrupted. When students learn more about chemistry, the range of the concepts they hold increases, the level of complexity of their concepts deepens, and their concepts are better integrated with each other (Taber & Watts, 1997). When learners encounter new ideas, they try to fit them into their existing schemas, and if they do not match, they try to either modify the present understanding or create a new understanding. Sheckley and Bell (2006) stated that the reflection process involves reinterpreting past experiences in the light of new experiences. If new experiences do not match pre-existing patterns, the brain makes sense of these experiences by making new connections from an alternative perspective.

Cognitivist and constructivist learning theories are two major theories of learning. Constructivism, which encompasses both cognitive and social dimensions, posits that learners actively construct knowledge through mental processes (cognitive constructivism) and through social interactions with others (social constructivism).These learning theories emphasise the role of prior knowledge and experience as the foundational structures that further knowledge builds upon. Constructivists view learning as an active process in which learners construct knowledge rather than passively absorb it (Waseem & Aslam, 2020). According to the constructivist view of learning, meaningful learning occurs when learners actively construct their knowledge by using existing knowledge to understand newly acquired experiences. Taber (2000) has stated that the first step in the constructivist learning approach is to inform the teacher and the student of the current ideas of the learner. Then, instruction is planned to challenge misconceptions, and teachers play a crucial role in providing students with opportunities for conceptual restructuring through thoughtful lesson planning. Teachers can help students eliminate their misconceptions by providing adequate knowledge and a clear understanding of these concepts.

According to constructivist theories, misconceptions formed by science students may be resistant to instruction. This resistance arises when new knowledge presented to students does not align with their previous experiences. In such cases, students try to replace the correct concepts by creating new concepts that better explain their experiences. No amount of instruction can help students change their conceptualisations until misconceptions are resolved by constructing new concepts (Bhola & Parchoma, 2015). Students' misconceptions interfere with subsequent learning. When the students are left to assimilate new information into their cognitive structure, these misconceptions hinder the integration of scientific knowledge. This causes a weak understanding or misunderstanding of the concept (Azizoglu et al., 2006). Thus, teachers should be aware of students' misconceptions and use appropriate educational methods to correct them.

In recent years, common alternative concepts held by students have been identified (Hakim et al., 2016; Jusniar et al., 2020; Suat et al., 2010; Tyson et al., 1999). Thus educators must understand their nature and source to be more effective in addressing those (Lamichhane et al., 2018). Unfortunately, the literature shows that teachers often have similar alternative conceptions to those of their students (Demircioglu et al., 2013; Hartelt et al., 2022) and can transfer their misconceptions to their students. Teachers' misconceptions are one of the sources of students' misconceptions. Identifying the chemical misconceptions in pre-service teachers and trying to eliminate them is very important during teacher training.

Literature Review

Ozmen (2004) reviewed some student misconceptions in chemistry such as those pertaining to mole concept, the nature of matter, bonding, molecules, chemical and physical changes, intermolecular forces, electrolysis, acids and bases, and chemical equilibrium. The nature of chemical equilibrium has been extensively studied at the secondary school and university levels since the 1960s, for example, in India (Banerjee, 1991), Spain (Quilez-Pardo & Solaz-Portoles, 1995), The Netherlands (van Driel et al., 1998), Australia (Tyson, et al., 1999), the US (Piquette & Heikkinen, 2005), Nigeria (Omilani & Elebute, 2020), Turkey (EyceYurt-Turk & Tuzun, 2021; Ozmen, 2008), China (Cheung, 2009) and, Malaysia (Karpudewan et al., 2015). Nowadays teaching chemical equilibrium takes up a large part of the chemistry curriculum (Doymus, 2008). Chemical equilibrium involves mathematical calculations, and graphing. To understand chemical equilibrium, students must be familiar with other related conceptions, including concentration, stoichiometry, states of matter, and the mole. Chemical equilibrium is required to understand other conceptions in chemistry (Kaya, 2013) such as oxidation-reduction, acids and bases, phase changes, reaction rate, and solubility (Karpudewan et al., 2015; Voska & Heikinnen, 2000). In addition, chemical equilibrium requires representations at the macro, micro and symbolic levels (Yıldırım et al., 2011). But chemical equilibrium is a difficult concept for both teachers and students due to its abstract nature and the use of inappropriate didactic approaches (Bernal-Ballen & Ladino-Ospina, 2019; Kurniawan et al., 2020; Aydeniz & Dogan, 2016). As a result, students at all levels of education hold misconceptions or alternative conceptions related to chemical equilibrium (Demircioglu et al., 2013; Voska & Heikinnen, 2000; Cakmakcı et al., 2006).

Identifying student misconceptions is a significant step in the learning process (Ghirardi et al., 2015; Prodjosantoso, 2019). Teachers should monitor students' understanding of scientific principles and develop teaching strategies to correct any wrong ideas. One way to find the misconceptions is to use a diagnostic test. Multiple-choice questions are suitable for statistical analyses due to their ease of administration, objective marking, and low cost effectiveness (Wuttiprom et al., 2009; Seni & Yilmaz, 2017) Sometimes the students may give correct answers to the chemical equilibrium questions, but they are not unable to provide correct reasons (Quiliz-Pardo & Solaz-Portoles, 1995). Therefore, a two-tier multiple-choice diagnostic test is helpful to teachers with an easy-to-administer pencil and-paper test designed to recognize alternative concepts of students. Two-tier multiple-choice tests can help teachers to determine reasons for misconceptions among the students, obtain the ratio of frequency in students, and the teachers' being aware of these alternative concepts (Cullinane, 2011; Tyson et al. 1999).

Several chemical equilibrium alternative conceptions reported in the literature (e.g., García-Lopera et al., 2014; Karpudewan et al., 2015; Omilani & Elebute, 2020; Satriana et al., 2018). Van Driel and Graber (2003) catalogued these alternative conceptions into five categories: (a) confusion of amount (moles) with concentration—for instance, the student tries to calculate concentration when given molarity; (b) confusion over the appearance/disappearance of material—for instance, the student mistakenly assumes the reverse reaction starts when the forward reaction has been completed; (c) erroneous interpretation of the equilibrium constant, K—for instance, the student mistakenly assumes that the value of the equilibrium constant changes according to the amounts of reactants or products; (d) erroneous in the application of Le Chatelier's principle—for instance, the student tries to adjust a system formerly at equilibrium; (e) misconceptions about gaseous systems—for instance, the student assumes that gaseous equilibrium can be achieved in an open container; and (f) other alternative concepts, including dynamism versus staticity—for instance, the student is unable to understand the nature of a system at dynamic equilibrium (Piquette & Heikkinen, 2005). Ozmen (2008) identified four categories of students' common alternative conceptions regarding chemical equilibrium, including the approach to equilibrium, application of Le Chatelier's principle, the equilibrium constant, and heterogeneous equilibrium. Later, Karpudewan et al. (2015) mentioned the following as alternative concepts related to chemical equilibrium: (a) the forward reaction rate enhances continually from the beginning of the reaction until the reaction reaches equilibrium; (b) the existence of a simple

relationship between the concentration of reactants and products; and (c) when a change is made to a system at equilibrium (e.g. adding a reactant), the rate of the 102 forward reaction increases while the rate of the reverse reaction decreases.

Several researchers (Banerjee, 1991; Cheung (2009); Ozmen, 2008; Piquette & Heikkinen, 2005; Quílez-Pardo & Solaz-Portolés, 1995) have studied how Le Chatelier's principle affects teacher's understanding of the effects of addition of more reactants or products on chemical equilibrium. Studies have shown that pre-service teachers may hold misconceptions about basic science concepts (Demircioglu et al., 2013). But what are the main misconceptions of pre-service chemistry teachers, and is there a significant difference between the level of understanding and the type of misunderstandings of male and female teachers in this field or not? To our knowledge, studies about pre-service chemistry teachers' chemical equilibrium misconceptions were limited.

A few studies have explored pre-service teachers' misunderstanding of chemical equilibrium. Recently, EyceYurt-Turk and Tuzun (2021) highlighted twenty Turkish pre-service science teachers' images and misconceptions about chemical equilibrium. Their study had beneficial information but did not include many important concepts of chemical equilibrium. It did not investigate the possible difference in chemical equilibrium understanding between male and female teachers.

Objectives of the Study and the Research Questions

Pre-service teachers must have a firm foundation in chemical equilibrium concepts. Therefore determining the chemical equilibrium misconceptions is very important (Mai et al., 2021; Eyceyurt-Turk & Tuzun, 2021). Teachers are the most important source of creating misconceptions in students. Pre-service teachers are future teachers; if they have misconceptions, their students will also have misconceptions. To avoid forming misconceptions in students, educators should be informed about pre-service teachers' misconceptions and try to construct the correct chemical equilibrium concepts for them. The results of such studies can help researchers, teachers, and teacher educators to develop new alternative teaching techniques to change and / or to prevent students' misconceptions The instrument used in this research that was adopted from previous studies or developed by the authors will increase the research literature with conceptual items in the chemical equilibrium area that could be referred to by other researchers. The main objective of this research was to explore the chemical equilibrium misconceptions of pre-service chemistry teachers at Farhangian University. Farhangian University is responsible for training teachers in Iran. The model of teacher education used in Farhangian University through which prospective chemistry teachers may enter the profession involves a four-year programme in chemistry and education i.e. the concurrent subject matter/professional training model. If student teachers' misconceptions are not directly addressed, they may persist throughout the four-year training programme and even beyond. An exploratory study was carried out to identify the chemical equilibrium misconceptions of a group of pre-service chemistry teachers in their fourth year of study with gender as a possible source of variation.

The research questions were

1- What chemical equilibrium misconceptions do these 4th-year pre-service chemistry teachers hold?

2. Is there a link between these misconceptions and gender?

Methods

Research Design

This research was of the survey type. To diagnose pre-service teachers' misconceptions of chemical equilibrium, a 20-item two-tier multiple choice test was developed. The analysis of the pre-service teachers' misconceptions was carried out by looking at the pattern of participants' answer

distribution on the first and second tiers. The answer patterns in the second tier, which are the reasons for the student's answers can be used as the basis to determine the participants' alternative conception. In order to find out the type of pre-service teacher's misconceptions, each option that the participants had chosen was carefully examined, and the type of misconceptions that led to the selection of each option was extracted. In other words, these results were used to elucidate pre-service teachers' conceptual understanding of chemical equilibrium concepts. The found misconceptions were coded and finally, types of misconceptions were extracted. Independent *t*-testing were used to obtain the results. The independent sample t-test (group t-test) is performed when the samples typically consist of an independent population. (Liang, Fu, & Wang, 2019). Inferential statistical tests are associated P value. In a 95% confidence interval, $P > 0.05$ in each research variable shows that the null hypothesis was not rejected, and no significant differences between the two groups were observed.

Participants

The population of this study covers all the pre-service chemistry teachers of Farhangian University. These teachers were in the fourth year of the teacher training programme and preparing to become high school chemistry teachers for Grades 10 to 12. Previously, they had completed most of their courses on the subject matter (chemistry) and pedagogy (learning theories, teaching methods, educational psychology, classroom management, material development, etc.). The research population consisted of 205 individuals, and based on the Cochran formula, 135 of them were selected as the statistical sample. 65 of the participants were male and 70 were female. The age range of the participants was between 21.0 and 24.8 years. There was no significant difference between the two groups of teachers in terms of demographic features. The selection criteria of the participants were their willingness for the study. All participants had the right to leave the study at any time. Also, all participants were anonymous, and based on research ethics codes were used instead of their names.

Instrument

The test items were selected from previous studies done by Ozmen (2008), Tyson et al. (1999), Cheung et al. (2009) and Karpudewan et al. (2015) with minor revisions. The final questionnaire was prepared in the primary language and then translated into the Standard English language. Two-tier-multiple-choice tests often have been used to determine alternative conceptions of students in science education. The first tier of each question has four choices used to recognise the chemical equilibrium knowledge of students; the second tier involves four possible reasons containing three wrong reasons and one right reason for the question posed in the first tier. The second tier is based on an alternative conception held by students. The questionnaire was classified into five categories consisting of the *equilibrium constant* (4 questions), application of *Le Chatelier's principle* (9 questions), *heterogeneous equilibrium* (2 questions), the *effect of a catalyst* (2 questions), and *approach to equilibrium* (3 questions). The reliability of this questionnaire was calculated using Cronbach's alpha coefficient. Cronbach's α values for each category of five chemical equilibrium categories ranged from 0.775 to 0.861. The content validity of the questionnaire was evaluated by three expert chemistry instructors who taught similar students. The experts were asked to evaluate the questions based on relevance, clarity, simplicity, ambiguity and scientific accuracy (Yaghmaie, 2003). The participants' responses were analysed and classified into three forms understanding, not understanding, and misconception (Table 1). Data were analysed statistically using an independent t-test. The software used was SPSS 26, and the significance level was 95 %. In the next step, responses were analysed to find misconceptions.

Table 1

Categories of Two-Tier-Multiple -Choice Test

Student' Answers		Level of understanding
First Tier	Second Tier	
True	True	Understanding
True	False	Misconception
False	True	Misconception
False/No Answer	False/No Answer	Not Understanding

Question 8, as shown in bellow box, was one of the questions that drew the lowest number of correct answers. This question, which was on the application of the *Le Chatelier's principle*, was designed to evaluate the impact of the conceptual understanding of concentration change on the direction of equilibrium.

Question 8: If you have a 0.5 M solution of sodium dichromate ($Na_2Cr_2O_7$) in which the following equilibrium is established

$2CrO_4^{2-}{}_{(aq)} + 2H^+(aq) \leftrightarrows Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)}$

yellow orange

and you add 10 mL of 0.5 M solution of sodium dichromate to the original solution what would you observe?

(a) the solution becomes yellow

(b) the solution becomes deeper orange

(c) *the solution remains unchanged

Reason

(1) to counteract the increased amount of $Cr_2O_7^{2-}{}_{(aq)}$ the system will form more $CrO_4^{2-}{}_{(aq)}$

(2) there will be more collisions between particles of $Cr_2O_7^{2-}{}_{(aq)}$ and $H_2O_{(l)}$

(3) *there is no change in the concentration of any species

(4) because of increase in $Cr_2O_7^{2-}$, Q will be greater than K_{eq}

Results & Analysis

The overall performance of pre-service chemistry teachers in all concept areas except *the application of Le Chatelier's principle* in the female group was greater than 50 %. The highest overall average score was related to *the approach to equilibrium*, while *the application of Le Chatelier's principle* has the lowest overall average score. Males left more questions unanswered than females (Table 2).

Table 2

Mean Scores for Each Chemical Equilibrium Categories in Instrument

Equilibrium categories	Questions	% Average score		% No Answer	
		female	male	female	male
Equilibrium constant	Q1, Q4, Q7, Q9	74.6	73.1	0.0	1.5
Application of Le Chatelier's principle	Q8, Q9, Q10, Q11, Q12, Q14, Q15, Q16, Q20	43.5	50.3	2.8	6.1
Heterogeneous equilibrium	Q2, Q6	63.6	64.6	0.0	1.5
Effect of a catalyst	Q3 , Q13	52.1	50.0	1.4	6.1

Approach to equilibrium	Q5, Q17, Q18	81.4	78.0	1.4	7.7
All categories		58.3	60.4	1.6	4.9

Table 3 presents the independent t-test to investigate the effect of gender on the performance of pre-service chemistry teachers in equilibrium concepts. The results showed that there was not a significant difference in the performance of the female and male participants in terms of the application of Le Chatelier's principle, the heterogeneous equilibrium, and the catalyst effect ($p \geq 0.05$) at 95% confidence interval. However, there was a significant difference in the *equilibrium constant* and the *approach to equilibrium* between the two groups ($p < 0.05$). However, the performance of pre-service chemistry teachers in all equilibrium categories in male and female participants was found to be 3.13 and 3.25, respectively [$t(133) = 3.642$; $P > 0.05$]. According to these findings, it can be argued that there is no significant difference between the performance of male and female pre-service chemistry teachers in terms of all equilibrium categories.

Figures 1 to 3 illustrates the performance of female and male pre-service chemistry teachers for each question in the Equilibrium Misconceptions Identification Instrument in the first tier, second tier, and both tiers, respectively. As can be seen in Figure 1, the poorly answered question in the first tier on the instrument, with less than 10.0 % in both groups, was Question 8. In addition to question 8, the percent of correct answers of prospective men teachers for the first tier in questions 3, 16, and 20 was less than 50.0 %, while females had a similar situation only in questions 20 and 16. In general, female pre-service teachers performed better in answering the first tier of instrument questions. The only question where males' performance was higher than females' is question 2, which is in the category of *heterogeneous equilibrium (see Table 2).* In questions 4, 8, 9, 11, 16, and 19, both males and females had almost the same performance, and in other questions, the percent of females' correct answers was higher. The biggest difference is related to question 18, which is in the category of *approach to equilibrium*.

When considering the correct reason (the second tier) for each question, Questions 8 and 20 exhibited correct answer frequencies below 10 % (Figure 2). These questions are concerned with the effect of concentration change on the direction of equilibrium in the category of *application of Le Chatelier's principle*. The highest difference in the correct answer in the second tier is related to question 18 (72.85 % of females versus 47.70 % of males). In questions 1, 2, and 8, the two groups had almost the same answer. Prospective men teachers performed slightly higher than females only in questions 7, 14, and 20, and in the other questions, the performance of female pre-service teachers was better.

Table 3

The Results of the Independent T-Test and the Comparison of Each Equilibrium Category As Well As All Equilibrium Categories in Male and Female Experimental Groups

Equilibrium Categories	Gender	Mean	SD	t	df	*p*-value
Equilibrium constant	Male	3.65	0.55	1.184	133	0.021
	Female	3.76	0.37			
Application of Le Chatelier's principle	Male	2.61	0.29	2.296	133	0.622
	Female	2.70	0.29			
Heterogeneous equilibrium	Male	3.50	0.74	0.430	133	0.974
	Female	3.52	0.77			
Effect of a catalyst	Male	3.59	0.95	1.932	133	0.456
	Female	3.79	0.89			

Approach to equilibrium	Male	3.47	0.60	3.510	133	0.000
	Female	3.65	0.41			
All categories	Male	3.13	0.27	3.643	133	0.053
	Female	3.25	0.21			

As seen in Figure 3, by considering correct answers for two-tier, in addition to questions 2, 8 and 20 in female and male groups, the correct answer rate to question 16 for female teachers decreased to 25 %. Also, the rate of correct answers to questions 11 and 14 dropped sharply in the female group. The performance of males and females in questions 1, 3, 4, 9, 13, and 19 were almost similar, while female pre-service teachers had a higher percent of correct answers for both tiers in questions 5, 12, 15, 17, and 18. Males performed better in other questions. The interesting point is that among the 5 questions that the performance of female pre-service teachers was higher, three questions 5, 17, and, 18 belong to the category of approach to equilibrium. Therefore, it can be concluded that the level of misconceptions related to this category was higher among male pre-service teachers than among females. A complete list of identified misconceptions can be found in Table 4.

Figure 1

Comparison of Performance of Female and Male Pre-Service Chemistry Teachers for the First Tier of Each Question in the Instrument

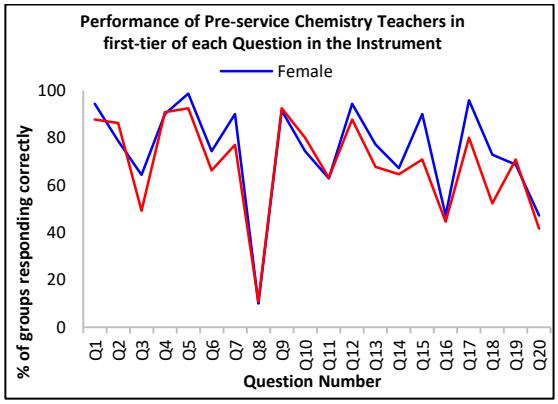


Figure 2

Comparison of Performance of Female and Male Pre-Service Chemistry Teachers for the Second Tier of Each Question in the Instrument

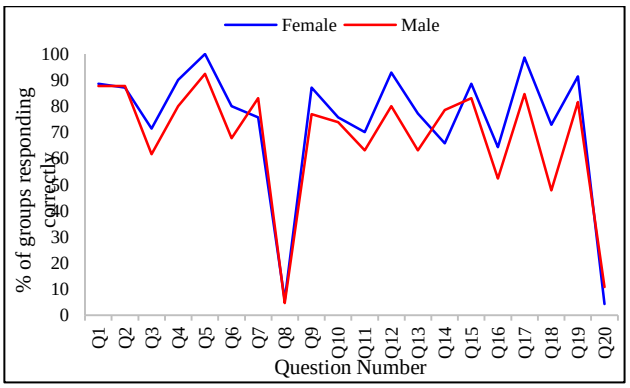
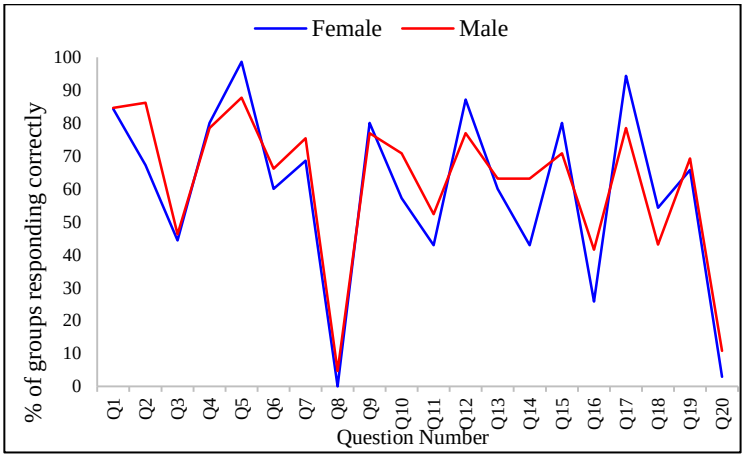


Figure 3

Comparison of Performance of Female and Male Pre-Service Chemistry Teachers for the Both Tier of Each Question in the Instrument



Fifteen alternative conceptions were identified and listed in Table 4. Similar types of students' alternative concepts have been reported in the literature (Karpudewan et al., 2015; Omilani & Elebute, 2020; Satriana et al., 2018; Sendur et al., 2011; Voska & Heikkinen, 2000).

Table 4

The Percentages of Students' Alternative Conceptions

Concept Area	Subtopic	Misconceptions	% sample		
			female N = 70	male N = 65	Total N = 135
Equilibrium constant	Dependence of the equilibrium Constant to the temperature	With decreasing the temperature in an exothermic reaction, fewer products are produced, and consequently, the Keq decreases.	20.0	13.8	17.1
	Constancy of the Concentrations in equilibrium	The higher initial concentrations of the reactants increased the numerical value of Keq.	28.6	9.2	19.3
	Constancy of the equilibrium constant	Keq and the concentration of the reactants changes in the equilibrium state.	42.8	20.0	31.8
Application of Le Chatelier's principle	The effect of temperature on the direction of equilibrium	As temperature increases, more products are formed.	18.6	16.9	17.8
		When the temperature is changed, whether the reaction is endothermic or exothermic does not affect the direction of the equilibrium shift.	14.3	12.3	13.3
	The effect of pressure and volume on the direction of equilibrium	As the volume increases (pressure decreases), the reaction moves towards the production of fewer gaseous moles.	22.8	21.5	22.2
		Pressure affects all reactions containing gaseous substances, whether the reaction has an equal or different number of gaseous substances on both sides.	18.6	12.3	15.5
		Pressure does not affect reactions containing gaseous substances.	60	13.8	37.8
	The effect of common ion on the direction of equilibrium	The addition of a substance containing common-ions does not affect the direction of equilibrium.	61.4	36.9	49.6
	The effect of concentration change on the direction of equilibrium	When a substance is added to an equilibrium mixture, the equilibrium will shift to the side of the addition.	94.3	38.5	67.4
Heterogeneous equilibrium	Study of Heterogeneous equilibrium	Le Chatelier's principle may apply to any system, including heterogeneous equilibrium systems.	65.7	1.5	34.8
Effect of catalyst	Effect of catalyst on the equilibrium	The rates of the forward and backward reactions could be affected differently when the catalyst was added.	47.1	15.4	31.8
		Catalysts cause an increase in product concentration.	34.3	7.7	21.5
Approach to equilibrium	Calculation of equilibrium concentrations	Equilibrium reactions continue until all the reactants are consumed.	28.6	16.9	23.0
		At equilibrium, concentrations of reactants and products are equal.	11.4	4.6	8.1

Discussion and Conclusion

In the current study, we used a two-tier multiple choice diagnostic test to identify chemical equilibrium misconceptions in pre-service chemistry teachers of Farhangian University in Iran Teachers do not have to construe the intention of students who cannot clearly explain their reasoning. Its results can be used to draw up a conception profile that maps a particular student's identified conceptions. Such profiles help teachers to identify a range of misconceptions that need to be corrected (Voska, 2000).

The current study focused on chemical equilibrium misconceptions. The content of chemical equilibrium is abstract, complicated, and has a high degree of connection with other content areas of chemistry. Teachers and students may tend to overlook the specific nature of the chemical equilibrium content and simplify their interpretation of related problems (Tyson et al., 1999). This can lead to the formation of misconceptions in them.

In this study, the misconceptions related to chemical equilibrium are classified into five categories: *equilibrium constant*, *application of Le Chatelier's principle*, *heterogeneous equilibrium*, *effect of a catalyst*, and *approach to equilibrium*. The student teachers generally performed well. However, the results also showed that they exhibited several misconceptions about chemical equilibrium concepts, and fifteen misconceptions were identified. As shown in Table 4, the percentage of observed misconceptions for all participants varied between 8.1 and 67.4%. These findings are consistent with the results of other studies (Voska & Heikkinen, 2000; Omilani & Elebute, 2020; García-Lopera et al., 2014; Ozmen, 2008). The percent of misconceptions varied between 11.4 % to 94.3 % for females and 1.5 % to 38.5 % for male pre-service teachers.

The most significant misconceptions revealed by this study fall in the *application of Le Chatelier's principle* category, as follows:

1- When a substance is added to an equilibrium mixture, the equilibrium will shift to the side of the addition in the subtopic of *the effect of concentration change in the direction of equilibrium*. This misconception held by 67.4 % pre-service chemistry teachers (94.3 % of females and 38.5 % of males). This misconception is due to an over-emphasis on the 'change-then-minimize' logic of Le Chatelier's principle in the Chemistry Curriculum and textbooks (Cheung et al., 2009; Yamtinah, 2019).

2- The addition of a substance containing common-ions does not any affect the direction of equilibrium in the subtopic of the effect of common ion on the equilibrium direction, which held by 49.6 % pre-service chemistry teachers (61.4 % of females and 36.9 % of males).

The study revealed that the lowest percent of misconceptions among prospective teachers were observed concerning two key concepts:

1- *At equilibrium, concentrations of reactants and products are equal* which held by 8.1 % of prospective teachers (11.4 % of females and 4.6 % of males).

2- *The temperature changes, does not effect on the direction of the equilibrium, whether the reaction is endothermic or exothermic* which held by 13.3 % of prospective teachers (14.3 % of females and 12.3 % of males).

One reason for these observations can be the instructional approaches used in teaching these chemical equilibrium concepts, which need more research.

This study revealed a new misconception: "the common ion has no effect on the direction of equilibrium" had not been exposed and investigated as a separate misunderstanding in previous studies. The common ion effect occurs when a given ion is added to an equilibrium mixture that already contains that ion and the position of equilibrium shifts away from forming more of it. To the best of our knowledge, the common ion effect as a separate issue in chemical equilibrium misconception has not been investigated in the literature so far. In the present study, we observed that nearly 50 % of pre-service teachers (61.4 % females and 36.9 % males) had problems understanding the effect of adding a substance containing common ions to the equilibrium mixture. This misconception ranks second among the fifteen misconceptions found in this research.

The interesting point is that the correct answers to most of the questions in the first tier and second tier were higher in the female pre-service teachers (Figures 1 and 2). The results of the answers to the first tier of questions showed that female pre-service teachers had a higher correct answer rate only in question 2. Question 18, which is in the category of approach to equilibrium, showed the highest difference in the performance between males and females (Figure 1). As in the first tier, in the answer to the second tier, the highest difference in the correct answer was related to question 18. Also, only in three questions 7, 14, and 20 did men perform slightly better (Figure 2). But when both tiers were combined, the results for the males were better (Figure 3). These findings agree with Table 2, which shows that male participants overall held fewer misconceptions than females. But, the overall rate in the case of *not understanding* of chemical equilibrium concepts in pre-service male teachers was higher than female participants (4.9 % vs. 1.6 %). On the other hands, Female pre-service teachers had better performance in only five questions, 5, 12, 15, 17, and 18. It is interesting to know that among these questions, three questions 5, 17, and 18 together forms the *approach to equilibrium* category and it is interesting that male pre-service teachers had a lower performance than females in all questions of this category**.**

As can be seen in Table 4, in some of the identified misconceptions, the observed difference between male and female participants is significant. For example, in the category of *heterogeneous equilibrium*, the percent of observed misconceptions in the males had the lowest amount of identified misconceptions in this research (only 1.5 %). While in the case of females, the percent is very high (65.7 %), and has been assigned the second rank of observed misconceptions in this research.

Because male and female teachers are trained in Farhangian University (Teacher Training University of Iran) in separate faculties, so we investigated the effect of gender on the rate of misconceptions in pre-service chemistry teachers in detail. The results showed that male subjects exhibit lower rates of misconceptions and also a higher rate of not understanding. Females and males showed significant differences in the terms of the equilibrium constant and the approach to equilibrium, which demonstrated that males showed better comprehension of these concepts than females. According to Table 4, the gender of participants has an important effect on the rate of misconceptions held by pre service chemistry teachers. The literature shows that when gender differences are studied in explaining scientific phenomena, Female pre-service teachers had more misconceptions than males in most countries (Harmala-Brasken et al., 2020, Sheehan et al., 2011). Boys, on average, have a greater ability to recall and apply their knowledge of science and identify and generate models and predictions based on the models (OECD, 2016). Kaufman (2007) and Soeharto & Csapó (2022) stated that males on average are better able to visualise submicroscopic levels of chemistry concepts, which is due to their better spatial ability compared to females. This ability of men, in turn, can be an advantage for conceptual understanding of submicroscopic levels of chemistry concepts. Thus, female pre-service teachers exhibit more misconceptions than males. This finding may be due to different learning strategies used by female learners. Sheehan et al. (2011) found that the number of chemistry misconceptions was higher in Irish pre-service female teachers**.** Meece and Jones (1996) found that female learners were more likely to engage in rote learning. According to Sheehan (2010), the differences in the number of misconceptions held by the genders may be the consequence of differences in cognitive development, so male students at upper secondary and university levels are more likely to operate at the formal operational level than female students.

One of the most essential conclusions of research on pre-service teachers' misconceptions is to inform educators about pre-service teachers' difficulties in understanding science knowledge. Teachers have a significant role to prevent students' misconceptions and can help to eliminate their misconceptions. Before teaching a chemical concept such as chemical equilibrium, teachers should be able to review the literature to find out alternative conceptions that students may bring to class and which teaching strategies are the best to correct them (Sendur et al., 2011). If chemistry teachers have problems understanding the chemistry concepts or have misconceptions about them, they cannot assist their students to resolve their conceptual difficulties. Therefore, the teachers themselves must have a deep understanding of chemical concepts and have no misconceptions.

One of the other important goals related to this study is to pay attention to the preparation process of prospective chemistry teachers. It is necessary to improve the preparation and professional development of pre-service chemistry teachers by discovering and identifying common chemical equilibrium alternative concepts and trying to modify them.

These findings may help chemistry educators ameliorate pre-service teachers' understanding of one of the important and complex topics of chemistry named chemical equilibrium (Piquette and Heikkinen, 2005).

This study reported several misconceptions in prospective chemistry teachers. The fact that individuals who hold these misconceptions are pre-service teachers makes the findings considerable. Teachers should have a proper understanding of science concepts before they can help students learn these science concepts. Prospective and in-service teacher training programs should emphasise the significance of conceptual problem-solving and supply opportunities for pre service and in-service teachers to inform their own understanding of science concepts.

Identifying of pre-service teachers' misconceptions about chemistry concepts can be effective in improving chemistry education and learning. Teachers around the world are always faced with the challenge of identifying and changing students' misconceptions, so it is necessary to teach those techniques to identify misconceptions and how to change concepts during the Teacher Training Program (Valanides et al., 2003). Valanides et al. (2003) pointed out changes in chemistry education, including chemistry curricula and textbooks, as well as teacher training programmes as solutions in this field. We hope that the results of this research will help design teaching approaches that can enhance pre-service teachers' conceptual understanding of chemical equilibrium concepts.

Recommendations

Based on the above findings and conclusions, the following recommendations are made:

1. Before teaching chemical concepts, including chemical equilibrium, educators should review the literature to identify alternative concepts that pre-service teachers may bring to the classroom and find appropriate instructional strategies to modify them.
2. Before teaching the lesson, the teachers should use a initial assessment to identify the misconceptions of the pre-service teachers on the topic of chemical equilibrium (students are told the test 'doesn't count').
3. Instructional approaches in teaching chemical equilibrium concepts should be investigated to determine if there is a relationship between instructional approaches and the rate of misconceptions observed.
4. The contents of textbooks should be examined to determine their possible impact on the development of misconceptions related to the concepts of chemical equilibrium.

Ethics Approval and Consent to Participate

All participants in this research were anonymised. Informed consent was obtained verbally before participation. All participants consented to their participation in this study.

References

Azizoglu, N., Alkan, M. and Geban, O. (2006). Undergraduate Pre-Service Teachers' 394 Understandings and Misconceptions of Phase Equilibrium. *Journal of Chemical Education*, *83*(6), 947-957.

Ausubel, D. P. (2012). *The acquisition and retention of knowledge: A cognitive view*. Springer Science & Business Media.

Aydeniz, M., & Dogan A. (2016). Exploring the impact of argumentation on pre-service science teachers' conceptual understanding of chemical equilibrium. *Chemical Education Research Practi*ce, 17(1), 111-119. https://doi.org/10.1039/C5RP00170F

Banerjee A.C. (1991). Misconceptions of students and teachers in chemical equilibrium Misconceptions of students and teachers in chemical equilibrium. *International Journal of Science*, *13*, 37–41. 10.1080/0950069910130411

Ben-Zvi, R., Eylon, B. & Silberstein, J. (1988). Theories, principles and laws. *Education in Chemistry*, *25*, 89-92.

Bernal-Ballen, A., & Ladino-Ospina, Y. (2019). Assessment: A Suggested Strategy for Learning Chemical Equilibrium. *Education Sciences*, 9, 174-192. https://doi.org/10.3390/educsci9030174

Bhola, S., Parchoma, G. (2015). Comparative Perspectives on Chemistry Teaching and Learning in Higher Education. Proceedings of the IDEAS: Designing Responsive Pedagogy Conference, 168-177. http://hdl.handle.net/1880/50871

Cakmakc, G., Leach, J., & Donnelly, J. (2006). Students'ideas about reaction rate and its relationship with concentration or pressure. *International Journal of Science Education,* 28(15), 1795–1815. 10.1080/09500690600823490

Chandrasegaran A. L., Treagust D. F. and Mocerino M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation, *Chemical Education Research and Practice,* 8, 293-307. https://doi.org/10.1039/B7RP90006F

Cheung, D. (2009). Using think-aloud protocols to investigate secondary school chemistry teachers' misconceptions about chemical equilibrium. *Chemical Education Research and Practice*, *10*, 97–108. https://doi.org/10.1039/B908247F

Cullinane, A. (2011). Two-tier multiple choice questions (MCQS)-How effective are they: A pre-service teachers' perspective. *The International Organization for Science and Technology Education*, *7*, 611–624.

Demircioglu, G., Demircioglu, H. & Yadigroglu, M. (2013). An investigation of chemistry student teachers' underestanding of chemical equilibrium. *International Journal on New Trends in Education and Their Implications*, *4*(2), 192-199.

Doymus, K. (2008). Teaching Chemical Equilibrium with the Jigsaw Technique. *Research in Science Education,* 38(2), 249–260. 10.1007/s11165-007-9047-8

Eyceyurt-Turk, G., & Tuzun, U .N. (2021). Pre-service science teachers' images and misconceptions about chemical equilibrium. *Educational Policy Analysis and Strategic Research*, *16*(4), 218-233. 10.29329/epasr.2021.383.12

Gabel D. (1999). Improving teaching and learning through chemistry education research: a look to the future, *Journal of Chemical Ediucation,* 76, 548-554. https://doi.org/10.1021/ed076p548

García-Lopera, R., Calatayud, M. L., & Hernández, J. (2014). A Brief Review on the Contributions to the Knowledge of the Difficulties and Misconceptions in Understanding the Chemical Equilibrium. *Asian Journal of Education and e-Learning*, *2*(6), 448-463.

Ghirardi, M., Marchetti, F., Pettinari, C., Regis, A., & Roletto, E. (2015). Implementing an equilibrium law teaching sequence for secondary school students to learn chemical equilibrium. *Journal of chemical education*, *92*(6), 1008-1015. 10.1021/ed500658s

Griffiths A. K. and Preston K. R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules, *Journal of Research Science Teaching*, *29*, 611-628. https://doi.org/10.1002/tea.3660290609

Hakim, A., Kadarohman, A., & Syah, Y. M. (2016). Effects of the natural product mini project laboratory on the students' conceptual understanding. *Journal of Turkish Science Education*, *13*(2), 27-36.

Harmala-Brasken, A.-S., Hemmi, K. & Kurten, B. (2020). Misconceptions in chemistry among Finnish prospective primary school teachers – a long-term study. *International Journal of Science Education*, 1-18. 10.1080/09500693.2020.1765046

Hartelt, T., Martens, H., & Minkley, N. (2022). Teachers' ability to diagnose and deal with alternative student conceptions of evolution. *Science Education*, *106*(3), 706-738. https://doi.org/10.1002/sce.21705

Johnstone, A. H. (2000). Teaching of Chemistry – logical or psychological? *Chemical Education Research in Europe, 1*, 9–15. https://doi.org/10.1039/A9RP90001B

Jusniar, J., Effendy, E., Budiasih, E. and Sutrisno, S. (2020). Developing a three-tier diagnostic instrument on chemical equilibrium (TTDICE). *Educación Química*, *31*(3), 84-102. http://dx.doi.org/10.22201/fq.18708404e.2020.3.72133

Lamichhane, R., Reck, C., & Maltese, A. V. (2018). Undergraduate chemistry students' misconceptions about reaction coordinate diagrams. *Chemistry Education Research and Practice*, *19*, 834-845. https://doi.org/10.1039/C8RP00045J

Liang, G., Fu, W., & Wang, K. (2019). Analysis of t-test misuses and SPSS operations in medical research papers. *Burns & trauma*, *7*(31), 1-5. https://doi.org/10.1186/s41038-019-0170-3

Karpudewan, M., Treagust, D. F., Mocerino, M., Won, M., & Chandrasegaran, A. L. (2015). Investigating High School Students' Understanding of Chemical Equilibrium Concepts. *International Journal of Environmental and Science Education, 10*(6), 845-863. 10.12973/ijese.2015.280a

Kaufman, S. B. (2007). Sex differences in mental rotation and spatial visualization ability: Can they be accounted for by differences in working memory capacity? *Intelligence*, *35*(3), 211–223. https://doi.org/10.1016/j.intell.2006.07.009

Kaya, E. (2013). Argumentation Practices in Classroom: Pre-service teachers' conceptual understanding of chemical equilibrium. *International Journal of Environmental and Science Education, 35*(7), 1139–1158. https://doi.org/10.1080/09500693.2013.770935

Keig P. F. and Rubba P. A. (1993). Translations of the representations of the structure of matter and its relationship to reasoning, gender, spatial reasoning, and specific prior knowledge, *Journal of Research Science Teaching*, *30*, 883-903. https://doi.org/10.1002/tea.3660300807

Kurniawan, M. A., Rahayu, S., Fajaroh, F., & Almuntasheri S. (2020). Effectiveness of dual situated learning model in improving high school students' conceptions of chemistry equilibrium and preventing their misconceptions. *Journal of Science Learning, 3*(2), 99-105. 10.17509/jsl.v3i2.22277

Mai, Y., Qian, Y., Lan, H., & Li, L. (2021). Students' concept organisation regarding chemical equilibrium in upper secondary education: Based on reaction time technique. *Journal of Baltic Science Education, 20*(3), 443-455. 10.33225/jbse/21.20.443

Meece, J. L. & Jones, M. G. (1996). Gender differences in motivation and strategy use in science: Are girls rote learners? *Journal of Research in Science Teaching*, *33*(4), 393-406. https://doi.org/10.1002/(SICI)1098-2736(199604)33:4<393::AID-TEA3>3.0.CO;2-N

Nur Akın, F. & Uzuntiryaki-Kondakci, E. (2018). The nature of the interplay among components of pedagogical content knowledge in reaction rate and chemical equilibrium topics of novice and experienced chemistry teachers. *Chemistry Education Research and Practice, 19*, 80-105. https://doi.org/10.1039/C7RP00165G

OECD. (2016). PISA 2015 results (volume I) *excellence and equity in education*. PISA OECD Publishing.

Omilani, N., & Elebute, F. D. (2020). Analysis of misconceptions in chemical equilibrium among senior secondary school students in Ilesa Metropolis in Osun State, Niger. *African Journal of Educational Studies in Mathematics and Sciences*, *16*(2), 1-13. https://dx.doi.org/10.4314/ajesms.v16i.2.1

Ozmen, H. (2008). Determination of students' alternative conceptions about chemical equilibrium: a review of research and the case of Turkey. *Chemistry Education Research and Practice,* 9, 225–233.

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology*, *13*(2), 147-159. 10.1023/B:JOST.0000031255.92943.6d

Piquette, J. S., Heikkinen, H. W. (2005). Strategies reported used by Iinstructors to address student alternate conceptions in chemical equilibrium. *Journal of Research in Science Teaching*, *42*(10), 1112–1134. 10.1002/tea.20091

Prodjosantoso, A. K., Hertina, A. & Irwanto M. (2019). The misconception diagnosis on ionic and covalent bonds concepts with three tier diagnostic test. *International Journal of Instruction*, *12*(1), 1477-1488. 10.29333/iji.2019.12194a

Quilez-Pardo, J. & Solaz-Portoles, J. (1995). Students' and teachers' misapplications of Le Chatelier's Principle: Implications for the teaching of chemical equilibrium. *Journal of Research in Science Teaching*, *32*(9), 939-957. https://doi.org/10.1002/tea.3660320906

Satriana T., Yamtinah S., Ashadi A., & Indriyanti N. Y. (2018). Student's profile of misconception in chemical equilibrium. *Journal of Physics: Conference Series*, 1097, 012066. 10.1088/1742-6596/1097/1/012066

Seni, S., & Yilmaz, A. (2017). The Development of a Three-tier Chemical Bonding Concept Test. *Journal of Turkish Science Education, 14*(1), 110-126.

Sendur, G., Toprak, M., Pekmez, E. S. (2011). How can secondary school students perceive chemical equilibrium? *New World Sciences Academy*, *6*(2), 1C0388.

Sheckley, B. G., & Bell, S. (2006). Experience, consciousness, and learning: Implications for instruction. *New directions for adult and continuing education*, *110*, 43-52. 10.1002/ace.218

Sheehan, M. (2010). *Identification of difficult topics in the teaching and learning of Chemistry in Irish schools and the development of an intervention programme to target some of these difficulties*. Ph.D. ed., University of Limerick.

Sheehan M., Childs, P. E., & Hayes, S. (2011). *Pre-service Irish Science teachers' misconceptions of chemistry*. Esera 2011 conference, 1-8.

Siswaningsih, W., Nahadi, & Widasmara, R. (2019). Development of Three Tier Multiple Choice Diagnostic Test to Assess Students' Misconception of Chemical Equilibrium. *Journal of Physics: Conference Series*, 1280(3), 032019. 10.1088/1742-6596/1280/3/032019

Soeharto, S., & Csapó, B. (2022). Exploring Indonesian student misconceptions in science concepts. *Heliyon*, 8(9), e10720. https://doi.org/10.1016/j.heliyon.2022.e10720

Suat, Ü. N. A. L., Coştu, B., & Alipaşa, A. Y. A. S. (2010). Secondary school students' misconceptions of covalent bonding. *Journal of Turkish Science Education*, *7*(2), 3-29.

Taber, K. (2000). Chemistry lessons for universities?: A review of constructivist ideas. *University Chemistry Education*, 4(2), 63-72.

Taber, K. S., and Watts, M. (1997). Constructivism and concept learning in chemistry: Perspectives from a case study. *Research in Education*, 58(1), 10-20. https://doi.org/10.1177/003452379705800102

Talanquar, V. (2010). Exploring dominant types of explanations built by general chemistry students. *International Journal of Science Education*, 32(18), 2393-2412. 10.1080/09500690903369662

Tyson, L., Treagust, D. F. & Bucat R. B. (1999). The Complexity of Teaching and Learning Chemical Equilibrium. *Journal of Chemical Education,* 76(4), 554-558. 10.1021/ed076p554

Üce, M., & Ceyhan, İ. (2019). Misconception in Chemistry Education and Practices to Eliminate Them: Literature Analysis. *Journal of Education and Training Studies*, 7(3), 202-208. https://doi.org/10.11114/jets.v7i3.3990

Valanides, N., Nicolaidou, A., Eilks, I. (2003). Twelfth Grade Students' Understanding of Oxidation and Combustion: Using action research to improve teachers' practical knowledge and teaching practice. *Research in Science and Technological Education,* 21(2), 159–175. https://doi.org/10.1080/0263514032000127211

Van Driel, J. H., De Vos, W., Verloop, N., & Dekkers, H. (1998). Developing secondary students' conceptions of chemical reactions: The introduction of chemical equilibrium. *International Journal of Science Education*, 20(4), 379-392. https://doi.org/10.1080/0950069980200401

Van Driel, J.H.; Gräber, W. (2003). The *Teaching and Learning of Chemical Equilibrium.* 505 *In Chemical Education:Towards Research-Based Practice*. Springer, Berlin, Germany, 271–292.

Voska, K. W. & Heikinnen, H. W. (2000). Identification and analysis of student conceptions used to solve chemical equilibrium problems. *Journal of Research in Science Teaching*, 37(2), 160-176. 10.1002/(SICI)1098-2736(200002)37:2<160::AID-TEA5>3.0.CO;2-M

Waseem, T., & Aslam, F. (2020). Educational learning theories & their implications in modern instructional designs. *Health Professions Educator Journal*, 3(2), 25-31. https://doi.org/10.53708/hpej.v3i2.9

Wuttiprom, S., Sharma, M. D., Johnston, I. D., Chitaree, R., & Soankwan, C. (2009). Development and use of a conceptual survey in introductory quantum physics. *International Journal of Science Education*, 31(5), 631-654. 31(5), 631-654. 10.1080/09500690701747226

Yaghmaie F. (2003), Content validity and its estimation, *Journal of Medical Education*, 3(1), 25–27. 10.22037/jme.v3i1.870

Yakmaci-Guzel B. (2013). Preservice chemistry teachers in action: an evaluation of attempts for changing high school students' chemistry misconceptions into more scientific conceptions. *Chemistry Education Research and Practice,* 14, 95-104. https://doi.org/10.1039/C2RP20109G

Yamtinah, S., Indriyanti, N. Y., Saputro, S., Mulyani, S., Ulfa, M., Mahardiani, L., Satriana, T., & Shidiq, A. S. (2019). The identification and analysis of students' misconception in chemical equilibrium using computerized chemical equilibrium using computerized two-tier multiple choice instrument. *Journal of Physics: Conferences Series,* 1157(4), 042015. 10.1088/1742-6596/1157/4/042015

Yildirım, N., Kurt, S. & Ayas, A. (2011). The Effect of the worksheets on students' achievement in chemical equilibrium. *Journal of Turkish Science Education*, *8*(3), 44-58. https://www.researchgate.net/publication/268436313

Journal of Turkish Science Education, 2024, *21*(1), 61-81.
DOI no: 10.36681/tused.2024.004

Socio-scientific Issues (SSI) research trends: A systematic literature review of publications 2011 – 2022

Muhammad Miftakhul Falah[1], Hartono [2], Sunyoto Eko Nugroho[3], Saiful Ridlo[4]

[1]*Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia, ORCID ID: 0000-0002-4769-9598*
[2]*Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia, hartono@mail.unnes.ac.id, Corresponding author, ORCID ID: 0000-0001-5684-9212*
[3]*Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia, ORCID ID: 0000-0002-7330-2857*
[4]*Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia, ORCID ID: 0000-0003-3117-6167*

ABSTRACT
This study aimed to investigate research trends related to socio-scientific issues (SSI). The SSI articles analysed were from highest-rating five science education journals with the highest impact ratings, published between 2011 and 2022, including Science Education [SE], Journal of Research in Science Teaching [JRST], Science and Education [S&E], International Journal of Science Education [IJSE], and Research in Science Education [RSE]. A total of 87 selected relevant SSI articles were analysed to determine research types, research topics, research sample groups, research sites, and authors with the most citations. According to the research findings, IJSE articles are the most widely published articles compared to other articles of similar journals. It is revealed that the most discussed issues in those articles of IJSE are argumentation and decision-making, followed by the nature of science. Pupils in middle and high schools constitute the largest sample groups. The continent that has been widely selected as research sites is European continent. Meanwhile, the country with the most research sites is the United States. The data collection tool most frequently used in the research is interview. S&E's Nature of Science, Scientific Inquiry, and Socio-Scientific Issues Arising from Genetics: A Pathway to Developing a Scientifically Literate Citizenry articles are the most cited articles. Challenges such as addressing efficacy, emotion, and attitude remain noticeably unexplored in SSI studies. Furthermore, exploratory studies on SSI for early childhood education.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 24.01.2023
Accepted: 16.08.2023

KEYWORDS:
Socio-scientific Issues, science education journals, systematic literature review.

To cite this article: Falah, M.M., Hartono, Nugroho, S.E., & Ridlo, S. (2024). Socio-scientific Issues (SSI) research trends: A systematic literature review of publications 2011 – 2022. *Journal of Turkish Science Education*, *21*(1), 61-81. DOI: 10.36681/tused.2024.004

Introduction

Scientific publication activities rely heavily on information about research trends. This article, in addition to disseminating research, serves to validate and legitimise ideas and outcomes (Milne et al., 2015). Research reviews serve as the foundation for scientific development (Zheng, 2017). Publications in the form of reviews, particularly in the field of science education, have been carried

out extensively recently, including mobile gamification in science education (Kalogiannakis et al., 2021; Ullah et al., 2022), the correlation between mathematics and science (Monferrer et al., 2022), STEM (Li et al., 2020; Sırakaya & Alsancak Sırakaya, 2022), human rights and science (Schuck & Feser, 2022), and the association between culture and science education (Kolovou, 2022).

Socio-scientific Issues, as a context for science education, connect science and society (Barrue & Albe, 2013; Herman et al., 2019). SSIs arise from the implementation of science to various societal and everyday life problems from the perspectives of social, moral, economic, regulatory, and political issues (Zeidler, 2014; Hsu & Lin, 2017; Cian, 2020). SSIs allow students to study science conceptually as well as practically in terms of the controversy investigated (Sadler et al., 2007; Zeidler, D. L., & Kahn, 2014). This controversy requires students to collect data and assess issues from various perspectives before making decision (Paul et al., 2019; Lin, 2020).

Various issues have been identified within the domain of various SSI studies. Notably, science teachers often encounter challenges when assessing SSI argumentation (Christenson et al., 2017). They are lacking a of suitable SSI materials, coupled with limited preparation time (Tidemand, 2017). Similarly, learners find it difficult to obtain evidence during SSI debates in classroom activities (Xiao, 2018). Both teachers and pupils frequently grapple with making appropriate decisions concerning real-world issues related to scientific and technological advancements (Lee, 2020). The implementation of SSI in classroom settings is often faced with resistance due to the emerging controversial aspects from school to university educational levels (Yahaya et al., 2016). Proficiency in SSI learning demands readiness on the part of both teachers and learners (Christenson et al., 2017; Macalalag et al., 2019).

SSI studies make substantial contributions to science education. SSI provides a platform that effectively examines issues that can be scientifically explained and may significantly transform pupils' attitudes towards controversial issues (Yahaya et al., 2016), fosters empathy and moral reasoning through collaborative exploration (Lee, 2020). Collaborative discussion was found to promote moral reasoning in both cultures, leading to more consideration of principles such as honesty, empathy, and trustworthiness. SSI also establishes a foundation for learners' understanding of science and the Nature of Science (NOS), evoking interest, motivation, argumentation, and critical thinking (Dawson, 2015). SSI promotes comprehension and application of scientific explanations and NOS in real-world contexts (Herman et al., 2019), establishes connections between attitude and science learning (Xiao & Sandoval, 2017), and holds potential for developing Emotional Competence (EC) to contribute to scientific learning and student character development (Gao et al., 2019). Students with positive attitudes towards science tend to have better understanding of scientific concepts. Meanwhile, students with scientific attitudes are more likely to develop critical thinking skills and engage in inquiry-based learning. Various contributions of SSI in science education involve attitude, empathy, moral reasoning, critical thinking skills, and an emphasis on contextualised learning. SSI research trends serves as an invaluable guide for both practical applications and theoretical advancements (Chen & Xiao, 2021). The correlation between SSI discussion activities and attitudes of primary school teacher candidates about life science teaching is evident in the study by Karakaş (2022) which showed that these discussion activities significantly influence attitudes, with changes in sub-dimensions such as liking, valuing, and caring showing notable significance. Examining the belief system of Turkish preservice science teachers (PSTs) regarding the teaching of a socio-scientific issue (GM Foods) reveals that PSTs possess relatively strong knowledge, hold substantial risk perceptions, and uphold certain moral and religious beliefs regarding GM Foods (Kilinç et al., 2014).

The findings of SSI studies in science education, along with unexplored research focus. Professional teacher education programmes that are aimed at fostering students' SSI argumentation skills are supposed to be adjusted to each individual teacher’s characteristics. However, these efforts often lack a strong connection between argumentation and conceptual science understanding (Dawson V. M., & Venville, 2010). Decision-making processes are facilitated through dialogic activities in pre-service training, yet a comprehensive understanding of the efficacy of argumentation schemes and critical questioning in improving the quality of students' dialogic argumentation remains an area to be fully examined (Kim et al., 2014). There has been a study addressing students' attitudes towards

controversial socio-scientific issues, particularly focusing on topics of a sexual nature, disregarding the roles of gender and participant backgrounds (Yahaya et al., 2016). Also, a study on perceptions regarding critical thinking and self-regulation in science learning through SSI has been explored, but it is not specific yet to examine how self-regulation and critical thinking can be developed in science teaching and learning (Wang et al., 2017). The use of multiple representations that mediate SSI argumentation in different forms and for different purposes. It did not examine the impact of peer influence on the use of diverse representations and students' argumentation processes (Wang et al., 2017). The integration of scientific argumentation within SSI serves as an indispensable scheme for fostering critical thinking skills, aiming to actively engage learners (Barrue & Albe, 2013; Khishfe, 2020). Some areas of SSI studies that have yet to be extensively explored include critical argumentation schemes in SSI, self-regulation, critical thinking, and students' multiple representations.

Systematic literature reviews are an essential component of educational research (Vojíř & Rusek, 2019). SLR, particularly in the field of science education, explicitly responded to various published scientific articles, including systematic maps of research and other relevant researches in numerous fields of science education (Bennett; et al., 2005). This study aims to look at how SSI studies are studied in the leading academic journals of *Science Education* [SE], *Journal of Research in Science Teaching* [JRST], *Science and Education* [S&E], *International Journal of Science Education* [IJSE] and *Research in Science Education* [RSE]). The rationale for the choice of these five journals SE, JRST, S&E, IJSE and RSE from 2004 to 2015 is that they are the major journals that have high impact factors in science education research (Tekin et al., 2016). This assessment encompasses the evolution of discussed topics, connections between different research themes, emerging patterns in methodological approaches, and a detailed exploration of the countries that have emerged as significant contributors in this research field. The inclusion of these five selected journals is also in alignment with the methodology applied in the study by Luo et al. (2023), wherein they utilised JRST, IJSE, RSE, SE, and S&E from 2017 to 2021, as well as the content analysis of publications in selected journals (Tsai & Lydia Wen, 2005; Lin et al., 2014). It is worth noting that high quality journals do not only provide a robust platform for scholarly discourse but also serve as catalysts for the advancement and development of the science education research (Lin et al., 2012). The identification result of the citation score for the aforementioned selected journals, as determined through the Scopus database, reveals SE (9.3), JRST (8.2), S&E (4.5), IJSE (4.7) RSE (5.4).

Comprehensive review studies of SSIs have previously been conducted, specifically focusing on content analysis studies covering the period from 2004 to 2015, originating from a selection of selected journals. This study delved into the domain of research methodologies employed, topic explorations, and sample demographics. However, it is noteworthy that the analysis remained confined to these dimensions and did not extend to encompass the complicated aspects of authors' identities, author specifications, and the extent of content knowledge underpinning the SSIs addressed in the examined articles (Tekin et al., 2016). However, this study does not explicitly examine the impact of the relationship between SSI issues and complex reasoning, sophisticated argumentation, and a deep understanding of science (Sadler, 2004). Several articles have been reviewed to contextualise the connection between SSI and the Nature of Science. This study has focused on reviewing 7 articles spanning from 2002 to 2014 (Karisan & Zeidler, 2016). Reviews on decision-making within the context of SSIs (Jho, 2015; Fang et al., 2019), SSIs and technology in problem-based learning (Hernández-Ramos et al., 2021), SSIs in science education in Turkey from 2002 to 2012 (Topçu et al., 2014) as well as review on SSIs for chemistry education (Çalık & Wiyarsi, 2021)

Despite the increasing number of research publications on SSIs each year, the underlying trends within this research domain remain unclear. This current study complements a range of previous review articles, offering a comprehensive evaluation of SSI research trends from the past 11 years (2011 – 2022).

To obtain the objective of this study, authors formulate the research questions as follows:

a. How were the research topic trends of the selected articles in these five journals from

2011 to 2022?

b. What methods were mostly employed in the selected articles in these five journals from 2011 to 2022?

c. How did the research types of the selected articles in these five journals change from 2011 to 2022?

d. Which country contributed the most to the SSI research publication in these five journals from 2011 to 2022?

e. What are the most cited articles regarding SSI in these five journals from 2011 to 2022?

Methods

This study comprehensively presents various SSI studies in science education. A Systematic Literature Review (SLR) was systematically carried out to identify, select, and collect all relevant research materials directly related to SSI and associated with the research questions (Kitchenham et al., 2010). The process and methodology in this study employed a systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model (Moher et al., 2009). The stages specifically adhered to the steps outlined by Kitchenham (2004) as follows:

a. Specifying research questions
b. Conducting database searches
c. Determining Inclusion/Exclusion criteria
d. Selecting relevant studies
e. Analysing and extracting data
f. Summarizing and interpreting findings
g. Writing the review report

Journal Research Methodology

A systematic review serves as a comprehensive exploration across specific electronic databases and web search engines to access scholarly literature and academic resources (Kalogiannakis et al., 2021). At this initial stage, the search for articles from various journal sources was open, allowing the search for articles as well as a broader description (Lee et al., 2009; Chang et al., 2010; Teo et al., 2014). Specific criteria were determined to facilitate the screening of diverse studies, selecting, and limiting the scope to encompass those directly relevant to the research topic while excluding studies deemed unnecessary. The inclusion and exclusion criteria were defined as follows:

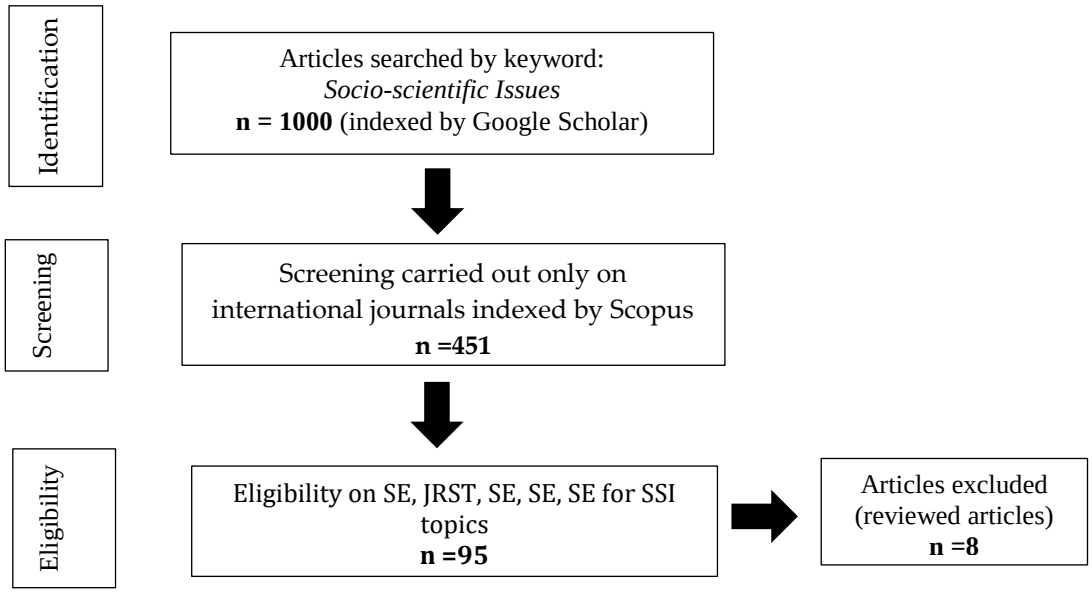
Inclusion	Exclusion
1. The studies must involve empirical research methods (quantitative, qualitative, and mixed methods)	1. The studies are not written in English.
2. The studies must be implemented at specified educational levels (kindergarten, primary, secondary, and higher education)	2. The studies are in the form of books or theses.
3. The SSI studies must be related to science education (chemistry, physics, biology, health, and natural science)	3. The studies are in the form of review articles.
4. The selected articles must be peer-reviewed.	4. The studies only publish abstracts
5. The selected articles must be sourced from five reputable and Scopus-indexed science education journals, such as Science Education (SE), Journal of Research in Science Teaching (JRST), Science & Education (S&E), International Journal of Science	5. The studies do not specifically examine SSI.

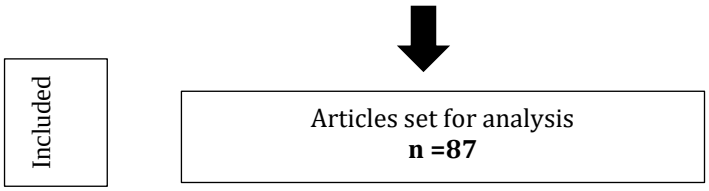
Education (IJSE), and Research in Science Education (RSE), which were published between 2011 and 2022.

Referring to the results of the initial search, 1000 articles indexed by Google Scholar were gathered. Google Scholar was selected due to its standing as a comprehensive academic search engine at present (Gusenbauer, 2019). the '*publish or perish software*' search engine on October 12, 2022 was applied to '*socio-scientific issues*' OR 'socioscientific' AND 'science education' keywords, with publication periods ranging from 2011 to 2022. The criteria for Scopus-indexed international journals were then applied, leaving 451 journal articles. Only articles from reputable international journals indexed by Scopus in Science Education [SE] journals, Journal of Research in Science Teaching [JRST], Science and Education [S&E], International Journal of Science Education [IJSE], and Research in Science Education [RSE]) (Tekin et al., 2016; Luo et al., 2023). This screening process resulted in the identification of 87 of 451 articles that warranted further investigation, following the exclusion of 8 articles due to their nature as literature reviews (Figure 1). The thematic analysis procedure employed in this review referred to the framework proposed by Braun & Clarke (2006). Each author independently engaged in the thorough reading and an in-depth examination of each article, aiming to acquire a comprehensive understanding of their content, methodologies, procedures, and research findings. Each identified theme was systematically documented in a Microsoft Excel table, facilitating subsequent comparison and discussion. A systematic keyword searching was employed to gather data. To ensure accuracy and cohesiveness in the findings of this study, a comprehensive document analysis was conducted. The following essential information was derived from each article: (a) methods; (b) research topic; (c) research sample; (d) research location; (e) data collection tools; and (f) most cited articles. The study's focal points were identified and grouped into different clusters. The density mapping of the co-authoring network of researchers was executed through the utilisation of the VOS Viewer software (Kamdem et al., 2019; Karimi Takalo et al., 2021). Finally, the finding indicates that the ensuing cartographic representation revealed that the distribution of analysed articles was as follows: Science Education (SE) 7 (8.04%), Journal of Research in Science Teaching (JRST) 15 (17.24%), Science & Education (S&E) 12 (13.79%), International Journal of Science Education (IJSE) 36 (41.37%), and Research in Science Education (RSE) 17 (19.54%). An overview of the stages involved in the article search is succinctly depicted in Figure 1.

Figure 1

Flow Chart of the Article Search Stages





Findings and Discussion

Research Types and Data Collection Tools

Research types are presented in Table 1. Qualitative research had the highest percentage (56,3%). IJSE contributed the most in qualitative research too. It also made the greatest contribution to quantitative research (63,15%), and 47,4% to mixed-research methods. The prevalence of qualitative methods highlights the complexity and multidimensionality inherent in SSI studies. This tendency for qualitative methodologies arises from the recognition that SSI investigations were complex and often defy straightforward experimental settings (Tetnowski & Damico, 2001). Qualitative studies in the realm of SSI result in a more comprehensive insight into the subject matter (Kolstø et al., 2006). Notably, most SSI studies use qualitative methods including SSI argumentation (Lee et al., 2020; Cebrián-Robles et al., 2021; Khishfe, 2021; Christenson & Walan, 2022) and decision-making (Lee et al., 2020; Cebrián-Robles et al., 2021; Ladachart & Ladachart, 2022) being particularly prominent examples. Certain SSI studies necessitate the application of quantitative methodologies to facilitate generalisation, such as the development of SSI instruments (Çalik & Coll, 2012; Sakschewski et al., 2014;) and the examination of SSI reasoning (Romine et al., 2020; Cian, 2020). The Nature of Science (NOS) within SSI emerged dominantly through mixed methods approaches (Khishfe et al., 2017; Herman et al., 2019). The combination of quantitative and qualitative elements within mixed methods studies enriches understanding by bridging micro and macro domains, culminating in holistic conclusions (Azorin, J.M., & Cameron, 2010).

Table 1

Research Types

Research types	Number of Articles	Percentage (%)
Qualitative	49	56,4
Quantitative	19	21,8
Mixed-Methods	19	21,8

The collected data reveal similarities among various data collection procedures. The percentage of articles reviewed using data collection tools is shown in Table 2. Based on this finding, it was determined that interviews (12,6%), open-ended questions (11,5%), and questionnaires (11,5%) were the most popular methods for collecting data on the SSI topics. The majority of the articles (25.3%) employed multiple data collection methods. Interviews, open-ended questions, audio and video transcription were the primary tools employed for data collection in qualitative and mixed methods approaches. Conversely, tests and questionnaires served as the primary data collection instruments in quantitative methodologies. Several studies employed multiple data collection tools, both qualitative (Gardner & Jones, 2011; Barrue & Albe, 2013; Karahan & Roehrig, 2017; Lee & Yang, 2019; Christodoulou et al., 2021) and quantitative (Bayram-Jacobs, 2019). Researchers opted for the utilisation of two to three data collection tools to improve the strength of their findings. This study also figured out the integration of technology in SSI data collection through computer log (Zhang &

Hsu, 2021).

Table 2

Data Collection Tools

Data Collection Tools	Number of Articles	Percentage (%)
Interview	11	12.6
Open Ended Question	10	11.5
Questionnaire	10	11.5
Audio Transcription	8	9.2
Documents	5	5.7
Video Recorded	5	5.7
Survey	4	4.6
Test	3	3.4
Research Report	2	2.3
Essay	1	1.1
Short answer questions	1	1.1
Computer Log	1	1.1
Annotation	1	1.1
Narrative Notes	1	1.1
Observation	1	1.1
Multiple Choice	1	1.1
Multiple Data Collection	22	25.3

Research Topics

In the following stage, a total of 87 articles were processed to be manually analysed by identifying titles, abstracts, and keyword lists, as in the study conducted by Erduran et al., (2015). Table 3 reveals that the topics with the highest percentage are argumentation (20,7%), decision-making (17,2%), nature of science (8%), and reasoning (8%). The categorisation of the article topics in this study was based on the studies conducted by Dewi et al., (2021) and Kalogiannakis et al., (2021).

Numerous studies have been conducted concerning argumentation in the context of SSI. Argumentation in SSI involving both science and language teachers in a collaborative project has been explored (Christenson et al., 2017). Argumentation through discussion activities has also been investigated (Nielsen, 2012). The correlation between argumentation, opinions, and decision-making in dialogues has been examined (Kim et al., 2014). Cultural perspectives have also been considered in SSI argumentation (Balgopal et al., 2017; Lee et al., 2020), as well as the use of teachers' PCK (Pedagogical Content Knowledge) for scientific SSI argumentation (Kutluca, 2021). The intersection of NOS and argumentation in the context of both SSI and non-SSI has also been explored (Khishfe, 2022). Additionally, the use of multiple representations in scientific argumentation has been explored (Namdar & Shen, 2016). It has been found that increased issue familiarity with SSI topics can enhance the diversity of discipline-related arguments among school students (Garrecht et al., 2021). The implementation of group-based discussions has been shown to stimulate students' argumentation, with shifts in their perspectives observed following group-based negotiation (Jafari & Meisert, 2022). Studies have evaluated SSI argumentation in a persuasive manner, encompassing the assessment of argumentative structures such as 'elements of argument', 'content of argument', 'rhetoric of argument', 'characteristics of arguer', and 'argumentative relationship with SSI' (Capkinoglu et al., 2021). The findings in the realm of SSI argumentation studies include the construction of arguments through dialogues and discussions, the enrichment of argumentative structures, and the utilisation of multiple representations in argumentation. This study reinforces the strong correlation between SSI and the

development of argumentation.

Numerous studies on decision-making within SSI domain have also been carried out. Noteworthy investigations have revolved around encouraging pupil engagement in decision-making processes in classroom activities. The study related to the issues in particular, focuses on student positioning and teacher-pupil interactions as pivotal elements shaping the dynamics of decision-making (Bossér & Lindahl, 2019). Additionally, the correlation between debate, decision-making, and fostering democratic participation in SSI has been explored (Ottander & Simon, 2021). The implementation of local SSI, drawing from domains such as media literacy and the Nature of Technology (NOT), has been strategically leveraged to facilitate pupil decision-making processes (Menke et al., 2022). The effect of NOS comprehension on decision-making in the SSI context has also been examined (Adal & Cakiroglu, 2022). Furthermore, the pedagogical proposition of embedding local cultural-based SSI into science learning has received attention, emphasising the alignment with the characteristics of global citizens through decision-making and informal reasoning frameworks (Ladachart & Ladachart, 2021). The unprecedented challenges posed by the Covid-19 pandemic have led to the exploration of decision-making facilitation through thinking and action (Herman et al., 2022) and collective decision-making within collaborative environments (Zhang & Hsu, 2021). It's noteworthy that studies on decision-making are often intricately intertwined with complementary skills and competencies, such as the understanding of the Nature of Science (NOS), reasoning, debate, and scientific argumentation. The essential core of SSI, characterised by unstructured and multifaceted topics, naturally lends itself as a fertile ground for the cultivation of decision-making competencies (Zamakhsyari, 2020; Christodoulou et al., 2021).

Table 3

Research Topics in Selected Articles

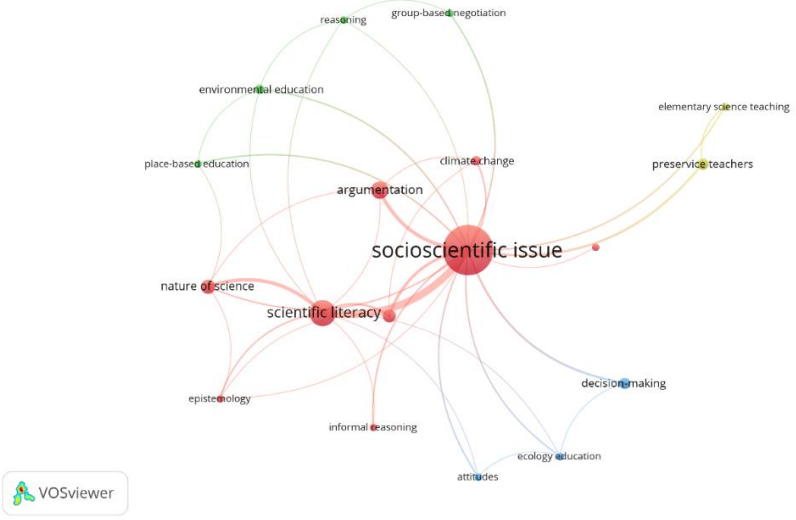
Topics	Total	Percentage (%)
Argumentation	18	20.7
Decision Making	15	17.2
Nature of science	7	8.0
Reasoning	7	8.0
Classroom practices	4	4.6
Attitudes	3	3.4
Discussion	3	3.4
Epistemological view	3	3.4
Character and Value	2	2.3
Conceptual studies	2	2.3
Critical Thinking	2	2.3
Curriculum	2	2.3
Efficacy	2	2.3
Instrument Development	2	2.3
Sustainability	2	2.3
Citizenship	1	1.1
Contemporary SSI	1	1.1
Debates	1	1.1
Emotions	1	1.1
Ethics	1	1.1
Informal reasoning	1	1.1
Narrative Text	1	1.1
Opinion	1	1.1
Pedagogical Content Knowledge	1	1.1
Perspective	1	1.1

Place Based Understanding	1	1.1
Scientific Inquiry	1	1.1
Textbooks	1	1.1

In addition to manual identification, co-occurrence or co-word analysis was employed to determine the article topics based on the relationship of keywords in titles, abstracts, or keyword lists. If the same keywords frequently appear interrelated, it indicates that the discussion in the article is sufficiently close (Zupic & Čater, 2015). The articles' co-word analysis contained a total of 168 co-occurring keywords, as shown in Figure 3. The closest co-occurring keywords directly related to SSI were scientific literacy, argumentation, and nature of science. On overlay visualisation, new keywords appeared on articles in 2021 and 2022, including place-based education, environmental education, group-based negotiation, as shown in Figure 2.

Figure 2

Keywords of Network Map Co-occurrence



A number of popular SSI topics related to argumentation included multidisciplinary argumentation (Garrecht et al., 2021), measurement of argumentation quality related to local socio-scientific issues (Capkinoglu et al., 2020), pedagogical content knowledge in teacher SSI argumentation (Kutluca, 2021), the relationship between students' disciplinary backgrounds and their SSI argumentation (Christenson et al., 2014), developing prospective teachers' competences in assessing SSI argumentation (Christenson & Walan, 2022), the relationship between the nature of science and scientific argumentation (Khishfe, 2022), argumentation and reasoning in group negotiations in the SSI context (Jafari & Meisert, 2022) as well as studies on the combination of debate and reflection activity in developing student argumentation (Bächtold & Pallarès, 2022).

Several other related studies comprised of scientific thinking and learner decision-making in learning (Menke et al., 2022), democratic citizen participation in decision-making and debate in the SSI context (K. Ottander & Simon, 2021), understanding the nature of science and deep decision-making through a referendum simulation in the SSI context (Adal & Cakiroglu, 2022), decision-making and informal reasoning in SSI agriculture (Ladachart & Ladachart, 2022), and the measurement of collective decision-making In students (Zhang & Hsu, 2021).

Several new topics in 2020 included SSI-based exhibitions with characteristics of critical reflection, contextualised information, and opinion sharing (Yun et al., 2022), compensatory weighting as the preferred strategy for decisions in SSIs, the cartography of controversy approach

was used to analyse the complexity controversy over SSI (Jafari & Meisert, 2022) as well as studies on the effect of SSIs on self-efficacy of science teaching (Kinskey & Callahan, 2021). Cartography of Controversy (CoC) approach in enabling students to understand and communicate about socioscientific issues. The method was used to explore and represent complex socioscientific issues. It involved mapping out the different perspectives, knowledge types, and uncertainties surrounding a controversy.

Research Samples

According to Table 4, the largest research sample groups were middle and high school (42,5%) pupils with contributions to IJSE, totalling 18.4%. A total of 16 studies at this level employed a qualitative approach (Balgopal et al., 2017; Herman et al., 2021; Kutluca, 2021). Among these, review of scientific argumentation has garnered significant interest from researchers, particularly in classroom settings (Evagorou & Osborne, 2013; Rudsberg et al., 2013; Capkinoglu et al., 2020; Bächtold & Pallarès, 2022). Studies focusing on character and value aspects of SSI within this level are limited (Lee et al., 2013), offering a substantial potential avenue for future studies. The reinforcement of character and values is crucial for imparting to pupils, emphasising the significance of this endeavour (Lee et al., 2012). The second-ranked group of samples is comprised of pre-service teachers, making up 27.6% of the total, with the International Journal of Science Education (IJSE) contributing the most (17.2%). Studies involving this sample category predominantly examined topics related to argumentation (Balgopal et al., 2017; Baytelman, 2020; Capkinoglu et al., 2021) and decision-making (Ladachart & Ladachart, 2022; Adal & Cakiroglu, 2022). Although studies exploring scientific inquiry within pre-service teacher training have been conducted (Eastwood et al., 2013), the scope of such investigations remains relatively limited, indicating a promising avenue for future studies in this domain. There were no pre-school group research samples. Providing a scientific environment stimulation from an early age is imperative (Tu, 2006). Thereby, conducting SSI studies at the pre-school level holds significant potential for future studies.

Table 4

Number of Articles Based on the Research Sample Groups

Research Samples	Total	Percentage
Middle and High School	37	42.5
Preservice Teacher	24	27.6
Primary School	10	11.5
Teacher	8	9.2
Undergraduate Students	5	5.7
Lecturer	1	1.1
None	2	2.3
Total	87	100

Research Sites Discussing SSIs

Upon analysing 87 articles, only 82 articles were acquired that specified the location of the research. Table 5 shows that countries in the European continent featured the most, followed by Asia. Studies conducted in Europe reveal that the topic of SSI argumentation has garnered significant attention, maintaining its popularity even in 2022 (Bächtold & Pallarès, 2022; Jafari & Meisert, 2022; Christenson & Walan, 2022). This emphasis on argumentation remains prominent, particularly concerning middle and high school students as well as pre-service teachers. However, few studies examined attitudes (Klaver & Molen, 2021); ethics (Saunders & Rennie, 2013), and

scientific inquiry (Eastwood et al., 2013). The development of science education in Europe is also influenced by biodiversity citizen science initiatives, which contribute to shaping pedagogical approaches (Jenkins, 2001; Van der Wende, 2011; Kelemen-Finan et al., 2018). Meanwhile, few countries on the American and Australian continents have studied this topic. The location of the author's affiliation does not always fit that of the research, as one carried out by Dewi et al. (2021). Researchers from 14 European countries participated in the studies. Meanwhile, the United States has studied SSI the most, with 22 articles (25,3%), followed by Sweden with 7 articles (8%). Popular studies in science education in the USA are decision making (Herman et al., 2022; Menke et al., 2022) and scientific argumentation (Namdar & Shen, 2016; Balgopal et al., 2017).

Table 5

Continental Locations of Different Countries

Continents	Countries
Asia	China, India, South Korea, Malaysia, Lebanon, Taiwan, and Thailand.
Europe	Denmark, Cyprus, Sweden, Turkey, UK, France, Netherlands, England, Germany, Portugal, and Greece.
America	USA and Canada
Australia/Oceania	Australia, New Zealand

Table 6

Distribution of the Number of Articles by Countries

Countries	Number of Articles	Percentage (%)
USA	22	25.3
Sweden	7	8.0
Turkey	7	8.0
South Korea	6	6.9
UK	6	6.9
Taiwan	4	4.6
Germany	4	4.6
Lebanon	3	3.4
France	3	3.4
New Zealand	3	3.4
Thailand	2	2.3
Denmark	2	2.3
Cyprus	2	2.3
Canada	2	2.3
Australia	2	2.3
China	2	2.3
India	1	1.1
Malaysia	1	1.1
Netherlands	1	1.1
Portugal	1	1.1
Greece	1	1.1
Not Detected	5	5.7

Most Cited Articles

Table 7 displays the 10 most cited articles from the 168 articles analysed, with a total of less than 100 citations. It is obvious that the article by Lederman et al. (2014) is the most frequently cited by other articles. This article investigates how teachers employ current socio-scientific issues to teach science materials. This study is also relevant to Eastwood et al. (2012)'s, which examines the explicit-

reflective contextualisation of SSIs in science learning.

This SSI study also mentioned characters and values (Lee et al., 2012; Lee et al., 2013), ethics (Saunders & Rennie, 2013), and the relationship between attitude and decision-making (Jho et al., 2014). These studies look at how a teacher fosters pupils' understanding of SSI contexts, as well as characters, ethics, and attitude in learners.

Table 7

The Most Cited Articles

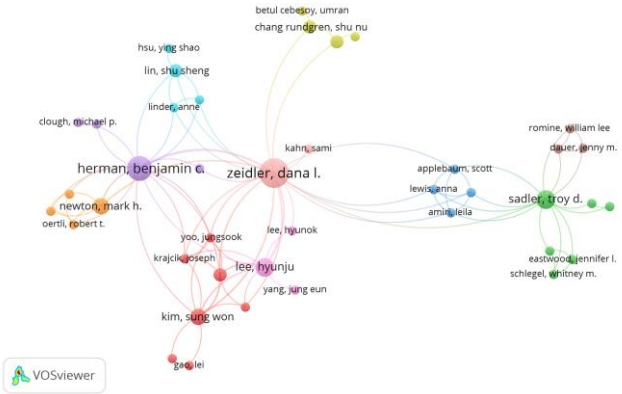
Authors	Article Titles	Number of Citations	Year	Journals
(Lederman et al., 2014)	Nature of Science, Scientific Inquiry, and Socio-Scientific Issues Arising from Genetics: A Pathway to Developing a Scientifically Literate Citizenry	364	2014	SE
(Evagorou & Osborne, 2013)	Exploring young students' collaborative argumentation within a socioscientific issue	272	2013	JRST
(Eastwood et al., 2012)	Contextualizing Nature of Science Instruction in Socioscientific Issues	267	2012	IJSE
(Lee et al., 2012)	Developing Character and Values for Global Citizens: Analysis of pre-service science teachers' Moral reasoning on socioscientific issues	215	2012	IJSE
(Lee et al., 2013)	Socioscientific Issues as a Vehicle for Promoting Character and Values for Global Citizens	210	2013	IJSE
(Khishfe, 2014)	Explicit Nature of Science and Argumentation Instruction in the Context of Socioscientific Issues: An Effect on Student Learning and Transfer	173	2014	IJSE
(Ottander & Ekborg, 2012)	Teachers' Experience of Working with Socio-scientific Issues:	166	2012	RSE

	A Large Scale and in Depth Study			
(Saunders & Rennie, 2013)	A Pedagogical Model for Ethical Inquiry into Socio-scientific Issues in Science	162	2013	RSE
(Bencze et al., 2012)	Students' Research-Informed Socio-scientific Activism: Re/Visions for a Sustainable Future	148	2011	RSE
(Jho et al., 2014)	The Relationship of Science Knowledge, Attitude and Decision Making on Socio-scientific Issues: The Case Study of Students' Debates on a Nuclear Power Plant in Korea	143	2013	S&E

Through author co-citation analysis in Figure 5, 210 authors meet the determined criteria. There are 10 cluster maps in the author co-citation map that can be recognised and indicated though different colours. Dana L. Zeidler of the Department of Teaching and Learning, College of Education, University of South Florida has the highest total link strength, with 29 out of 10 documents. Benjamin C. Herman of the Department of Learning, Teaching and Curriculum, College of Education, University of Missouri, Columbia, is another researcher with a second total link strength of 20. Benjamin, serving as the first author, co-authored with Dana L. Zeidler on several related papers. The third researcher with a total link strength of 13 is Hyunju Lee from WCU Global Institute for STS Education, Ewha Womans University, with 4 article documents.

Figure 5

Author Co-citation Map



Conclusion and Implications

An analysis of 87 articles from top-tier journals in the field of science education reveals that IJSE had the most published SSI articles, with 36 in numbers. With a 56,3% contribution, qualitative research methods are the most commonly employed in research. While argumentation, decision-making, and nature of science are the most frequently discussed topics in SSIs. Middle and high

school students make up the majority of the sample groups (42.4%). The European continent is widely used as research sites (14 countries), but the United States has the most articles about research sites (22 articles). Interview (12,6%) is the most commonly used data collection tool. The most cited articles in 2014 by S&E were Nature of Science, Scientific Inquiry, and Socio-Scientific Issues Arising from Genetics: A Pathway to Developing a Scientifically Literate Citizenry, which received 364 citations. These findings suggest that the SSI studies have been improved year after year. The following are several points of recommendations for researchers regarding SSI studies:

- The scope of research topics relevant to SSI remains broad, and areas such as efficacy, emotion, and attitude have received limited attention.
- Further exploration is needed in investigating SSI studies in the context of early childhood education.
- There is a potential to conduct cross-country studies in the domain of SSI, particularly by focusing on biodiversity-related issues that are unique and distinct to various regions. Currently, a majority of SSI studies are confined to samples from a single country, limiting the broader perspective that international collaboration can provide.

References

Adal, E. E., & Cakiroglu, J. (2022). Investigation of Preservice Science Teachers' Nature of Science Understanding and Decision Making on Socioscientific Issue through the Fractal Model. In *Science and Education* (Zenbakia 0123456789). Springer Netherlands. https://doi.org/10.1007/s11191-022-00319-1

Azorin, J.M., & Cameron, R. (2010). The application of mixed methods in organisational research: a literature review. *The Electronic Journal of Business Research Methods*, *8*, 95–105.

Bächtold, M., & Pallarès, G. (2022). Combining debates and reflective activities to develop students ' argumentation on socioscientific issues. August. https://doi.org/10.1002/tea.21816

Balgopal, M. M., Wallace, A. M., & Dahlberg, S. (2017). Writing from different cultural contexts: How college students frame an environmental SSI through written arguments. *Journal of Research in Science Teaching*, *54*(2), 195–218. https://doi.org/10.1002/tea.21342

Barrue, C., & Albe, V. (2013). Citizenship Education and Socioscientific Issues: Implicit Concept of Citizenship in the Curriculum, Views of French Middle School Teachers. *Science and Education*, *22*(5), 1089–1114. https://doi.org/10.1007/s11191-012-9571-4

Bayram-Jacobs, D. (2019). Science teachers' pedagogical content knowledge development during enactment of socioscientific curriculum materials. *Journal of Research in Science Teaching*, *56*(9), 1207–1233. https://doi.org/10.1002/tea.21550

Baytelman, A. (2020). Epistemic beliefs and prior knowledge as predictors of the construction of different types of arguments on socioscientific issues. *Journal of Research in Science Teaching*, *57*(8), 1199–1227. https://doi.org/10.1002/tea.21627

Bencze, L., Sperling, E., & Carter, L. (2012). Students' Research-Informed Socio-scientific Activism: ReVisions for a Sustainable Future. *Research in Science Education*, *42*(1), 129–148. https://doi.org/10.1007/s11165-011-9260-3

Bennett, J., Lubben, F., Hogarth, S., & Campbell, B. (2005). Systematic reviews of research in science education: rigour or rigidity? *International Journal of Science Education*, *27*(4), 387–406. https://doi.org/10.1080/0950069042000323719

Bossér, U., & Lindahl, M. (2019). Students' Positioning in the Classroom: a Study of Teacher-Student Interactions in a Socioscientific Issue Context. *Research in Science Education*, *49*(2), 371–390. https://doi.org/10.1007/s11165-017-9627-1

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Çalik, M., & Coll, R. K. (2012). Investigating Socioscientific Issues via Scientific Habits of Mind: Development and validation of the Scientific Habits of Mind Survey. *International Journal of Science Education*, *34*(12), 1909–1930. https://doi.org/10.1080/09500693.2012.685197

Çalık, M., & Wiyarsi, A. (2021). A systematic review of the research papers on chemistry-focused socio-scientific issues. *Journal of Baltic Science Education*, *20*(3), 360–372. https://doi.org/10.33225/jbse/21.20.360

Capkinoglu, E., Cetin, P. S., & Metin Peten, D. (2021). How do pre-service science teachers evaluate the persuasiveness of a socioscientific argument? *International Journal of Science Education*, *43*(4), 594–623. https://doi.org/10.1080/09500693.2021.1876273

Capkinoglu, E., Yilmaz, S., & Leblebicioglu, G. (2020). Quality of argumentation by seventh-graders in local socioscientific issues. *Journal of Research in Science Teaching*, *57*(6), 827–855. https://doi.org/10.1002/tea.21609

Cebrián-Robles, D., España-Ramos, E., & Reis, P. (2021). Introducing preservice primary teachers to socioscientific activism through the analysis and discussion of videos. *International Journal of Science Education*, *43*(15), 2457–2478. https://doi.org/10.1080/09500693.2021.1969060

Chang, Y.-H., Chang, C.-Y., & Tseng, Y.-H. (2010). Trends of Science Education Research: An Automatic Content Analysis. *Journal of Science Education and Technology*, *19*(4), 315–331. https://doi.org/10.1007/s10956-009-9202-2

Chen, L., & Xiao, S. (2021). Perceptions, challenges, and coping strategies of science teachers in teaching socioscientific issues : A systematic review. *Educational Research Review*, *32*(October 2020), 100377. https://doi.org/10.1016/j.edurev.2020.100377

Christenson, N., Chang Rundgren, S. N., & Zeidler, D. L. (2014). The Relationship of Discipline Background to Upper Secondary Students' Argumentation on Socioscientific Issues. *Research in Science Education*, *44*(4), 581–601. https://doi.org/10.1007/s11165-013-9394-6

Christenson, N., Gericke, N., & Rundgren, S. N. C. (2017). Science and Language Teachers' Assessment of Upper Secondary Students' Socioscientific Argumentation. *International Journal of Science and Mathematics Education*, *15*(8), 1403–1422. https://doi.org/10.1007/s10763-016-9746-6

Christenson, N., & Walan, S. (2022). Developing Pre-service Teachers' Competence in Assessing Socioscientific Argumentation. *Journal of Science Teacher Education*, 1–23. https://doi.org/10.1080/1046560X.2021.2018103

Christodoulou, A., Levinson, R., Davies, P., Grace, M., Nicholl, J., & Rietdijk, W. (2021). The use of Cartography of Controversy within socioscientific issues-based education: students' mapping of the badger-cattle controversy in England. *International Journal of Science Education*, *43*(15), 2479–2500. https://doi.org/10.1080/09500693.2021.1970852

Cian, H. (2020). The influence of context: comparing high school students' socioscientific reasoning by socioscientific topic. *International Journal of Science Education*, *42*(9), 1503–1521. https://doi.org/10.1080/09500693.2020.1767316

Dawson, V. (2015). Western Australian High School Students' Understandings about the Socioscientific Issue of Climate Change. *International Journal of Science Education*, *37*(7), 1024–1043. https://doi.org/10.1080/09500693.2015.1015181

Dawson, V. M., & Venville, G. (2010). Teaching strategies for developing students' argumentation skills about socioscientific issues in high school genetics. *Research in Science Education*, *40*(2), 133–148. https://doi.org/10.1007/s11165-008-9104-y

Dewi, N. R., Rusilowati, A., Saptono, S., Haryani, S., Wiyanto, W., Ridlo, S., Listiaji, P., & Atunnisa, R. (2021). Technological, Pedagogical, Content Knowledge (TPACK) Research Trends: A Systematic Literature Review of Publications Between 2010 - 2020. *Journal of Turkish Science Education*, *18*(4), 589–604. https://doi.org/10.36681/tused.2021.92

Eastwood, Jennifer L., Sadler, T. D., Sherwood, R. D., & Schlegel, W. M. (2013). Students' Participation in an Interdisciplinary, Socioscientific Issues Based Undergraduate Human Biology Major and Their Understanding of Scientific Inquiry. *Research in Science Education*, *43*(3), 1051–1078. https://doi.org/10.1007/s11165-012-9298-x

Eastwood, Jennifer Lynne, Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing nature of science instruction in socioscientific issues. *International Journal of Science Education*, *34*(15), 2289–2315. https://doi.org/10.1080/09500693.2012.667582

Erduran, S., Ozdem, Y., & Park, J. Y. (2015). Research trends on argumentation in science education: a journal content analysis from 1998–2014. *International Journal of STEM Education*, *2*(1), 5. https://doi.org/10.1186/s40594-015-0020-1

Evagorou, M., & Osborne, J. (2013). Exploring young students' collaborative argumentation within a socioscientific issue. *Journal of Research in Science Teaching*, *50*(2), 209–237. https://doi.org/10.1002/tea.21076

Fang, S.-C., Hsu, Y.-S., & Lin, S.-S. (2019). Conceptualizing Socioscientific Decision Making from a Review of Research in Science Education. *International Journal of Science and Mathematics Education*, *17*(3), 427–448. https://doi.org/10.1007/s10763-018-9890-2

Gao, L., Mun, K., & Kim, S. W. (2019). Using Socioscientific Issues to Enhance Students' Emotional Competence. *Research in Science Education*. https://doi.org/10.1007/s11165-019-09873-1

Gardner, G. E., & Jones, M. G. (2011). Science Instructors' Perceptions of the Risks of Biotechnology: Implications for Science Education. *Research in Science Education*, *41*(5), 711–738. https://doi.org/10.1007/s11165-010-9187-0

Garrecht, C., Reiss, M. J., & Harms, U. (2021). 'I wouldn't want to be the animal in use nor the patient in need' – the role of issue familiarity in students' socioscientific argumentation. *International Journal of Science Education*, *43*(12), 2065–2086. https://doi.org/10.1080/09500693.2021.1950944

Gusenbauer, M. (2019). Google Scholar to overshadow them all? Comparing the sizes of 12 academic search engines and bibliographic databases. *Scientometrics*, *118*(1), 177–214. https://doi.org/10.1007/s11192-018-2958-5

Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific Issues Thinking and Action in the Midst of Science-in-the-Making. *Science and Education*. Springer Netherlands. https://doi.org/10.1007/s11191-021-00306-y

Herman, B. C., Newton, M. H., & Zeidler, D. L. (2021). Impact of place-based socioscientific issues instruction on students' contextualization of socioscientific orientations. *Science Education*, *105*(4), 585–627. https://doi.org/10.1002/sce.21618

Herman, B. C., Owens, D. C., Oertli, R. T., Zangori, L. A., & Newton, M. H. (2019). Exploring the Complexity of Students' Scientific Explanations and Associated Nature of Science Views Within a Place-Based Socioscientific Issue Context. *Science and Education*, *28*(3–5), 329–366. https://doi.org/10.1007/s11191-019-00034-4

Hernández-Ramos, J., Pernaa, J., Cáceres-Jensen, L., & Rodríguez-Becerra, J. (2021). The Effects of Using Socio-Scientific Issues and Technology in Problem-Based Learning: A Systematic Review. *Education Sciences*, *11*(10), 640. https://doi.org/10.3390/educsci11100640

Hsu, Y. S., & Lin, S. S. (2017). Prompting students to make socioscientific decisions: embedding metacognitive guidance in an e-learning environment. *International Journal of Science Education*, *39*(7), 964–979. https://doi.org/10.1080/09500693.2017.1312036

Jafari, M., & Meisert, A. (2022). Potential of Group-Based Negotiation to Promote Learner-Based Reasoning and Weighting of Arguments on Socioscientific Issues. *Research in Science Education*, *0123456789*. https://doi.org/10.1007/s11165-022-10059-5

Jenkins, E. W. (2001). Research in Science Education in Europe: Retrospect and Prospect. In *Research in Science Education - Past, Present, and Future* (or. 17–26). Springer Netherlands. https://doi.org/10.1007/0-306-47639-8_2

Jho, H. (2015). A Literature Review of Studies on Decision-making in Socio-scientific Issues. *Journal of The Korean Association For Science Education*, *35*(5), 791–804. https://doi.org/10.14697/jkase.2015.35.5.0791

Jho, H., Yoon, H. G., & Kim, M. (2014). The Relationship of Science Knowledge, Attitude and Decision Making on Socio-scientific Issues: The Case Study of Students' Debates on a Nuclear Power Plant in Korea. *Science and Education*, *23*(5), 1131–1151. https://doi.org/10.1007/s11191-013-9652-z

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in Science Education. A Systematic Review of the Literature. *Education Sciences*, *11*(1), 22. https://doi.org/10.3390/educsci11010022

Kamdem, J. P., Duarte, A. E., Lima, K. R. R., Rocha, J. B. T., Hassan, W., Barros, L. M., Roeder, T., & Tsopmo, A. (2019). Research trends in food chemistry: A bibliometric review of its 40 years anniversary (1976–2016). *Food Chemistry*, *294*, 448–457. https://doi.org/10.1016/j.foodchem.2019.05.021

Karahan, E., & Roehrig, G. (2017). Secondary School Students' Understanding of Science and Their Socioscientific Reasoning. *Research in Science Education*, *47*(4), 755–782. https://doi.org/10.1007/s11165-016-9527-9

Karakaş, H. (2022). *The Effect of Socioscientific Issues-Based Discussion Activities on the Attitudes of Primary School Teacher Candidates to the Life Science Teaching*. *19*(1), 17–36.

Karimi Takalo, S., Sayyadi Tooranloo, H., & Shahabaldini parizi, Z. (2021). Green innovation: A systematic literature review. *Journal of Cleaner Production*, *279*, 122474. https://doi.org/10.1016/j.jclepro.2020.122474

Karisan, D., & Zeidler, D. L. (2016). Contextualization of Nature of Science Within the Socioscientific Issues Framework: A Review of Research. *International Journal of Education in Mathematics, Science and Technology*, 139–152. https://doi.org/10.18404/ijemst.270186

Kelemen-Finan, J., Scheuch, M., & Winter, S. (2018). Contributions from citizen science to science education: an examination of a biodiversity citizen science project with schools in Central Europe. *International Journal of Science Education*, *40*(17), 2078–2098. https://doi.org/10.1080/09500693.2018.1520405

Khishfe, R. (2014). Explicit Nature of Science and Argumentation Instruction in the Context of Socioscientific Issues: An effect on student learning and transfer. *International Journal of Science Education*, *36*(6), 974–1016. https://doi.org/10.1080/09500693.2013.832004

Khishfe, R. (2020). Retention of acquired argumentation skills and nature of science conceptions. *International Journal of Science Education*, *42*(13), 2181–2204. https://doi.org/10.1080/09500693.2020.1814444

Khishfe, R. (2021). Explicit Instruction and Student Learning of Argumentation and Nature of Science. *Journal of Science Teacher Education*, *32*(3), 325–349. https://doi.org/10.1080/1046560X.2020.1822652

Khishfe, R. (2022). Nature of Science and Argumentation Instruction in socioscientific and scientific contexts. *International Journal of Science Education*, *44*(4), 647–673. https://doi.org/10.1080/09500693.2022.2050488

Khishfe, R., Alshaya, F. S., BouJaoude, S., Mansour, N., & Alrudiyan, K. I. (2017). Students' understandings of nature of science and their arguments in the context of four socio-scientific issues. *International Journal of Science Education*, *39*(3), 299–334. https://doi.org/10.1080/09500693.2017.1280741

Kilinç, A., Afacan, O., Polat, D., & Güler, P. D. (2014). *Preservice Science Teachers ' Belief Systems about Teaching a Socioscientific Issue*. https://doi.org/10.12973/tused.10120a

Kim, M., Anthony, R., & Blades, D. (2014). Decision Making Through Dialogue: a Case Study of Analyzing Preservice Teachers' Argumentation on Socioscientific Issues. *Research in Science Education*, *44*(6), 903–926. https://doi.org/10.1007/s11165-014-9407-0

Kinskey, M., & Callahan, B. E. (2021). The Influences of Socioscientific Issues on General Science Teaching Self-Efficacy. *Research in Science Education*, *0123456789*. https://doi.org/10.1007/s11165-021-09991-9

Kitchenham, B. (2004). *Procedures for Performing Systematic Reviews*. Newcastle : Keele University.

Kitchenham, Barbara, Pretorius, R., Budgen, D., Pearl Brereton, O., Turner, M., Niazi, M., & Linkman, S. (2010). Systematic literature reviews in software engineering – A tertiary study. *Information and Software Technology*, *52*(8), 792–805. https://doi.org/10.1016/j.infsof.2010.03.006

Klaver, L. T., & Walma van der Molen, J. H. (2021). Measuring Pupils' Attitudes Towards Socioscientific Issues: Development and Validation of a Questionnaire. *Science and Education*, *30*(2), 317–344. https://doi.org/10.1007/s11191-020-00174-y

Kolovou, M. (2022). Embracing Culturally Relevant Education in Mathematics and Science: A Literature Review. *The Urban Review*. https://doi.org/10.1007/s11256-022-00643-4

Kolstø, S. D., Bungum, B., Arnesen, E., Isnes, A., Kristensen, T., Mathiassen, K., Mestad, I., Quale, A., Tonning, A. S. V., & Ulvik, M. (2006). Science students' critical examination of scientific information related to socioscientific issues. *Science Education*, *90*(4), 632–655. https://doi.org/10.1002/sce.20133

Kutluca, A. Y. (2021). An investigation of elementary teachers' pedagogical content knowledge for socioscientific argumentation: The effect of a learning and teaching experience. *Science Education*, *105*(4), 743–775. https://doi.org/10.1002/sce.21624

Ladachart, Ladapa, & Ladachart, L. (2022). Preservice biology teachers' decision-making on, and informal reasoning about, an agriculture-based socioscientific issue. *Journal of Biological Education*, 1–17. https://doi.org/10.1080/00219266.2022.2058587

Ladachart, Luecha, & Ladachart, L. (2021). Preservice biology teachers' decision-making and informal reasoning about culture-based socioscientific issues. *International Journal of Science Education*, *43*(5), 641–671. https://doi.org/10.1080/09500693.2021.1876958

Lederman, N. G., Antink, A., & Bartos, S. (2014). Nature of Science, Scientific Inquiry, and Socio-Scientific Issues Arising from Genetics: A Pathway to Developing a Scientifically Literate Citizenry. *Science and Education*, *23*(2), 285–302. https://doi.org/10.1007/s11191-012-9503-3

Lee, H. (2020). Examining tensions in the socioscientific issues classroom: Students' border crossings into a new culture of science. *Journal of Research in Science Teaching*, *57*(5), 672–694. https://doi.org/10.1002/tea.21600

Lee, Hyunju, Chang, H., Choi, K., Kim, S. W., & Zeidler, D. L. (2012). Developing Character and Values for Global Citizens: Analysis of pre-service science teachers' moral reasoning on socioscientific issues. *International Journal of Science Education*, *34*(6), 925–953. https://doi.org/10.1080/09500693.2011.625505

Lee, Hyunju, & Yang, J. eun. (2019). Science Teachers Taking their First Steps toward Teaching Socioscientific Issues through Collaborative Action Research. *Research in Science Education*, *49*(1), 51–71. https://doi.org/10.1007/s11165-017-9614-6

Lee, Hyunju, Yoo, J., Choi, K., Kim, S. W., Krajcik, J., Herman, B. C., & Zeidler, D. L. (2013). Socioscientific Issues as a Vehicle for Promoting Character and Values for Global Citizens. *International Journal of Science Education*, *35*(12), 2079–2113. https://doi.org/10.1080/09500693.2012.749546

Lee, Hyunok, Lee, H., & Zeidler, D. L. (2020). Examining tensions in the socioscientific issues classroom: Students' border crossings into a new culture of science. *Journal of Research in Science Teaching*, *57*(5), 672–694. https://doi.org/10.1002/tea.21600

Lee, M., Wu, Y., & Tsai, C. (2009). Research Trends in Science Education from 2003 to 2007: A content analysis of publications in selected journals. *International Journal of Science Education*, *31*(15), 1999–2020. https://doi.org/10.1080/09500690802314876

Li, Y., Wang, K., Xiao, Y., & Froyd, J. E. (2020). Research and trends in STEM education: a systematic review of journal publications. *International Journal of STEM Education*, *7*(1), 11. https://doi.org/10.1186/s40594-020-00207-6

Lin, J. W. (2020). The effects of socioscientific issues web searches on grade 6 students' scientific epistemological beliefs: the role of information positions. *International Journal of Science Education*. https://doi.org/10.1080/09500693.2020.1821258

Lin, T.-C., Lin, T.-J., & Tsai, C.-C. (2014). Research Trends in Science Education from 2008 to 2012: A systematic content analysis of publications in selected journals. *International Journal of Science Education*, *36*(8), 1346–1372. https://doi.org/10.1080/09500693.2013.864428

Lin, T., Lin, T., & Tsai, C. (2012). *International Journal of Science Research Trends in Science Education from 2008 to 2012 : A systematic content analysis of publications in selected journals*. *April 2014*, 37–41. https://doi.org/10.1080/09500693.2013.864428

Luo, K., Saleh, S., Zhang, P., & Zhu, Q. (2023). *Science Education Research Trends in the Chinese Mainland From 2017 – 2021 : A Systematic Literature Review in Selected Journals*. *August*, 1–23. https://doi.org/10.1177/2212585X231175485

Macalalag, A. Z., Johnson, J., & Lai, M. (2019). How do we do this: learning how to teach socioscientific issues. *Cultural Studies of Science Education*. https://doi.org/10.1007/s11422-019-09944-9

Menke, L., Voss, S., Kruse, J., & Zacharski, K. (2022). Investigating the Knowledge Domains Science Teachers Use When Considering a Socioscientific Issue. *Research in Science Education*. https://doi.org/10.1007/s11165-022-10067-5

Milne, C., Siry, C., & Mueller, M. (2015). Reflections on the challenges and possibilities of journal publication in science education. *Cultural Studies of Science Education*, *10*(4), 1063–1069. https://doi.org/10.1007/s11422-015-9719-z

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Monferrer, L., Lorenzo-Valentín, G., & Santágueda-Villanueva, M. (2022). Mathematical and Experimental Science Education from the School Garden: A Review of the Literature and Recommendations for Practice. *Education Sciences*, *12*(1), 47. https://doi.org/10.3390/educsci12010047

Namdar, B., & Shen, J. (2016). Intersection of argumentation and the use of multiple representations in the context of socioscientific issues. *International Journal of Science Education*, *38*(7), 1100–1132. https://doi.org/10.1080/09500693.2016.1183265

Nielsen, J. A. (2012). Science in discussions: An analysis of the use of science content in socioscientific discussions. *Science Education*, *96*(3), 428–456. https://doi.org/10.1002/sce.21001

Ottander, C., & Ekborg, M. (2012). Students' Experience of Working with Socioscientific Issues - a Quantitative Study in Secondary School. *Research in Science Education*, *42*(6), 1147–1163. https://doi.org/10.1007/s11165-011-9238-1

Ottander, K., & Simon, S. (2021). Learning democratic participation? Meaning-making in discussion of socioscientific issues in science education. *International Journal of Science Education*, *43*(12), 1895–1925. https://doi.org/10.1080/09500693.2021.1946200

Paul, J., Stadtler, M., & Bromme, R. (2019). Effects of a Sourcing Prompt and Conflicts in Reading Materials on Elementary Students' Use of Source Information. *Discourse Processes*, *56*(2), 155–169. https://doi.org/10.1080/0163853X.2017.1402165

Romine, W. L., Sadler, T. D., Dauer, J. M., & Kinslow, A. (2020). Measurement of socio-scientific reasoning (SSR) and exploration of SSR as a progression of competencies. *International Journal of Science Education*, *42*(18), 2981–3002. https://doi.org/10.1080/09500693.2020.1849853

Rudsberg, K., ÖHman, J., & ÖStman, L. (2013). Analyzing Students' Learning in Classroom Discussions about Socioscientific Issues. *Science Education*, *97*(4), 594–620. https://doi.org/10.1002/sce.21065

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching*, *41*(5), 513–536. https://doi.org/10.1002/tea.20009

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What Do Students Gain by Engaging in Socioscientific Inquiry? *Research in Science Education*, *37*(4), 371–391. https://doi.org/10.1007/s11165-006-9030-9

Sakschewski, M., Eggert, S., Schneider, S., & Bögeholz, S. (2014). Students' Socioscientific Reasoning and Decision-making on Energy-related Issues-Development of a measurement instrument. *International Journal of Science Education*, *36*(14), 2291–2313. https://doi.org/10.1080/09500693.2014.920550

Saunders, K. J., & Rennie, L. J. (2013). A Pedagogical Model for Ethical Inquiry into Socioscientific Issues In Science. *Research in Science Education*, *43*(1), 253–274. https://doi.org/10.1007/s11165-011-9248-z

Schuck, P., & Feser, M. S. (2022). Science Education as a Human Right: A Systematic Review of the Literature. *European Journal of Science and Mathematics Education*, *10*(3), 338–351. https://doi.org/10.30935/scimath/11967

Sırakaya, M., & Alsancak Sırakaya, D. (2022). Augmented reality in STEM education: a systematic review. *Interactive Learning Environments*, *30*(8), 1556–1569. https://doi.org/10.1080/10494820.2020.1722713

Tekin, N., Aslan, O., & Yilmaz, S. (2016). Research Trends on Socioscientific Issues: A Content Analysis of Publications in Selected Science Education Journals. *Journal of Education and Training Studies*, *4*(9). https://doi.org/10.11114/jets.v4i9.1572

Teo, T. W., Goh, M. T., & Yeo, L. W. (2014). Chemistry education research trends: 2004–2013. *Chem. Educ. Res. Pract.*, *15*(4), 470–487. https://doi.org/10.1039/C4RP00104D

Tetnowski, J. A., & Damico, J. S. (2001). A demonstration of the advantages of qualitative methodologies in stuttering research. *Journal of Fluency Disorders*, *26*(1), 17–42. https://doi.org/10.1016/S0094-730X(01)00094-8

Tidemand, S. (2017). The role of socioscientific issues in biology teaching: from the perspective of teachers. *International Journal of Science Education*, *39*(1), 44–61. https://doi.org/10.1080/09500693.2016.1264644

Topçu, M. S., Muğaloğlu, E. Z., & Güven, D. (2014). Socioscientific issues in science education: The case of Turkey. *Kuram ve Uygulamada Egitim Bilimleri*, *14*(6), 2340–2348. https://doi.org/10.12738/estp.2014.6.2226

Tsai, C., & Lydia Wen, M. (2005). Research and trends in science education from 1998 to 2002: a content analysis of publication in selected journals. *International Journal of Science Education*, *27*(1), 3–14. https://doi.org/10.1080/0950069042000243727

Tu, T. (2006). Preschool Science Environment: What Is Available in a Preschool Classroom? *Early Childhood Education Journal*, *33*(4), 245–251. https://doi.org/10.1007/s10643-005-0049-8

Ullah, M., Amin, S. U., Munsif, M., Safaev, U., Khan, H., Khan, S., & Ullah, H. (2022). Serious Games in Science Education. A Systematic Literature Review. *Virtual Reality & Intelligent Hardware*, *4*(3), 189–209. https://doi.org/10.1016/j.vrih.2022.02.001

Van der Wende, M. (2011). The Emergence of Liberal Arts and Sciences Education in Europe: A Comparative Perspective. *Higher Education Policy*, *24*(2), 233–253. https://doi.org/10.1057/hep.2011.3

Vojíř, K., & Rusek, M. (2019). Science education textbook research trends: a systematic literature review. *International Journal of Science Education*, *41*(11), 1496–1516. https://doi.org/10.1080/09500693.2019.1613584

Wang, H. H., Chen, H. T., Lin, H. S., Huang, Y. N., & Hong, Z. R. (2017). Longitudinal study of a cooperation-driven, socio-scientific issue intervention on promoting students' critical thinking and self-regulation in learning science. *International Journal of Science Education*, *39*(15), 2002–2026. https://doi.org/10.1080/09500693.2017.1357087

Xiao, S. (2018). Rhetorical Use of Inscriptions in Students' Written Arguments About Socioscientific Issues. *Research in Science Education*, 1–17. https://doi.org/10.1007/s11165-018-9730-y

Xiao, S., & Sandoval, W. A. (2017). Associations Between Attitudes Towards Science and Children's Evaluation of Information About Socioscientific Issues. *Science and Education*, *26*(3–4), 247–269. https://doi.org/10.1007/s11191-017-9888-0

Yahaya, J. M., Nurulazam, A., & Karpudewan, M. (2016). College students' attitudes towards sexually themed science content: a socioscientific issues approach to resolution. *International Journal of Science Education*, *38*(7), 1174–1196. https://doi.org/10.1080/09500693.2016.1174349

Yun, A., Shi, C., & Jun, B. G. (2022). Dealing with Socio-Scientific Issues in Science Exhibition: a Literature Review. *Research in Science Education*, *52*(1), 99–110. https://doi.org/10.1007/s11165-020-09930-0

Zamakhsyari. (2020). Fostering ill-structured problem-solving skills of chemistry students using socioscientific issues as learning contexts. In *AIP Conference Proceedings* (Libk. 2215). https://doi.org/10.1063/5.0000533

Zeidler, D. L., & Kahn, S. (2014). *It's debatable! Using socioscientific issues to develop science literacy*. NSTA Press.

Zeidler, D. L. (2014). *Socioscientific issues as a curriculum emphasis: Theory, research, and practice* (& S. K. A. In N. G. Lederman (arg.); II). Routledge.

Zhang, W.-X., & Hsu, Y.-S. (2021). The interplay of students' regulation learning and their collective decision-making performance in a SSI context. *International Journal of Science Education*, *43*(11), 1746–1778. https://doi.org/10.1080/09500693.2021.1933250

Zheng, T. (2017). A Literature Review on Knowledge Sharing. *Open Journal of Social Sciences*, *05*(03), 51–58. https://doi.org/10.4236/jss.2017.53006

Zupic, I., & Čater, T. (2015). Bibliometric Methods in Management and Organization. *Organizational Research Methods*, *18*(3), 429–472. https://doi.org/10.1177/1094428114562629

Journal of Turkish Science Education, 2024, *21*(1), 82-101.
DOI no: 10.36681/tused.2024.005

Science learning needs of preschool children and science activities carried out by teachers

Cansu Yıldız Taşdemir[1], Tülin Güler Yıldız[2]

[1]*Faculty of Health Sciences, University of Health Sciences, Türkiye, cytasdemir@gmail.com, Corresponding author, ORCID ID: 0000-0003-0638-3826*
[2]*Faculty of Education, Hacettepe University, Türkiye, ORCID ID: 0000-0002-9518-0336*

**This study is derived from a doctoral dissertation prepared by the first author under the supervision of the second author.*

ABSTRACT
The study aimed to investigate preschool children's learning needs related to science and their teachers' science activity practices. A basic qualitative research design was applied. Interviews were conducted with 15 preschool teachers and 48 children living in Ankara and subjected to content analysis. It was found that teachers mostly carried out activities and science experiments to support sense development and observation skills, used science and sensory centres and mostly preferred natural objects and living things. However, it was found that about half of the teachers considered themselves inadequate in science activities. Teachers stated that children need science activities that they can experience on their own, that take place outdoors and that are appropriate for their age, development and interests. They also stated that children need learning experiences that will improve their sensory development, observation and questioning skills. It was found that children mostly wanted to get to know scientists, learn how tools and equipment work, and conduct experiments. As a result of the research, it was revealed that teachers were aware of the importance of developing children's skills and reflected this in practice, but they could not identify the topics that children were interested in very well.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 19.06.2023
Accepted: 01.03.2024

KEYWORDS:
Preschool science education, science education, early childhood, preschool teachers.

To cite this article: Yıldız Taşdemir, C., & Güler Yıldız, T. (2024). Science learning needs of preschool children and science activities carried out by teachers. *Journal of Turkish Science Education, 21*(1), 82-101. DOI: 10.36681/tused.2024.005

Introduction

Learning takes place as a result of children's interactions with their natural and social environment. Children who actively play, wonder and explore their environment gain knowledge and experience as a result of these actions. According to Piaget, as a result of the new knowledge acquired through these experiences, schemas are formed and stored in the child's mind, and then the child uses this knowledge and experience to cope with new situations or problems (Berk, 2022). The child's curiosity, sense of discovery and desire to learn serve as a catalyst for the emergence of scientific actions in the early years. Children who enjoy thinking about natural phenomena, making observations in nature, collecting natural objects such as stones and shells, and playing games in nature take the first steps towards science and scientific knowledge (Eshach & Fried, 2005). While exploring the world during these activities, children, like scientists, constantly ask questions, investigate and research (Conezio & French, 2002).

Like many other concepts that children have, concepts related to science begin to form in the preschool period (Lind, 1998). Science education in preschool period is all the activities that children experience by using their senses (Uyanık Balat & Arslan Çiftçi, 2019). The fact that science is sometimes difficult to understand even by adults does not mean that scientific concepts and actions are beyond the capacity of children. Research shows that children can think about scientific concepts, and children who encounter scientific concepts at an early age are more successful in science education in their future learning (Eshach & Fried, 2005). It is of critical importance to provide children with quality science education experiences in order to develop a solid scientific foundation by developing children's research and observation skills in the preschool period (Bahar & Aksüt, 2020). Engaging in scientific activities in the preschool period supports children's readiness for the study of science and builds a foundation for future scientific understanding. Studies have shown that quality practices related to science education at an early age have positive effects on children's large muscle and small muscle motor skills, vocabulary, receptive and expressive language development, science process skills, early mathematical skills, concept development, creativity, school readiness, self-efficacy, attitudes towards science, and motivation (Brenneman, 2011; Conezio & French, 2002; Gölcük, 2017; Karamüftüoğlu, 2012; Morgan et al, 2016; Öztürk, 2016; Peterson & French, 2008; Tekerci, 2015; Uludağ, 2017; Worth, 2010). In addition, science activities offer children the opportunity to learn through trial and error without fear of making mistakes, and children can use the problem-solving skills they acquire during science activities in social situations (Conezio & French, 2002). In addition, science activities can respond to children's individual differences and different learning needs as they can be easily integrated with all other areas such as art, play, and mathematics.

Children's self-directed research is as valuable as the work of a scientist, but instead of leaving children to their own devices, guidance is needed to direct their natural curiosity and actions in a more scientific direction (Conezio & French, 2002). Appropriate guidance in science learning, combined with children's curiosity and the need to make sense of the world, can help children begin to use their inquiry skills. At this point, the preschool teacher has a critical role. Children's scientific investigations are guided by the teacher's understanding of science and scientific concepts. Whether the teacher misconceptions or not, the quality of the activities he/she plans, facilitating learning, the questions he/she asks and the comments he/she makes affect children's learning experiences related to science (Worth, 2010). Therefore, preschool teachers have an important role in helping children develop accurate understandings about scientific concepts and scientific processes and make sense of the world in the early years.

Preschool teachers should design science activities as processes in which the child plays an active role in the learning process, which do not involve too many instructions, and which are based on the child's curiosity, interaction with environment and the urge to question. In science activities, the child should be mentally engaged with questions and given enough time to interact with scientific concepts and processes. In this way, an inquiry-based approach can enable children to make sense of the world and their environment in a holistic way, rather than learning isolated pieces of science. For this, science activities should take place while children explore and play (Dejonckheere et al., 2016). Science is a part of our daily lives and science education should be incorporated into the curriculum by relating it to children's daily lives (Eliason & Jenkins, 2008). Events in the natural environment, such as observing anthills or examining the change in the leaves of a tree according to the seasons, can provide children with meaningful and relevant science experiences. Teachers should guide children by supporting their self-regulation skills, asking probing questions, focusing children's attention on causes and effects, and helping children reflect on their findings. In this way, a scientific process can take place rather than an acquisition of factual knowledge that the teacher imparts and the child receives (Dejonckheere et al., 2016). Worth and Grollman (2003) stated that for a quality science education in preschool, activities should be structured on developmental theories specific to early childhood, integrated with the child's daily life and other activities, taking into account the individual differences between children. In addition, providing children with a variety of learning opportunities, different materials and sufficient time, supporting children in developing their own ideas and

questions, having a strong communication environment in the classroom to discuss their ideas with others, documenting, presenting and reflecting on their experiences are among the foundations on which a quality science education should be based (Worth & Grollman, 2003).

Although it is known that teachers play a critical role in science education in the early years, there are some problems when international and national studies on teachers are examined. Teachers' lack of self-confidence and knowledge about science (Gerde et al., 2018; Park et al., 2017), their inability to allocate enough time for science activities (Greenfield et al. 2009, Park et al., 2017), and their inability to use materials effectively (Tu, 2006) have been shown among the factors that hinder science education. Similarly, in studies conducted in Turkey, it has been reported that preschool teachers do not use different methods, techniques and materials (Karamustafaoğlu & Kandaz, 2006; Yıldız & Tükel, 2018), have difficulties in providing suitable materials (Babaroğlu & Okur Metwalley, 2018; Ültay et al, 2018); they do not have the necessary competencies related to science (Aslan et al., 2015; Karaer & Kösterelioğlu, 2005), they do not make children active in experimental activities (Polat et al., 2021), and they do not provide children with problem-solving opportunities (Gündüz & Akduman, 2015).

To guide quality learning, teachers should create carefully designed activities based on learners' learning needs, interests and prior knowledge (Darling-Hammond et al., 2020). Research shows that interest is positively related to motivation and learning (Renninger et al., 2015). Learning environments designed by taking children's interests and learning orientations into account can have an impact on children's participation in classroom discussions and inquiry behaviours (Neitzel et al., 2017). From this point of view, it can be stated that it is very important to start from children's interests and learning needs in order to plan process-based science activities that make children active and emphasise inquiry. In addition, it is known that children's early interests and learning needs in science can continue in the following years and have significant effects on the learning process (Alexander et al., 2012). For example, a study found that preschool girls' early interest in science is a predictor of future science achievement (Leibham et al., 2013). Recognising preschool children's early interest in science by teachers and planning activities around children's interests and learning needs are also important for future science achievement (Hamel, 2021).

Although the question "What should we teach children about science at an early age?" often occupies the minds of educators and researchers, it is thought that the questions "What do children want to learn about science?" and "What are children's learning needs in science?" are often ignored. If the importance of starting from children's interests and learning needs and including children in the learning process is emphasised, investigating what they want to learn is also of critical importance. From this perspective, this study is important in that it includes children's voices by revealing not only what teachers do in science activities, but also what children want to learn about science. It is thought that this study will contribute to the literature on how well children's science-related learning needs are met by teachers. From this point of view, this study aimed to investigate preschool children's learning needs related to science and what teachers do in science activities and to examine whether these activities meet children's interests and needs. In line with this purpose, the following research questions were sought to be answered:

"What kind of science activities do preschool teachers conduct?"

"What are the materials that preschool teachers use in science activities?"

"What are the opinions of preschool teachers about their competencies in planning and implementing science activities?"

"According to preschool teachers, what kind of science activities do today's children need?"

"What are preschool children curious about science? (What do children want to learn about science?)"

Methods

Research Design

The research design was basic qualitative. This design aims to obtain detailed first-hand information about a topic or problem from individuals or other data sources (Merriam, 2013). In this design, the researcher tries to discover and understand a phenomenon, process, perspective or worldview of the participants through interviews, observations or document analysis. Basic qualitative research design is particularly well suited to gaining an in-depth understanding of educational processes (Merriam, 2002). In this study, a basic qualitative research design was used to determine what preschool children want to learn about science and what kind of science activities teachers conduct. Interviews were conducted with children and teachers to obtain detailed first-hand detailed information.

Study Group

The convenience sampling method was used to determine the study group and 15 preschool teachers and 48 children attending preschool were included in the study. Johnson and Christensen (2014) stated that in the convenience sampling method, people who meet various practical criteria (easy accessibility, geographical proximity, volunteerism, etc.) can be included in the research. In this study, teachers and children who met the criteria of geographical proximity, accessibility and volunteer constituted the study group. Table 1 shows the demographic information of the preschool teachers in the study group.

Table 1

Demographic Characteristics of the Preschool Teachers in the Study Group

Code	Educational Background	Type of Institution Worked	Duration of Professional Experience (Years)
T1	Bachelor's degree	Preschool	22
T2	Bachelor's degree	Preschool	10
T3	Bachelor's degree	Preschool	18
T4	Bachelor's degree	Preschool	12
T5	Bachelor's degree	Preschool	10
T6	Bachelor's degree	Preschool	10
T7	Bachelor's degree	Preschool	10
T8	Bachelor's degree	Preschool	19
T9	Bachelor's degree	Preschool	13
T10	Bachelor's degree	Preschool	20
T11	Bachelor's degree	Preschool	10
T12	Bachelor's degree	Preschool classroom within secondary school	2
T13	Bachelor's degree	Preschool	5
T14	Bachelor's degree	Preschool classroom within primary school	1
T15	Bachelor's degree	Preschool classroom within primary school	1

Table 1 shows that all of the 15 preschool teachers who participated in the study were female. All of the teachers work in public schools While one of the teachers has an associate degree, the remaining 14 teachers have a bachelor's degree. It was determined that 5 of the teachers had 6-10 years of professional experience, 4 had 0-5 years of professional experience, 3 had 16-20 years of professional experience, and 2 had 11-15 years of professional experience. One teacher had more than

21 years of professional experience. The demographic information of the children in the study group is given in Table 2.

Table 2

Demographic Characteristics of the Children in The Study Group

Gender	n	%	Age Group	n	%
Female	28	58	4 years	8	17
Male	20	42	5 years	40	83
Total	48	100	Total	48	100

While determining the children to be included in the study group, it was taken as a basis that the parents gave their consent for the study and that the children volunteered. Table 2 shows that 28 of the 48 children in the study group were girls and 20 were boys. In addition, 8 of the children were in the four-year age group and 40 were in the five-year age group.

Data Gathering Tools

In the study, demographic information of teachers and children were collected with the "Teacher Information Form" and "Child Information Form" developed by the researchers. The teacher information form includes items related to the teacher's gender, educational level, type of institution worked at, and length of professional experience. In the child information form, items related to the child's gender and the age group of the child attending the preschool education institution were included.

"Teacher Interview Form" and "Child Interview Form" were the other data collection tools used in the study. The questions of the Teacher Interview Form and the Child Interview Form were primarily prepared by the researchers. It was then sent to 5 faculty members who are experts in the field of pre-school education to get their opinions about validity and reliability of forms. The questions were finalised in line with their feedback. In the teacher interview form, there are four open-ended questions aimed at revealing the science activities that teachers implement, the materials they use in science activities, their thoughts about their competencies in planning and implementing science activities, and their views on what kind of science activities today's children need. During the interview, additional questions were asked to elaborate the teachers' answers if needed. In the child interview form, there was one open-ended question about what children were curious about in science. In cases where the question was not understood by the children, the question was rephrased and they were asked what they wanted to learn about science.

Data Collection Process

After obtaining the necessary permissions, semi-structured interviews were conducted with teachers and children in accordance with the research design. The interviews with the teachers were conducted face-to-face in a suitable room in the institution where they work. Before the interviews, the teachers' written consent was obtained that they participated in the research and that the interviews would be audio recorded. The interviews with teachers lasted an average of 20 minutes. For the interviews with the children, the researcher first went to the institution where the implementation would take place and explained the purpose of the research to the administrators and teachers. After obtaining the necessary permissions and parental approvals, one-on-one interviews were conducted with the children in the classroom environment where the teacher was present. The children were asked what they were curious about science and what they wanted to learn, and the answers given by

the children were recorded in writing by the researcher. Interviews with a total of 48 children were completed in one day.

Data Analysis

Merriam (2002) stated that in basic qualitative research design, an inductive analysis path should be followed to identify repeated patterns or common themes in the data. Inductive content analysis was conducted by using MAXQDA 2020 Plus software programme to analyse the data. For this purpose, firstly, the audio-recorded teacher interviews were transcribed by the researcher on computer. Then, the transcribed interviews with children were also transferred to the computer. The data obtained from all interviews were coded by two preschool education experts. During coding, the codes and data were constantly compared in order to ensure that the analysis process proceeded without errors. Sub-themes and themes were then created by the researchers from the grouped codes. While determining themes and sub-themes, interview questions and published research (Akcanca et al., 2017; Zembat et al., 2020) were utilised. While transforming the data into findings, one-to-one quotes obtained from the participants were also included. In order to ensure the confidentiality of the participants, teachers were given the codes T1, T2, T3, ..., T15 and children were given the codes C1, C2, ..., C48.

In order to ensure the validity of the study, in-depth description, expert review and the use of qualitative analysis software were used (Creswell, 2014; Glesne, 2013; Merriam, 2013; Whittemore et al., 2001). In the study, in-depth description strategy was realised by describing the study group, data collection tools, data collection process, data analysis and presentation of the findings in detail and clearly. In addition, while conveying the findings to the reader, one-to-one quotes obtained from the participants were included to help readers enter the research context. For expert review, after the interview questions were prepared by the researchers, the interview questions were finalised by taking the opinions of five experts working in the field of preschool education. Finally, in order to strengthen the validity, qualitative data analysis software was used as suggested by Whittemore et al. (2001) and analysed with MAXQDA 2020 Plus qualitative analysis program.

For the reliability of the study, the strategies suggested by Gibbs (2007) were followed. At each stage of data analysis, the analysis was carefully checked, care was taken to ensure that the meaning of the codes did not change, and the percentage of inter-coder agreement was calculated. Miles and Huberman's (1994) formula for inter-coder agreement, which is used in content analysis and increases reliability, was used and it was determined that the inter-coder reliability coefficient was 0.96.

Findings

In this section, the findings obtained from the research are presented in parallel with the research questions. Table 3 presents the findings related to the science activities carried out by preschool teachers.

Table 3

Science Activities Carried Out by Preschool Teachers

Theme	Subtheme	Code	f
Science activities	For skills	For the senses	6
		For observation skills	5
	For activity type	Observation and investigation	9
		Experiment	6
		Outdoor activity	4
		Field trip	3
		Grouping studies	3
		Science workshops with family participation	2
		Cause and effect studies	1
	For organising the environment	Use of the science centre	6
		Use of the sensory centre	5

Table 3 presents the findings related to the science activities carried out by preschool teachers. In the sub-theme "For skills", teachers stated that they carried out activities to support the senses (f=6) and observation skills (f=5); in the sub-theme "For activity type", they stated that they carried out activities such as observations and investigations (f=9), experiments (f=6) and outdoor activities. When the sub-theme "For organising the environment " is examined, it is seen that teachers stated that they used the science centre (f=6) and sensory centre (f=5) as science activities (open ended science learning experiences).

In the sub-theme "For skills", the teacher coded T2 stated that she did activities to develop senses and observation skills, and in the sub-theme "For activity type", she stated that she carried out observation, examination and grouping activities with the following sentences:

> *I think observation skill is very important. In outdoor activities, we definitely observe the seasons, for example, we take a certain tree. The reason why we take a certain tree in particular is so that children can see it and observe the continuity of the change that takes place every season. We have a nature notebook where we record the changes in nature that they observe, including the date and the weather in every nature study. What differences did we see today, what changes were there in nature? Sometimes we examine the materials we collect on a large cloth, especially a dark cloth. For example, we study leaves, they group leaves according to their characteristics... Touching the water makes them feel great, I use water a lot for the development of their senses.*

In the sub-theme of "For activity type", the teacher coded T8 stated that she conducted experiments and science workshops with family participation as follows:

> *I care about experiments in my class. For example, while younger age groups are interested in experiments such as mixing and foaming, at the age of five, children want to see a reality, a result, they are focused on the result. Last semester, we planned a science workshop with family participation. We sat down with the parents, divided everyone into groups of four, and created science workshops together. It was also a very nice interaction tool. It was very effective and satisfying for children... These are activities that make children's learning more enjoyable and more permanent...*

The last sub-theme in Table 3 is the sub-theme of "For organising the environment". The teacher coded T6, who stated that she used the science and sensory centre as a science activity, expressed her thoughts and experiences as follows:

> *We have a very well-functioning centre system in our school. We can do activities in the science centre, they can experience various materials in the sensory centre. I want them to discover the centres themselves. Otherwise, science activities are not something that can be done by telling them...*

The findings regarding the materials used by preschool teachers in science activities are presented in Table 4.

Table 4

Materials Used by Preschool Teachers in Science Activities

Theme	Subtheme	Codes	f
Materials	Natural objects and living things	Trees, leaves, flowering and non-flowering plants, seeds, water, salt, soil, ants, worms	9
	Foods	Nuts, pasta, fruits, black pepper, legumes	4
	Artificial objects	Balloons, magnets, toys and objects in the classroom	4
	Malleable and manipulative materials	Clay, sand	2

Table 4 shows that the materials used by the teachers participating in the study were included in the sub-themes of "Natural objects and living things" (f=9), "Foods" (f=4), "Artificial objects" (f=4) and "Malleable and manipulative materials" (f=2). Based on the findings, it can be stated that teachers used natural objects and living things such as plants. Use scientific terms properly the most in science activities (f=8), and malleable and manipulative materials such as clay and kinetic sand the least.

In the sub-theme of "Natural objects and living things", the teacher coded T13 stated that she used plants, soil, seeds and water in science activities as follows:

> *The materials I use are usually natural. For example, observation of the roots of plants, studies on soil, planting acorns, observations on ice, water, steam formation. Always from nature...*

The response of the teacher coded T10 regarding the materials he used in the sub-themes of "Natural objects and living things" and "Foods" is given in the following sentence:

> *I usually use materials that will enable them to discover by experimenting. We use water a lot, we can use dried legumes... We use the materials in the garden again. For example, we put some soil from the garden in a container and examine it, ants, worms, whatever is in that soil...*

In the sub-themes of "Foods" and "Artificial objects", the teacher coded T1, who stated that she used food items such as tangerines, black pepper and balloons as an artificial material, expressed her thoughts on the subject as follows:

> *For example, we do the experiment of which one floats and which one sinks, we throw peeled tangerines and unpeeled tangerines into the water. We have an experiment in which we use black pepper to teach microbes. We have activities where we use balloons.*

Table 5 presents the findings regarding preschool teachers' competencies in planning and implementing science activities.

Table 5

Teachers' Views on Their Competencies in Planning and Implementing Science Activities

Themes	Subthemes	Code	f
Teacher competence	Sufficient	Implement plans effectively	1
	Partially sufficient	Continue to develop and learn	5
		Collaborating with and receiving support from colleagues	2
	Not sufficient	Inability to conduct experiments	3
		Having problems with physical conditions (Problems in obtaining materials, limited nature opportunities)	2
		Not interested in science	1
		Large class size	1

It is a remarkable finding of the study that only 1 teacher out of 15 teachers who participated in the research stated that she considered herself sufficient in planning and implementing science activities. It is seen that 7 of the teachers consider themselves partially competent and 7 teachers do not consider themselves competent. Five of the teachers stated that they were partially competent because they continued to develop and learn, and two of them conducted science activities with the support of their colleagues. The teachers who stated that they were not adequate explained this situation with reasons such as being inadequate in conducting experiments (f=3), having problems with physical conditions due to limited material supply and nature facilities (f=2), science being out of their field of interest (f=1) and overcrowded class size (f=1).

The teacher coded T3, who considered herself sufficient in science activities, expressed her views as follows:

I feel good and sufficient in science activities because I implement the plans effectively.

In the sub-theme of "Partially sufficient", the teacher coded T6 explained that she received support in planning and implementing science activities in cooperation with her colleagues with the following sentences:

We can never be complete, there is no end to learning, but I do my best, I think about it, at least I ask what I can do. When we come together with friends and do this, it opens up ideas, more different opinions can emerge...

The teacher coded T5, who stated that she was not sufficient in planning and implementing science activities, expressed her thoughts as follows:

One point where I see myself lacking is science activities. I cannot say that I am sufficient. I am not someone who applies experiments a lot. Experiment is a very good thing in terms of enabling children to learn the cause and effect relationship. Unfortunately, I don't do experiments much...

The findings regarding the views of preschool teachers on what kind of science activities today's children need are presented in Table 6.

Table 6

Teachers' Views on What Kind of Science Activities Children Need

Theme	Subtheme	Code	f
Science activities that children need	Activity type	Activities for the child to experience first-hand	5
		Outdoor and nature activities	4
		Activities suitable for age, developmental level and interests	4
		Unstructured activities	2
		Field trips	1
		Experiments with fast results	1
	Contribution to the development area	Sensory development	2
		Cognitive development (Observation skill, questioning skill	2
	Material and environment	Sensory materials	2
		Sensory centre	1

When the table is examined, it is seen that in the sub-theme of "Activity type", teachers stated that children need activities that they can experience on their own (f=5), activities that take place outdoors and in nature (f=4), activities that are appropriate for their age, development and interests (f=4), unstructured activities (f=2), field trips (f=1) and experiments with quick results (f=1). In the sub-theme "Contribution to the development area", teachers stated that they needed activities that would improve children's sensory development (f=2) and cognitive development (f=2). In the last theme, "Material and environment", teachers stated that children need to experience sensory materials (f=2) and sensory centre (f=1).

In the sub-theme of "Activity type", the teacher coded T12 stated that children need activities that take place in nature as follows:

They need activities to get to know nature because they spend very little time in nature.

In the sub-theme of "Activity type", teacher coded T7 explained that children need activities and field trips appropriate to their age, developmental level and interests with the following statements:

In the era of technology, of course, children always need more and more, and children adapt to this very quickly. For example, we went to the science centre, Ali Kuşçu Science Centre. There were more sky and space-themed things there. We saw that the children there had a good command of this and were very interested in it. Field trips are very useful in really high quality places, you know, places that are suitable for children, where it is explained at the level of children. Afterwards, complementary activities can be done in the classroom...

The opinions of the teacher coded T9 under the sub-themes of "Activity type" and "Contribution to the development area" are given below:

Children need activities that develop their questioning skills. You know, like why this happened. Children are very unresponsive to experiments that are too far above their age, they cannot question. I can say that they need science activities that are appropriate for their age level and most importantly, planned in a way that they can do it themselves.

In the sub-theme of "Contribution to the development area", the teacher coded T4 stated that children need support for their sensory development and cognitive development (observation skills) with the following sentences:

There is a situation like this, observation skills need to develop right now. Let me put it this way, one day I didn't give any instructions when we went out to the garden, I came back and asked what sound

did you hear in the garden and they all stayed. There is no answer from any of them, there are those who say it by heart, I heard a bird, I heard a cricket. What is a cricket doing in the middle of winter? I analysed this situation. I said, 'Next time when you go out, please listen to the sounds, I'll ask you when you enter the classroom, let's see who heard which sounds.' One of them finally realised that there was a song playing from a car, we talked about what the sounds in the environment are and what they are not... They don't have observation skills right now. In other words, they don't have the ability to use the five senses. Children come home, get in the car, get out of the car, walk to the school gate, enter the school, leave the school gate, get in the car and go home. So there is no experience.

In the sub-theme of "Material and environment", the teacher coded T2 explained that today's children need sensory materials and sensory centres as follows:

I think that since the sensory centre is a centre with a lot of learning, which they really like, I think the area of that centre can be expanded even more. And we have plastic containers that we use to fill with water, but I think we can expand it with a large table and a covered area where they can play with sand more easily. I think we can actually work a little bit towards this, the area can be kept wider. Because it is a centre where children participate with great pleasure, after all, it is a part of our lives. Even when grating a piece of soap, they enjoy it, we don't spare anything. Of course, our parents are a little worried about this, but we always say that they will learn by experimenting. Of course, small accidents will always happen in life, even when we grow up, not only when we are young. We don't want to cause any harm, but we think we should give them the opportunity to learn... As I said, the new generation is deprived of many natural things, closed environments, concrete buildings and schools. And school has become an environment where they can develop their senses...

The findings of the research on what children want to learn about science and what they are curious about are shown in Table 7.

Table 7

Topics That Children Want to Learn About Science

Theme	Code	f
Science subjects	Meeting scientists	10
	Learning how tools and equipment are made/work (how magnets work, how balls are inflated, how napkins are made, how telescopes work, etc.)	8
	Conducting experiments	7
	Conducting research and investigations	5
	Getting to know space (astronauts, stars, etc.)	4
	Learning to do science	3
	Recognising living things (dinosaurs, forest plants, etc.)	3
	Getting to know nature and natural phenomena (clouds, doing research on nature, etc.)	3
	Looking at books about science	2
	Going to the past	1
	Learning why fingerprints are different	1
	Learning how planes and birds fly	1

It is seen that children mostly want to get to know scientists (f=10), learn how tools and equipment are made/work (f=8) and conduct experiments (f=7). In addition, children stated that they wanted to conduct research and investigations (f=5), get to know space (f=4), get to know living things (f=3), learn how to do science (n=3), get to know nature and natural phenomena (f=3) and look at

books about science (f=2). Other responses included learning how to go back in time, why fingerprints are different, and how to fly.

Examples of children's answers about what they were curious about or what they wanted to learn about science are given below in the form of one-to-one quotations:

I would like to learn about events related to nature. (C41, age 4, female)
I wonder about scientists, how they are. (C43, 4 years old, male)
How did dinosaurs become extinct? (C44, age 4, female)
How magnetic things attract. (C47, age 4, male)
I would like to learn experiments. (C8, 5 years old, female)
For example, I am curious about space, to learn how I can go there. (C22, 5 years old, male)
To learn how clouds are formed. (C30, 5 years old, female)
I wonder how the balls are inflated. (C37, 5 years old male)

Discussion

In the study, it was found that the science activities carried out by preschool teachers took place under the sub-themes of "For skills", "For activity type", and "For organising the environment". Teachers stated that they conducted activities that supported senses and observation skills under the sub-theme of "For skills"; observations and investigations, experiments, outdoor activities, field trips, grouping activities, science workshops with family participation and cause and effect studies under the sub-theme of "For activity type". In the sub-theme "For organising the environment", it was determined that teachers used the science centre and sensory centre as science activities (Child-initiated open-ended science learning experiences). Similar to the results of this study, in other studies, preschool teachers stated that they mostly conducted experiments, observations and nature study activities (Akcanca et al., 2017; Polat et al., 2021; Simsar et al., 2017). The results of the studies and the results of this study show that observation, investigation and experimentation activities are frequently preferred by teachers within the scope of science studies in preschool period. Observation, investigation and experiment studies are very important in terms of the fact that children use all their senses, actively participate by doing and experiencing, communicate, generate ideas by asking questions, establish cause and effect relationships, facilitate the understanding of scientific concepts and support the sense of discovery (Uyanık Balat & Önkol, 2017). In this context, this result of the study can be considered positive in terms of preschool teachers providing qualified science learning experiences appropriate to children's ages and developments. In this study, activities that children can experiment completely by themselves were ranked first by the teachers. A quality science education at preschool level is based on child-centred activities in which children are actively involved and implement (Uyanık Balat & Arslan Çiftçi, 2019). The fact that the teachers in the study carried out sensory activities, observation activities, investigations, experiments, and used the science centre and sensory centre, which enabled children to gain first-hand experience, suggests that they made children active in science studies.

Worth (2010) stated that the quality of the activities planned by the teacher affects children's learning experiences related to science. Materials are also an important component of activities and therefore, it can be stated that the materials used in science activities can also affect the learning process. In support of this view, Nayfeld et al. (2011) stated that children should interact with science content and materials appropriate to their developmental level in order to explore the world around them and develop their scientific reasoning skills during science activities. In this study, it was found that the materials used by preschool teachers in science activities were mostly natural objects and living things such as trees, leaves, seeds, ants, followed by foods such as nuts, fruits and pasta, and artificial objects such as balloons, magnets and toys in the classroom. Malleable and manipulative materials such as kinetic sand and clay were found to be less preferred by teachers. In another study, similar to the research result, teachers stated that they mostly used plants, magnifying glass, stones, soil, sand and objects in nature in science activities (Karaman Eflatun & Kuloğlu, 2021). In preschool

learning environments, open-ended materials should be presented to children, materials should be kept up-to-date and accessible to children with different experiences and backgrounds (Tu, 2006). From this point of view, the fact that the teachers participating in this study included open-ended natural and non-natural materials can be considered as a positive finding. In addition, children should benefit from tools such as magnifying glasses, microscopes, magnets, compasses and binoculars in preschool science studies (Ministry of National Education, 2013). These tools can contribute to the development of children's science process skills such as observation. It is noteworthy that the number of teachers who stated that they use these tools is low. In another study conducted on the subject, unlike the results of the research, it was found that teachers most frequently used materials such as the Earth sphere, human body, tooth model, magnifying glass and scales, while they used natural materials such as seeds, soil, leaves, stones and water very rarely. In the same study, most of the teachers stated that the classroom environments in which they carried out science and nature studies were inadequate in terms of materials (Simsar et al., 2017). Considering the results of the research and the results of related studies, it can be said that including more natural materials in the implementation of science activities can provide children with more experience with open-ended materials. Tools such as scales, magnifying glasses, binoculars and magnets should be used together with open-ended natural materials to support the scientific, qualified and effective progress of the learning process.

Teachers have an important role in ensuring effective science education in the preschool period (Ormancı & Çepni, 2019). Teachers' access to resources, field knowledge and self-efficacy in science are important variables that affect the time they allocate to science education in preschool (Kallery & Psillos, 2001; Saçkes, 2014). It is a striking finding of the study that only one teacher out of the 15 teachers who participated in the study stated that she considered herself competent in planning and implementing science activities. It was determined that half of the remaining teachers considered themselves partially competent and half of them did not consider themselves competent. Teachers who considered themselves partially competent stated that they continued to learn, that there was no end to learning and research, and that they improved themselves by cooperating with their colleagues. Teachers who stated that they were not adequately competent in science activities explained this situation with reasons such as being inadequate in conducting experiments, having problems with physical conditions due to the limited supply of materials and nature, science being out of their field of interest and the large class size. In the study conducted by Babaroğlu and Okur Metwalley (2018) on the subject, it was concluded that 55.5% of preschool teachers considered themselves sufficient in science education, while 44.5% considered themselves insufficient. Teachers who considered themselves inadequate attributed this situation to reasons such as lack of knowledge, deficiencies and inadequacies in practice, difficulties in providing materials, and problems in planning activities. The results of this study and related studies show that class size, lack of equipment and materials, inadequate classroom environment and garden are among the most frequently mentioned problems in preschool science education (Akcanca et al., 2017; Aslan et al., 2015; Çınar, 2013; Karaman Eflatun & Kuloğlu, 2021; Karamustafaoğlu & Kandaz, 2006).

In the study, preschool teachers stated that children need science activities that they can experience on their own, that take place outdoors and in nature, that are appropriate for their age, development and interests, that are unstructured, that will develop their senses, observation and questioning skills, and that they need to experience sensory materials and sensory centres. Teachers also stated that children preferred field trips and experiments with quick results. It is seen that these views coincide with the activities that teachers stated that they carried out, such as activities to develop senses and observation skills, observations and investigations, experiments, outdoor activities and field trips. Based on the teachers' statements, it can be said that they take children's needs into consideration when planning science activities. It is noteworthy that the teachers who participated in the study emphasised children's need for their own learning experiences, nature, observation and questioning. Teachers stated that children spend very little time in nature, do not mobilise their questioning skills, do not use their observation skills effectively enough, and do not have

opportunities to use their five senses. Similarly, Sağlam and Aral (2015) concluded that preschool teachers believe in the effectiveness of science activities in which children are actively involved, methods such as trial-and-error, learning by doing and experimentation, and processes that children directly observe. In the study conducted by Ültay et al. (2018), preschool teachers emphasised that for an effective science education, children should be made more active, the importance of being intertwined with nature, and the variety of materials and materials should be increased. The findings of both this study and other studies reveal that preschool children especially need science activities that they experience completely on their own, learning experiences that take place outdoors and in nature, and activities that develop their observation and questioning skills and support their sensory development.

The interests that children have in the preschool period can affect academic achievement and become permanent interests in later life (Alexander et al., 2012; Leibham et al., 2013; Neitzel et al., 2019). In addition, research shows that interest is related to motivation and learning (Renninger et al., 2015). Therefore, it can be stated that in science activities prepared for preschool children, it is critical to plan learning processes based on their interests so that children can be motivated to apply scientific processes and learning can take place. Some studies indicate that the use of ready-made plans is very common among preschool teachers in planning science activities (Sağlam & Aral, 2015). In the study conducted by Alabay and Yağan Güder (2015), it was concluded that a large proportion of the science activities in the ready-made plans did not meet criteria such as being child-centred, play-based, discovery learning, family involvement, use of learning centres and use of daily life experiences. When planning science activities, teachers should prepare their activities by determining the concepts to be addressed in line with children's developmental needs and interests, rather than preferring ready-made plans. Approximately one third of the teachers participating in the study stated that they need activities that are appropriate for children's age, developmental level and interests. As a result of the research, it was found that children wanted to get to know scientists, learn how tools and equipment are made/work, conduct experiments, conduct research and investigations, get to know space and living things, and get to know nature and natural phenomena. Supporting the research result, in the study conducted by Torres-Porras and Alcantara-Manzanares (2022), it was found that children ask complex questions that require explanations about the functional, evolutionary or process-related features of scientific phenomena. In another study, similar to the results of this study, it was found that children were most curious about space, astronauts, clouds, animal species, plant growth and how machines work (Gözün Kahraman et al., 2015). When planning science activities, children's interests should be identified. In this study, it was concluded that children most wanted to get to know scientists. However, none of the teachers mentioned that they had conducted studies on scientists or that children needed these activities. It appears that teachers are aware of children's skills that need to be developed, but they do not identify the topics that children are interested in well enough. Based on this point, it can be stated that teachers should identify children's interests and learning needs by using multiple data sources. For this purpose, teachers can utilise assessment methods such as observations and anecdotes, and they can also have conversations with children about what they want to learn about science. Science activities can be based on the lives of scientists and include how the tools and equipment we use in our daily lives work. Including scientists in science activities in preschool has positive effects on children's learning and motivation towards science (Yıldız Taşdemir, 2021). Children's attitudes and thoughts about science and scientists begin to form in the preschool period. These perceptions acquired at an early age can have an impact on children's solutions to problems and play a role in shaping their thoughts and attitudes towards scientific actions at a later age (Ayvacı et al., 2016). In addition, introducing scientists to children dispels common myths, helps children perceive that thinking and research are the basis of science and that science is a method for understanding and exploring the world and benefiting humanity (Altun & Yıldız Demirtaş, 2013; Hickey & Robson, 2013).

Conclusion and Implications

Although the use of natural materials by the preschool teachers participating in the study is positive, it is noteworthy that the number of teachers who stated that they use tools such as magnifying glasses, scales, binoculars is quite low. Teachers should strengthen the scientific process in their activities by including more open-ended activities in which natural materials (stones, soil, leaves, branches, etc.) and scientific tools (magnifying glass, scales, magnets, etc.) are used together. In this context, activities such as examining the differences of various stones collected from nature with magnifying glasses and weighing various natural materials with scales and discussing which of them is heavier can be planned in this way they can use both natural materials and scientific tools together.
In the study, teachers stated that they considered themselves inadequate in science activities due to reasons such as being inadequate in conducting experiments, having problems with physical conditions due to the limited supply of materials and nature, science being out of their field of interest, and overcrowded class sizes. Workshops on experiments can be organised for teachers through university collaborations. Through these workshops, teachers' perspectives on experiments and other science activities that can be planned with accessible materials can be expanded. In crowded preschool classrooms, science activities can be implemented in small groups, more than one sensory centre and science centre can be established and children can spend time in these centres in stations.

As a result of the research, it was concluded that children wanted to get to know scientists, learn how tools and equipment are made/work, conduct experiments, conduct research and investigations, get to know space and living things, and get to know nature and natural phenomena. Using illustrated children's books introducing local and foreign scientists in science activities can help children recognise scientists and their work. Movies and animations about scientists that are appropriate for children's age and developmental level can be watched. Field trips to planetariums can be organized to support children to learn what they are curious about space. In addition, open source planetarium software can be used to provide learning experiences about space in the classroom environment. Animals and plants can be observed with the naked eye or with tools such as binoculars and magnifying glasses. Projects can be organized about living things that children especially want to get to know.

The findings obtained in this study regarding the topics that children want to learn about science are specific to the research group. Each child may be interested in different topics related to science. Therefore, before planning science activities, teachers should determine what children want to learn about science by observing children both during science activities and other activities, as well as during different time periods in the daily flow such as free time, garden time and mealtime. In addition to revealing children's interest in science by observing them, teachers can shape the learning process according to children's interests by determining what they want to learn about science at the time of starting the day or evaluating the day.

References

Akcanca, N., Aktemur Gürler, S., & Alkan, H. (2017). Okul öncesi öğretmenlerinin fen eğitimi uygulamalarına yönelik görüşlerinin belirlenmesi. *Caucasian Journal of Science*, *4*(1), 1-19.

Alabay, E., & Yağan Güder, S. (2015). Examining of science activities in terms of basic characteristics of preschool education program. *International Journal of Education Sciences, 2*(4), 1-21.

Alexander, J. M., Johnson, K. E., & Kelley, K. (2012). Longitudinal analysis of the relations between opportunities to learn about science and the development of interests related to science. *Science Education, 96*(5), 763–786. https://doi.org/10.1002/sce.21018

Altun, E., & Yıldız Demirtaş, V. (2013). Effectiveness of Science and Scientists Teaching Program prepared for children age 6. *Mehmet Akif Ersoy University Journal of Education Faculty, 27*, 67-97.

Aslan, O., Şenel Zor, T., & Tamkavas Cicim, E. (2015). Determining views of early childhood teachers on science education and relevant in-service training needs. *The Journal of International Social Research, 8*(40), 519-530.

Ayvacı, H. Ş., Atik, A., & Ürey, M. (2016). The perceptions of preschool children on the concept of scientist. *Bartın University Journal of Faculty of Education, 5*(3), 669-689. https://doi.org/10.14686/buefad.v5i3.5000193186

Babaroğlu, A., & Okur Metwalley, E. (2018). Opinions of preschool teachers on science education in early childhood. *Hitit University Journal of Social Sciences Institute*, *11*(1), 125-148. https://doi.org/10.17218/hititsosbil.389149

Bahar, M., & Aksüt, P. (2020). Investigation on the effects of activity-based science teaching practices in the acquisition of problem solving skills for 5-6-year-old pre-school children. *Journal of Turkish Science Education, 17*(1), 22-39. https://doi.org/10.36681/tused.2020.11

Berk, L. E. (2022). *Infants and children: Prenatal through middle childhood* (9th edition). Sage Publications.

Brenneman, K. (2011). Assessment for preschool science learning and learning environments. *Early Childhood Research & Practice*, *13*(1), 1-9. https://files.eric.ed.gov/fulltext/EJ931225.pdf

Conezio, K., & French, L. A. (2002). Science in the preschool classroom: Capitalizing on children's fascination with the everyday world to foster language and literacy development. *Young Children, 57*(5), 12-18.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative and mixed methods approaches* (4th edition). Sage Publications.

Çınar, S. (2013). Determining the activities used by pre-school teachers in science and nature uses. *Journal of Research in Education and Teaching, 2*(1), 363-371.

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97-140. https://doi.org/10.1080/10888691.2018.1537791

Dejonckheere, P. J., Nele, D. E., Van de Keere, K., & Vervaet, S. (2016). Exploring the classroom: Teaching science in early childhood. *European Journal of Educational Research, 5*(3), 149-164. https://doi.org/10.12973/eu-jer.5.3.149

Eliason, C., & Jenkins, L. (2008). *A practical guide to early childhood curriculum* (9th edition). Pearson.

Eshach, H., & Fried, M. N. (2005). Should science be taught in early childhood? *Journal of Science Education and Technology, 14*(3), 315-336. https://doi.org/10.1007/s10956-005-7198-9

Gerde, H. K., Pierce, S. J., Lee, K., & Van Egeren, L. A. (2018). Early childhood educators' self-efficacy in science, math, and literacy instruction and science practice in the classroom. *Early Education and Development*, *29*(1), 70-90. https://doi.org/10.1080/10409289.2017.1360127

Gibbs, G. R. (2007). *Analyzing qualitative data.* Sage Publications.

Glesne, C. (2013). *Becoming qualitative researchers: An introduction* (4th edition). Pearson.

Gölcük, A. (2017). *The effect of science education that is supported by scientific stories on students' creativity and affective properties* [Unpublished master's thesis]. Hacettepe University. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=vYksFGf-UvW068-hIdLi-A&no=1ng7pFcgd6-s8SzCwsiw2A

Gözün Kahraman, Ö., Ceylan, Ş., & Ülker, P. (2015). The feeling creating science: the knowledge and curiosity of children with regard to science and nature. *The Journal of Turkish Social Research, 19*(1), 207-230.

Greenfield, D. B., Jirout, J., Dominguez, X., Greenberg, A., Maier, M., & Fuccillo, J. (2009). Science in the preschool classroom: A classroom programmatic research agenda to improve science readiness. *Early Education and Development, 20*(2), 238-264. https://doi.org/10.1080/10409280802595441

Gündüz, A., & Akduman, G. G. (2015). A research on the practices of preschool teachers about gaining problem solving ability in science activities. *International Journal of Education Sciences, 2*(3), 102-114.

Hamel, E. E. (2021). Science starts early: A literature review examining the influence of early childhood teachers' perceptions of gender on teaching practices. *Journal of Childhood, Education & Society*, *2*(3), 267-286. https://doi.org/10.37291/2717638X.202123118

Hickey, I., & Robson, D. (2013). *The Leonardo Effect: Motivating children to achieve through interdisciplinary learning.* Routledge.

Johnson, R. B., & Christensen, L. B. (2014). *Educational research: Quantitative, qualitative, and mixed approaches* (5th edition). Sage Publications.

Kallery, M., & Psillos, D. (2001). Pre-school teachers' content knowledge in science: Their understanding of elementary science concepts and of issues raised by children's questions. *International Journal of Early Years Education, 9*(3), 165-179. https://doi.org/10.1080/09669760120086929

Karaer, H., & Köstereliоğlu, M. (2005). The determination of the methods used in teaching the science concepts by the preschool teachers serving in Amasya and Sinop. *Kastamonu Education Journal, 13*(2), 447-454.

Karaman Eflatun, H., & Kuloğlu, A. (2021). The pre-school teachers' attitudes towards science teaching and their views on science and nature activities. *Inonu University Journal of the Faculty of Education, 22*(3), 2078-2095. https://doi.org/10.17679/inuefd.1000517

Karamustafaoğlu, S., & Kandaz, U. (2006). Using teaching methods in the science activities and difficulties encountered in preschool education. *Gazi University Journal of Gazi Educational Faculty, 26*(1), 65-81.

Karamüftüoğlu, İ. O. (2012). *The effect of science education to the students at the social services and child protection agency (SSCPA) on their attitudes towards science, self-efficacy and motivation* [Unpublished master's thesis]. Kırşehir Ahi Evran University. https://acikbilim.yok.gov.tr/handle/20.500.12812/588212

Leibham, M. B., Alexander, J. M., & Johnson, K. E. (2013). Science interests in preschool boys and girls: Relations to later self-concept and science achievement. *Science Education, 97*(4), 574-593. https://doi.org/10.1002/sce.21066

Lind, K. (1998). Science in early childhood: Developing and acquiring fundamental concepts and skills. *Early Childhood Science, Mathematics and Technology Education, February,* 6-8. https://files.eric.ed.gov/fulltext/ED418777.pdf

Merriam, S. B. (2002). Introduction to qualitative research. In S. B. Merriam (Ed.), *Qualitative research in practice: Examples for discussion and analysis* (pp. 3-27). Jossey Bass.

Merriam, S. B. (2013). *Qualitative research: A guide to design and implementation*. John Wiley & Sons Inc.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analyses: An expanded sourcebook.* Sage Publications.

Ministry of National Education (2013). *Preschool Education Program*. Republic of Türkiye Ministry of National Education.

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher, 45*(1), 18-35. https://doi.org/10.3102/0013189X16633182

Nayfeld, I., Brenneman, K., & Gelman, R. (2011). Science in the classroom: Finding a balance between autonomous exploration and teacher-led instruction in preschool settings. *Early Education & Development*, *22*(6), 970-988. https://doi.org/10.1080/10409289.2010.507496

Neitzel, C., Alexander, J., & Johnson, K. (2017). The influence of early interest orientations and time on kindergartners' academic monitoring and information-seeking behaviors. *Journal of Early Childhood Research*, *15*(4), 389-409. https://doi.org/10.1177/1476718X15616832

Neitzel, C. L., Alexander, J. M., & Johnson, K. E. (2019). The emergence of children's interest orientations during early childhood: When predisposition meets opportunity. *Learning, Culture and Social Interaction*, *23*, 100271. https://doi.org/10.1016/j.lcsi.2019.01.004

Ormancı, Ü., & Çepni, S. (2019). Thematic analysis of conducted studies regarding preschool science education in Turkey. *Journal of Turkish Science Education, 16*(3), 415-.439. https://doi.org/0.12973/tused.10291a

Öztürk, M. (2016). *The effect of inquiry based science education program on 60-72 months old children's science process skills concept and language development* [Unpublished doctoral dissertation]. Hacettepe University. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=wcupKTUhKg3VvkBo-9B5TQ&no=MNrQWI-UHAZSVPWEwXX9dw

Park, M. H., Dimitrov, D. M., Patterson, L. G., & Park, D. Y. (2017). Early childhood teachers' beliefs about readiness for teaching science, technology, engineering, and mathematics. *Journal of Early Childhood Research, 15*(3), 275-291. https://doi.org/10.1177/1476718X15614040

Peterson, S. M., & French, L. (2008). Supporting young children's explanations through inquiry science in preschool. *Early Childhood Research Quarterly, 23,* 395-408. https://doi.org/10.1016/j.ecresq.2008.01.003

Polat, S., Zengin, R., & Elmalı, F. (2021). Attitude and practice analysis of preschool teachers for science practice in classroom. *Turkish Journal of Educational Studies*, *8*(1), 47-67. https://doi.org/10.33907/turkjes.771896

Renninger, A., Nieswandt, M., & Hidi, S. (2015). *Interest in mathematics and science learning*. American Educational Research Association.

Saçkes, M. (2014). How often do early childhood teachers teach science concepts? Determinants of the frequency of science teaching in kindergarten. *European Early Childhood Education Research Journal, 22*(2), 169-184. https://doi.org/10.1080/1350293X.2012.704305

Sağlam, M., & Aral, N. (2015). The study of determine pre-school teachers' ideas about science education. *Inonu University Journal of the Faculty of Education*, *16*(3), 87-102. https://doi.org/10.17679/iuefd.16308213

Simsar, A., Doğan, Y., & Yalçın, V. (2017). Examination and uses of science centers within pre-school classrooms-Kilis sample. *Kilis 7 Aralik University Journal of Social Sciences*, *7*(14), 147-164. https://doi.org/10.31834/kilissbd.354745

Tekerci, H. (2015). *The effect of sense based science education program on 60-66 month old children's science process skills* [Unpublished master's thesis]. Gazi University. https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=1MFFW_WQLkDRgT3oem3VzA&no=x2FbUdBShy87ZCH8ShpGYA

Torres-Porras, J., & Alcantara-Manzanares, J. (2022). Are pre-service teachers able to answer children's questions about the natural sciences? The characterization of questions by children and students of the early childhood education degree. *Journal of Turkish Science Education, 19*(2), 374-388. https://doi.org/10.36681/tused.2022.126

Tu, T. (2006). Preschool science environment: what is available in a preschool classroom? *Early Childhood Education Journal, 33,* 245-251. https://doi.org/10.1007/s10643-005-0049-8

Uludağ, G. (2017). *The effect of using out-of-school learning environments for science education on preschool children's science process skills* [Unpublished doctoral dissertation]. Hacettepe University. https://openaccess.hacettepe.edu.tr/xmlui/handle/11655/3982

Uyanık Balat, G., & Arslan Çiftçi, H. (2019). Erken çocukluk döneminde fen eğitimi ve önemi. In B. Akman, G. Uyanık Balat, & T. Güler Yıldız (Eds.), *Erken çocukluk döneminde fen eğitimi* (pp.1-19). Anı.

Uyanık Balat, G., & Önkol, F. L. (2017). Okul öncesi dönemde fen eğitimi öğretim yöntemleri. In B. Akman, G. Uyanık Balat, & T. Güler Yıldız (Eds.), *Erken çocukluk döneminde fen eğitimi* (pp. 99-134). Anı.

Ültay, N., Ültay, E., & Çilingir, S. K. (2018). Examination of preschool teachers' practices about science subjects. *Atatürk University Journal of Graduate School of Social Sciences*, *22*(Special Issue), 773-792.

Whittemore, R., Chase, S. K., & Mandle, C. L. (2001). *Validity in qualitative research. Qualitative health research, 11*(4), 522-537. https://doi.org/10.1177/104973201129119299

Worth, K. (2010). Science in early childhood classrooms: Content and process. *Early Childhood Research & Practice (ECRP)*, *12*(2), 1-17.

Worth, K., & Grollman, S. (2003). *Worms, shadows and whirlpools: Science in the early childhood classroom.* Heinmann Publishing.

Yıldız, S., & Tükel, A. (2018). Evaluation of preschool teachers' use of science activities. *International Social Sciences Education Journal*, *4*(1), 49-59.

Yıldız Taşdemir, C. (2021). *The reflections of 'Exploration with Art and Science Program' on children's creative thinking and scientific process skills* [Unpublished doctoral dissertation]. Hacettepe University. https://openaccess.hacettepe.edu.tr/xmlui/handle/11655/25731

Zembat, R., Tosun, D., Çalış, N. B., & Yılmaz, H. (2020). Teachers' views on the use of natural and waste materials in preschool education. *Journal of The Institute of Education Sciences Dumlupınar University*, *4*(1), 19-32.

Appendix 1

Teacher Information Form

1. Name / Surname:

2. Type of institution where you work:

3. Sex: Female ☐ Male ☐

4. Education level:

   ☐ Associate degree
   ☐ Undergraduate degree
   ☐ Master's degree
   ☐ Doctorate degree

   Last graduated program:

5. Duration of professional experience:

Child Information Form

1. Name / Surname:

2. Name of pre-school education institution:

3. Sex: Female ☐ Male ☐

4. Age group:

   ☐ 4
   ☐ 5

Teacher Interview Form

1. What kind of science activities do you implement in your classroom?
2. What kind of materials do you use in science activities?
3. Do you think you are competent in planning and implementing science activities? Could you explain why you think so?
4. What kind of science activities do you think today's children need?

Child Interview Form

What are you curious about science? / What do you want to learn about science?

Journal of Turkish Science Education, 2024, *21*(1), 102-117.
DOI no: 10.36681/tused.2024.006

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Factors affecting pro-environmental behaviour of Indonesian university students

Karunia Puji Hastuti[1], Deasy Arisanty[2], Muhammad Muhaimin[3], Parida Angriani[4], Eva Alviawati[5], Nevy Farista Aristin[6], Akhmad Munaya Rahman[7]

[1]*Universitas Lambung Mangkurat, Indonesia, karuniapuji@ulm.ac.id, Corresponding author, ORCID ID: 0000-0002-0813-7699*
[2] *Universitas Lambung Mangkurat, Indonesia, ORCID ID: 0000-0001-5937-2309*
[3] *Universitas Lambung Mangkurat, Indonesia, ORCID ID: 0000-0002-4957-6225*
[4] *Universitas Lambung Mangkurat, Indonesia, ORCID ID: 0000-0001-6847-8834*
[5] *Universitas Lambung Mangkurat, Indonesia, ORCID ID: 0009-0003-3468-3954*
[6] *Universitas Lambung Mangkurat, Indonesia, ORCID ID: 0000-0002-1551-6654*
[7] *Universitas Lambung Mangkurat, Indonesia, ORCID ID: 0000-0002-1748-9717*

ABSTRACT
Environmental damage is a negative effect of human activities. The young generation is saddled with the burden of environmental damage left by the previous generations and must take on a role as an agent of change in improving the environment. This study analyses the pro-environmental behaviour of Indonesian students, the factors affecting such behaviour, and efforts to improve those behaviours. This research uses a quantitative approach with survey methods. Four hundred seventy (470) students in the department of geography and department of geography education from various public and private universities in Indonesia have participated as research respondents. The research instrument used was a questionnaire employing the Likert scale. The research variables were environmental knowledge (X1), environmental responsibility (X2), value–belief–norm (X3), environmental education (X4), and pro-environmental behaviour (Y). Data were analysed using path analysis through partial least squares structural equation modelling (PLS-SEM) software version 3. Findings revealed high levels of pro-environmental behaviour, affected by environmental knowledge, environmental responsibility, value-belief-norm, and environmental education having convincing positive effects on forming environmental behaviour.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 18.03.2023
Accepted: 04.09.2023

KEYWORDS:
Environmental damage, pro-environmental behaviour, human activities, young generation.

To cite this article: Hastuti, K.P., Arisanty, D., Muhaimin, M., Angriani, P., Alviawati, E., Aristin, N.F., & Rahman, A.M. (2024). Factors affecting pro-environmental behaviour of Indonesian university students. *Journal of Turkish Science Education, 21*(1), 102-117. DOI: 10.36681/tused.2024.006

Introduction

Environmental damage has been the topic of many discussions by governments, researchers, and local and international organisations. Their concerns have mostly been waste, pollution, deforestation, extreme climate change, global warming, ozone depletion, the greenhouse effect, and acid rain. Human behaviour dramatically impacts the environment (Gifford & Nilsson, 2014; Steg &

Vlek, 2009). Most environmental damage happens due to human activities; the damage will affect our ecosystem now and in the future.

Awareness of environmental problems and efforts to preserve the environment are indispensable to prevent further damage to our only planetary home; this can be done through inculcating pro-environmental behaviour. Pro-environmental behaviour refers to conscious efforts to minimise the negative impact of human activities on the environment (Kollmuss & Agyeman, 2002). Pro-environmental behaviour can also be defined as actual or perceptual actions contributing to environmental conservation (Kurisu, 2015). The United Nations Commission on Sustainable Development (UN CSD) International Work Programme defines pro-environmental behaviour as the use of products and services to fulfil primary needs and bring about a better quality of life while minimising the use of natural resources and reducing hazardous materials, waste, emission, and other pollutants (Jensen, 2002; Steg & Vlek, 2009).

Education is essential in raising awareness of environmental behaviour (Zilahy & Huisingh, 2009; Zsóka et al., 2013). Previous studies suggest that people with higher educational levels tend to care more about the quality of the environment and are motivated to be directly involved in environmental preservation due to their greater awareness of damage potential (Lozano & Vallés, 2007; Ramos et al., 2015). Universities play a crucial role in directing students to develop environmental awareness in both the social and physical environments (Meyer, 2016).

University students are intelligent young people who will become the nation's next intelligentsia—they must accordingly exhibit pro-environmental behaviour. Universities in Indonesia assist students in improving their pro-environmental behaviour through a course named *Pendidikan Lingkungan Hidup* (Environmental Education). The course is also provided to students majoring in Geography Education. The course teaches students the importance of the environment, environmental issues, and tangible actions to preserve the environment. Integrating this course into the curriculum will likely increase pro-environmental behaviour. Even though the effect of knowledge has not been ascertained precisely, some studies show that learning plays a crucial role in increasing pro-environmental behaviour; it also helps individuals to have alternative perspectives through the formation of arguments to support their beliefs and behaviour (Larson et al., 2015).

This aligns with the role of universities as effective agents of change. A study by mentions that specific policies, programmes and courses on the environment can affect student conceptions related to the environment because the students have more knowledge and skills for environmental preservation (Jurdi-Hage et al., 2019; Meyer, 2016). The research question in this research is: What factors affecting the pro-environmental behaviour of Indonesian University Students. The present study aims to analyse the pro-environmental behaviour of Indonesian students, the factors affecting such behaviour, and the efforts to improve those behaviours.

Literature Review

Pro-environmental behaviour can be construed as actions that show concern for the environment in everyday life. The activities can be repetitive or just occasional. The measures deal with preserving natural resources and the environment, such as preserving specific natural resources (water, soil and air), reducing energy consumption (electricity, oil and gas), recycling (recycling paper, plastics, and others), and preserving life (animals and plants) (Erdogan & Ozsoy, 2007). Pro-environmental behaviour also refers to any actions to minimise environmental damage or to improve the environment (Scannell & Gifford, 2010). Pro-environmental behaviour includes recycling, which means reusing or remanufacturing what has been used.

Environmental Knowledge

Environmental knowledge means knowledge and awareness of environmental problems and their solutions. The most crucial thing in any individual's environmental awareness is environmental

knowledge, values, willingness to act, and actual behaviour that is influenced by several factors, including elements of intention and situation (Jensen, 2002; Latif et al., 2013).

Environmental knowledge is a process of acquiring values and concepts and developing skills. It is a necessary medium to understand and appreciate the interaction between humans and their culture and the physical environment (Latif et al., 2013; Zareie & Navimipour, 2016). Awareness of the environment is needed to recognise environmental problems and issues. Environmental knowledge can be held formally or informally by families, communities, governments and schools (P. Liu et al., 2020).

Knowledge can influence students' attitudes and behaviour toward the environment. Students with high environmental knowledge will be aware of the need to preserve their environment. According to (Otto & Pensini P, 2017) students' awareness of the environment will shape responsible environmental attitudes and behaviours. Based on the results of research by (Janmaimool & Khajohnmanee, 2019) there is a positive correlation between students' awareness of and attitudes toward the environment, so if students have a lot of knowledge about environmental issues, then they will become more aware of environmental issues that are happening and this awareness encourages them to act responsibly towards the environment. According to (Jensen, 2002), behaviour based on knowledge will last longer than behaviour that is not based on knowledge. Research conducted by (Latif et al., 2013) found that factual knowledge is a variable that correlate with pro-environmental knowledge.

Environmental Responsibility

Fettahlıoğlu & Aydoğdu, (2020) revealed that environmentally responsible behaviour seeks to preserve the environment and look for environmental problems. environmentally responsible citizenry refers to individual or group action aimed at doing the right thing to protect the environment in everyday life, such as recycling, energy conservation and reducing littering. According to (Kaiser, Ranney, et al., 1999), environmentally responsible behaviour contains several dimensions: recycling, avoiding purchases to minimise environmental impact as a form of green consumerism, being politically active in communities to influence decisions that impact the environment, and educating oneself about environmental awareness.

Singh & Gupta, (2013) argues that environmentally responsible behaviour measures a person's readiness to protect the environment actively. That’s mean environmentally responsible behaviour is an environmental protection mechanism to reduce and prevent damage to environmental resources.

Value-Belief-Norm

Young people are the key to facing environmental issues today and so on (Stern et al., 1999). A conceptual framework that can explain the relationship between environmental beliefs and pro-environmental behaviour is the Value Belief Norm (VBN) Theory. (Stern et al., 1999) explained, variables such as value orientation, New Ecological Paradigm (NEP), awareness of consequences, beliefs to be able to act, and individual norms are variables that can influence pro-environmental behaviour. VBN theory combines value, NEP, and norm-activation theories as causal chains that lead to pro-environmental behaviour. Several previous studies conducted by (Liobikienė & Poškus, 2019; Oreg & Katz-Gerro, 2006) have shown a positive relationship between VBN and pro-environmental behaviour.

Environmental Education

Environmental education is an educational programme to encourage children as learners to exhibit rational and responsible understanding, awareness, attitudes, and behaviours about the mutual influence between residents and the environment in various aspects of human life (Kollmuss & Agyeman, 2002; Zsóka et al., 2013). Environmental education seeks to change behaviour and attitudes aiming to increase people's knowledge, skills, and awareness of environmental values and

environmental issues, which in turn can move the community to play an active role in environmental conservation and safety efforts for the benefit of current and future generations. environmental education is about internalisation, directly or indirectly.

Pro-environmental behaviour refers to conscious efforts to minimise the negative impact of one's action on nature (both natural and artificial ecosystems), such as reducing natural resources and consumption, toxin, waste, and so forth (Kollmuss & Agyeman, 2002). Several factors affecting pro-environmental behaviour, environmental commitment and awareness, green lifestyle, and green self-efficacy positively affect the pro-environmental behaviour of young people (Yusliza et al., 2020). Holistic and systemic perspectives on the environment are crucial in promoting pro-environmental behaviour (P. Liu et al., 2020; X. Liu et al., 2018). Pro-environmental behaviour also increases with factors, including knowledge, awareness, and understanding of environmental damage (Soares et al., 2021). Social norms and lifestyle contribute to pro-environmental behaviour. There is also a difference in pro-environmental behaviour between the younger and older generations (Alzubaidi et al., 2021). The novelty of this study compared to several previous studies lies in determining how environmental knowledge, environmental responsibility, value-belief-norm, and environmental education influence pro-environmental behaviour in Indonesian university students.

Methods

Research Design

This research uses a quantitative approach with survey methodology. The survey method is a research method that takes samples from a population using questionnaires as a data collection tool (Creswell & Creswell, 2017; Hoy & Adams, 2015). The survey aims to get a general picture of the characteristics of the population that can be seen from attitudes, values, beliefs, opinions, habits, behaviours, and others. In this study, the picture/information researchers want to get from respondents is pro-environmental behaviour seen from environmental knowledge, environmental responsibility, value–belief–norm, and environmental education.

Data Collection

The respondents in this study were students of geography and geography education programmes from various public and private universities in Indonesia. The reason for choosing students of these programmes is the presence of environmental education courses in this study programme. Four hundred seventy (470) students participated as research respondents. The universities included Universitas Lambung Mangkurat, Universitas PGRI Kanjuruhan, Universitas Khairun Ternate, Universitas Samudra, Universitas Negeri Makasar, Universitas Negeri Malang, IKIP PGRI Pontianak, Universitas Al Muslim, Universitas Widya Dharma, Universitas Hamzanwadi, Universitas Negeri Padang, Universitas Muhammadiyah Mataram, STIKIP Kei Raga Ternate, Universitas Tadulako, USK, Universitas Halu Oleo, Universitas Siliwangi, IKIP PGRI Palangkaraya, Universitas Nusa Cendana Kupang, Amikom Yogyakarta, and Universitas Negeri Jember. Data collection in this study used questionnaires filled out online through Google form and shared via WhatsApp group.

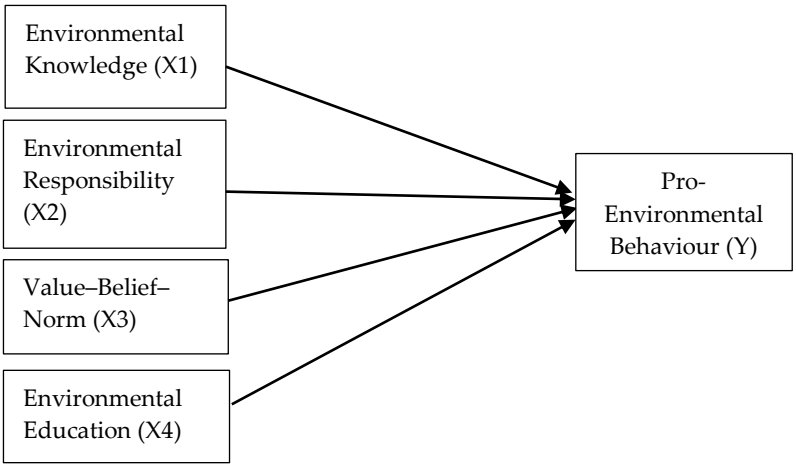
Data Analysis

The Smart PLS 3.0 Program was used to check our instruments' validity by looking at each construct indicator's loading factors. The outer model was used to check the validity and reliability of the model (Hair et al., 2020). The standard requirement to test the validity of research instruments is that the loading factor must be more significant than 0.70 (Chan & Lay, 2018; Zürich et al., 2005). Reliability was tested by calculating the composite reliability—the range is 0.6 to 0.7 (Chan & Lay,

2018; Rasoolimanesh, 2022). The research variables were environmental knowledge (X1), environmental responsibility (X2), value–belief–norm (X3), environmental education (X4), and pro-environmental behaviour (Y).

Figure 1

Theoretical Framework



Data were analysed using the Structural Equation Modelling (SEM) Partial Least Square (PLS). SEM-PLS is a causal model explaining the effect of variables on the constructed variable (Chan & Lay, 2018).

Table 1

Research Variables

Variable	Indicator
Environmental knowledge (X1)	1. Knowing daily environmental problems
	2. Knowing the causes of environmental problems
	3. Learning the solutions to solve environmental problems
	4. Understanding the dependency of human beings on the environment
	5. Knowing renewable energy
Environmental responsibility (X2)	1. No littering
	2. Keeping the environment clean
	3. Using environmentally friendly energy and resources
	4. Greening the surrounding areas
Value–belief–norm (X3)	1. Believing that everything on earth is God's creation
	2. Being thankful for what is available on earth
	3. Sticking to the concept of cleanliness in doing religious rituals
	4. Practicing religious advice to protect the environment
Environmental education (X4)	1. Increasing understanding of environmental problems
	2. Improving acceptance, assessment, organization, and personality characteristics in managing life in harmony with nature
	3. Growing a love of the environment
	4. Increasing interest in the environment

Pro-Environmental Behaviour (Y)	1. Participating in events/seminars/workshops on environmental issues 2. Reducing the use of plastic 3. Replacing disposable drinking bottles with tumblers 4. Replacing food wrapping paper with lunch boxes 5. Buying items with a recyclable sign 6. Reusing usable things 7. Using rechargeable batteries 8. Sorting waste 9. Reusing things that are still suitable for use 10. Disposing of phone batteries or electronic device batteries properly 11. Turning off electronic devices that are not in use 12. Using electronic devices with energy-saving features 13. Turn off the lights during daytime 14. Using water wisely 15. Using a water storage tank

Our research hypotheses are as follows:

Hypothesis 1

H0: Environmental Knowledge of students does not have a positive and significant correlation with

Pro-Environmental Behaviour

Hypothesis 2

H0: Environmental Responsibility of students does not have a positive and significant correlation with

Pro-Environmental Behaviour

Hypothesis 3

H0: Environmental Education of students does not have a positive and significant correlation with Pro-

Environmental Behaviour

Hypothesis 4

H0: Value-belief-norm of students does not have a positive and significant correlation with Pro-

Environmental Behaviour

Findings

Outer Model

Before hypothesis testing to predict the relationship between latent variables in a structural model, we first evaluated the outer model to verify indicators and latent variables for further analysis. The validity test evaluates the ability of research instruments to measure what they are intended to measure (Hair et al., 2017; Hair Jr et al., 2020). The reliability test evaluates the consistency of a measurement instrument in measuring a concept or the character of research respondents in answering questionnaire items or research instruments. The result is presented in discriminant validity (outer loadings), Cronbach's alpha, composite reliability, and Average Variance Extracted (AVE).

Table 2

Structural Model

Construct	Items	Loading Factors	Cronbach's alpha	Composite Reliability	Average Variance Extracted (AVE)
Environmental knowledge	X1.1	0.855	0.903	0.928	0.720
	X1.2	0.866			
	X1.3	0.857			
	X1.5	0.837			
	X1.5	0.826			
Environmental responsibility	X2.1	0.855	0.874	0.914	0.726
	X2.2	0.878			
	X2.3	0.845			
	X2.4	0.829			
Value–belief–norm	X3.1	0.831	0.868	0.910	0.715
	X3.2	0.866			
	X3.3	0.838			
	X3.4	0.848			
Environmental education	X4.1	0.869	0.881	0.918	0.737
	X4.2	0.844			
	X4.3	0.874			
	X4.4	0.846			
Pro-Environmental Behaviour	Y1	0.747	0.924	0.934	0.505
	Y2	0.670			
	Y3	0.614			
	Y4	0.663			
	Y5	0.678			
	Y6	0.731			
	Y7	0.744			
	Y8	0.749			
	Y9	0.758			
	Y10	0.755			
	Y11	0.737			
	Y12	0.746			
	Y13	0.672			
	Y14	0.670			

Table 2 shows that measuring discriminant validity through outer loadings ensures that each concept of the latent model is different from other variables. An indicator is reliable if it has a correlation value of more than 0.70. An indicator is valid if its outer loading is between 0.50 – 0.60, so its presence is acceptable (Hair et al., 2020).

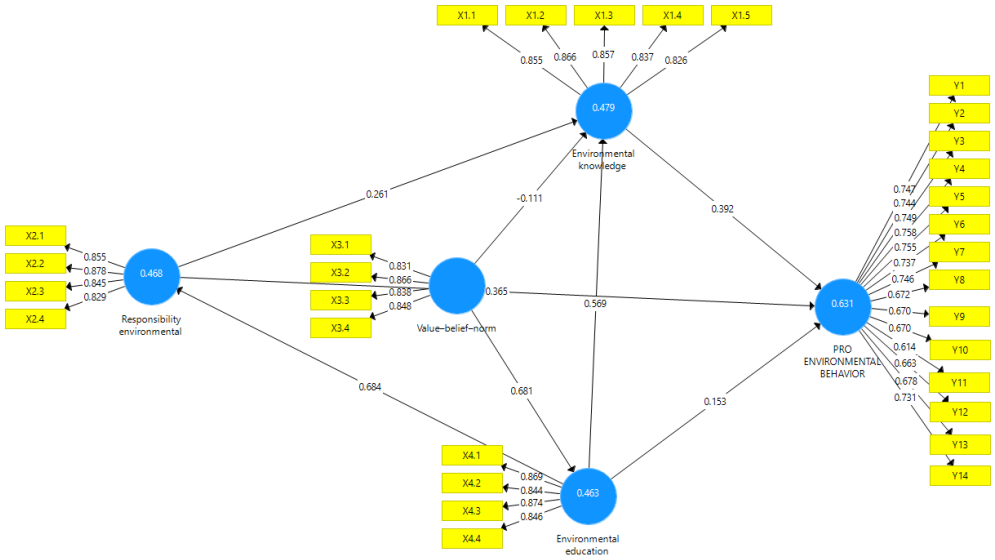
Table 2 shows that all indicators of the latent variables are valid and reliable because their outer loading values are between 0.60 and 0.70. Thus, all latent variables could explain the variable of each indicator that measured them. Discriminant validity can be determined using AVE for each construct or latent variable. The model has better discriminant validity if the AVE square root for each construct is greater than the correlation between the two constructs in the model.

Table 2 shows that the AVE value for all constructs is > 0.50. Therefore, convergent validity in the model being tested is acceptable. The Cronbach Alpha and composite reliability values for all

constructs are also > 0.60, which means that all constructs have very good reliability. Figure 2 shows that the variables environmental knowledge, environmental responsibility, values-beliefs-norms, and environmental education have a high influence on Pro-Environmental Behaviour. This is proven by the loading factor value for each construct indicator being in the range of 0.6 – 0.7. The results of the outer model analysis are presented in Figure 2.

Figure 2

Model Pro-Environmental Behaviour of University Students in Indonesia



Measuring the Structural Model (Inner Model)

Coefficient of Determinant (R-square)

The R-square value is used to assess the extent of influence certain independent latent variables have on the dependent latent variable. Using SmartPLS 3.0 software, we obtained the following results.

Table 3

Coefficient of Determinant (R-square)

	R-square	R-square Adjusted
Environmental education	0.463	0.462
Environmental knowledge	0.479	0.476
Pro-environmental behaviour	0.631	0.629
Environmental responsibility	0.468	0.466
Value–belief–norm	0.430	0.433

Table 3 shows the R-square value for environmental education is 0.463; this shows that environmental education has an influence of 46.3% on pro-environmental behaviour. The R-square value for environmental knowledge is 0.479; this indicates that environmental knowledge has a 47.6% influence on pro-environmental behaviour. The R-square value for environmental responsibility is 0.468; this shows that environmental responsibility has a 46.8% influence on pro-environmental behaviour. The R-square value for the value-belief-norm is 0.430; this indicates that Value-belief-norm

has a 43.0% influence on pro-environmental behaviour. The R-square value for pro-environmental behaviour, which indicates that environmental education, environmental knowledge, value-belief-norm, and environmental responsibility factors influence pro-environmental behaviour by 40%.

Hypothesis Testing

The p-value is set at a significance level (α) of 5% or 0.05 to determine whether the hypothesis is accepted or rejected. If the p-value < 0.05, H0 is rejected, meaning an effect exists. Conversely, if the p-value > 0.05, H0 is accepted, indicating no effect exists. Table 4 presents the results of evaluating the structural model of the hypothesis test using the PLS method obtained from the SmartPLS 3.0 Bootstrapping Report.

Table 4

Path Coefficients

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Environmental education-> Pro-environmental behaviour	0.153	0.154	0.059	2.611	0.009
Environmental knowledge-> Pro-environmental Behaviour	0.392	0.395	0.046	8.618	0.000
Environmental responsibility -> Pro-environmental behaviour	0.365	0.365	0.052	7.043	0.000
Value–belief–norm-> Pro-environmental behaviour	0.430	0.433	0.033	13.234	0.000

Table 4 shows that environmental education has a positive relationship with pro-environmental behaviour, with a p-value of 0.009 (p < 0.05). Environmental knowledge has a positive relationship with pro-environmental behaviour, with a p-value of 0.000 (p < 0.05). Environmental responsibility has a positive relationship with pro-environmental behaviour, with a p-value of 0.000 (p < 0.05). Value–Belief–Norm has a positive relationship with pro-environmental behaviour, with a p-value of 0.000 (p < 0.05).

Discussion

Factors Affecting Pro-Environmental Behaviour of University Students

Environmental knowledge has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 2.611 and a p-value of 0.009 (p < 0.05). Most students were already concerned about the environment, such as environmental problems and the causes of such problems. Students also knew solutions to environmental problems and about renewable energy to overcome the problems. Renewable energy sources are environmentally friendly, do not pollute the environment, and do not contribute to climate change and global warming because the energy comes from sustainable natural sources, such as sunlight, wind, water, biofuels, and geothermal.

Knowledge is crucial to determining behaviour. Students with environmental knowledge tend to change their behaviour due to education; this aligns with the view that environmental knowledge affects pro-environmental behaviour (Gifford & Nilsson, 2014).

Developing students' environmental knowledge is important, especially on campus. A study in Canada reveals that more than 60% of the study respondents agree that one factor hindering pro-

environmental behaviour is a lack of knowledge (Kennedy et al., 2009; Kennedy & Kmec, 2018). Other studies also confirm that more profound and broader knowledge of environmental issues and solutions to such issues will increase the possibility of individuals taking-action to protect the environment (Farrukh et al., 2022; Jensen, 2002; Kaiser, Ranney, et al., 1999; Kaiser, Wölfing, et al., 1999; Kollmuss & Agyeman, 2002; Latif et al., 2013). Individuals with sound knowledge of environmental issues tend to show pro-environmental behaviour. Previous studies show that knowledge relates to actions and becomes a predictor of actions (Neolaka, 2020). To sum up, individuals with sound knowledge of environmental issues and solutions to such issues tend to show pro-environmental behaviour to protect the environment.

P. Liu et al., (2020) find a significant relationship between the level of knowledge and the pro-environmental behaviour of students—the higher the level of environmental knowledge, the better the pro-environmental behaviour of students and vice versa. Fawehinmi et al., (2020) reveal a positive and significant relationship between environmental knowledge and attitudes towards environmental sustainability. If environmental knowledge increases, attitudes towards environmental sustainability will also increase, and vice versa.

Ardoin et al., (2020) provide an opinion that people with better environmental knowledge will be better aware of the environment and environmental issues. Thus, they will be motivated to act responsibly toward the environment. Developing environmental awareness through education has always been critical in building pro-environmental behaviour. Knowledge of people will guide them to determine whether their actions will be good or bad for the environment. Environmental knowledge can be in the form of knowledge of environmental issues, causes, effects, solutions, and how to become an environmentally responsible agent of change related to the problems (Fawehinmi et al., 2020).

The path coefficient analysis presented in Table 3 for testing the second hypothesis shows that H0: Environmental Responsibility of students has no positive and significant correlation with Pro-Environmental Behaviour is rejected. This means that environmental responsibility has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 7.043 and a p-value of 0.000 ($p < 0.05$). Environmental responsibility is an action motivated by one's willingness to prevent environmental damage or preserve the environment. Our findings showed that the students had good environmental responsibility. They did not litter, cared for environmental cleanliness, used recyclable goods, and did greening of their surrounding areas. Environmental responsibility is closely related to the ascription of responsibility. Initially, the ascription of responsibility is defined as a feeling of responsibility from the negative consequences of not behaving in a pro-social manner. This theory is widely applied in green behaviour because most people behave green based on their altruistic feelings, such as recycling, energy policies, and other green behaviours in general.

Increased awareness and understanding of changing environmental issues and improved skills for environmentally responsible actions can be developed through environmental education (Jurdi-Hage et al., 2019). This is consistent with the university's role as an effective agent of change.

Building awareness to be environmentally responsible aims to preserve the environment, so human beings not only take benefit of the environment for their lives but also take care of and be accountable for preserving the environment. Individuals with high environmental awareness can improve pro-environmental behaviour (Zareie & Navimipour, 2016). In addition, students with higher environmental awareness show more pro-environmental behaviour (S.-C. Liu & Lin, 2015; S. Liu & Guo, 2018). As previously indicated, specific environmental awareness can lead to better predictability of environmentally responsible behaviour if certain pro-environmental behaviours are assessed.

As formal education institutions, universities must implement pro-environmental behaviour (Usaini et al., 2015). People are not born with pro-environmental behaviour—the behaviour is taught

and shaped along with their developmental stages. Increased environmental responsibility will finally lead to positive changes toward pro-environmental behaviour.

The path coefficient analysis presented in Table 4 for testing the third hypothesis shows that H0: Environmental Education of students does not have a positive and significant correlation with Pro-Environmental Behaviour is rejected. This means that environmental education has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 2.611 and a p-value of 0.009 ($p < 0.05$). Our findings confirmed that the students received environmental education, proven by increased environmental knowledge and understanding that they refused to damage the environment at any cost.

Education is crucial in forming pro-environmental behaviour (Iswari & Kusuma, 2022). Human behaviour greatly impacts the environment. Environmental knowledge gained through education is positively and significantly important to preserve the environment (Azhar et al., 2015; Erdogan & Ozsoy, 2007; Sontay et al., 2015). Environmental education teaches students the importance of preserving the environment—it increases students' awareness, directs students, and shapes their attitudes toward preserving the environment (Hassan & Pudin, 2011; Mulyana, 2009; Özalemdar, 2021). Environmental education aims to increase people's understanding and concern and is oriented toward preventing environmental damage and finding solutions to environmental issues.

The findings align with (Meyer, 2016), stating that specific policies, programmes and courses on the environment can affect the preferred construction of students related to the environment because the students have more knowledge and skills for environmental preservation.

The fourth hypothesis testing shows that H0: Value-belief-norm of students does not have a positive and significant correlation with Pro-Environmental Behaviour is rejected. This means the value-belief-norm has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 13.234 and a p-value of 0.000 ($p < 0.05$). Our findings showed that students had good value-belief-norm for pro-environmental behaviour, as seen from the willingness of students to protect the environment and support policies to preserve the environment. This aligns with (Mahat et al., 2020; Whitley et al., 2018), revealing that biosphere and altruistic values make students more willing to be involved in pro-environmental activities, such as supporting policies to protect the environment.

The value-belief-norm theory is proposed by (Stern et al., 1999), stating that value orientation can, directly and indirectly, affect pro-environmental behaviour. The theory assumes three value orientations related to environmental concerns relevant to understanding pro-environmental attitudes, preferences, and behaviour: altruistic, egoistic, and biosphere value orientations (Oreg & Katz-Gerro, 2006; Stern et al., 1999). Our findings strengthen the theory since the results show a direct contribution of value orientation toward pro-environmental behaviour.

Norms inform a person about acceptable and unacceptable behaviour. Norms are the rules of society regarding good and bad attitudes and actions that are permissible and not permissible. There are three types of norms: habits, prohibitions, and conventions (Kaiser et al., 2005, 2006). Personal norms are moral ethics and obligations towards something related to orientation in creating something. An ethical approach to dealing with environmental problems is needed. This approach is intended to determine attitudes, actions, and ethical perspectives and appropriately manage environmental care and its ecosystem (Hassan & Pudin, 2011; Liobikienė & Poškus, 2019).

The principle of respect for nature deals with a moral responsibility towards nature. This responsibility is individual and collective (Stern et al., 1999). Moral responsibility requires humans to take concrete initiatives, efforts, policies, and actions to protect the universe and everything in it. This means the preservation and destruction of nature is a shared responsibility of all humankind. This responsibility also manifests in warning, prohibiting, and punishing those who damage and endanger nature (Kurisu, 2015; Stern et al., 1999).

Building students' positive environmental values in educational institutions are essential as it should help solve environmental problems and improve environmental quality (Chen, 2015). This will help to create a knowledgeable society about environmental issues that will play a significant role in preserving the environment.

Efforts to Improve Pro-Environmental Behaviour

Improving pro-environmental behaviour, especially among the younger generation, can be done through education. Building a character of caring for the environment through education is an effort the government of Indonesia takes to preserve the environment. Such character is manifested in attitudes and actions of preventing environmental damage and taking steps to repair the already-happen environmental damage. Some activities to form pro-environmental behaviour are: (1) caring for the environment, (2) reducing plastic use, (3) sorting waste, (4) reducing carbon emission, and (5) saving energy. Actions to repair environmental damage include (1) planting trees, (2) reusing goods, and (3) using environmentally friendly technology. Caring for the environment must be inculcated from an early age through fun learning. This is in line with the research results (Yüzüak & Erten, 2022), which suggest that environmental education be included in various disciplines and raise environmental awareness among individuals should become one of national education's primary objectives.

Other efforts to increase public awareness of the importance of protecting the environment can be carried out through informational and structural strategies. Informative strategies refer to interventions through campaigns to increase knowledge to minimise environmentally damaging behaviour. For example, the reduce, reuse, and recycle (3R) campaign and creating eco-points for residential communities to collect metal, paper, glass, and organic waste for recycling. In addition to reducing waste, the 3R programme can also be a means of earning income in which people can deposit their waste to waste banks or recycling facilities.

Efforts to increase public awareness through structural strategies can be made through behavioural changes that affect behavioural decisions. This strategy focuses on external environmental planning that can support pro-environmental behaviour—for example, providing easily-accessible bins to avoid littering.

Governments, companies and other organisations can also improve people's pro-environmental behaviour through appropriate environmental policies primarily aimed at increasing self-motivation from the community to behave pro-environmentally. This can be done through activities including providing infrastructure that makes it easier for people to adopt pro-environmental behaviour, such as providing environmentally friendly objects at lower prices, providing pro-environmental education to students as early as possible, developing an in-depth understanding of waste recycling efforts through various media, and supervising the public in subsidy programs for people with pro-environmental behaviour and fines for violators of environmental policies.

Conclusion and Implications

It is significant for everyone, especially the young generation, to behave pro-environmentally to reduce environmental problems. Our findings confirm that environmental knowledge has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 2.611 and a p-value of 0.009 ($p < 0.05$). Environmental responsibility has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 7.043 and a p-value of 0.000 ($p < 0.05$). Environmental education has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 2.611 and a p-value of 0.009 ($p < 0.05$). The value-belief-norm has a significant and positive relationship with pro-environmental behaviour, evidenced by a t-statistic value of 13.234 and a p-value of 0.000 ($p < 0.05$). That means students in

university exhibit excellent pro-environmental behaviour where factors of environmental knowledge, environmental responsibility, environmental education, and values influence this behaviour.

Acknowledgement

We thank to the Faculty of Teacher Training and Education, Lambung Mangkurat University, for supporting and funding the research.

References

Alzubaidi, H., Slade, E. L., & Dwivedi, Y. K. (2021). Examining antecedents of consumers' pro-environmental behaviours: TPB extended with materialism and innovativeness. *Journal of Business Research*, *122*, 685–699. https://doi.org/10.1016/j.jbusres.2020.01.017

Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation*, *241*, 108224. https://doi.org/10.1016/j.biocon.2019.108224

Azhar, A., Basyir, M. D., & Alfitri, A. (2015). The relationship between environmental knowledge and ethics with attitudes and behavior in preserving the environment. *Jurnal Ilmu Lingkungan*, *13*(1), 36–41. https://doi.org/10.14710/jil.13.1.36-41

Chan, S. H., & Lay, Y. F. (2018). Examining the reliability and validity of research instruments using partial least squares structural equation modeling (PLS-SEM). *Journal of Baltic Science Education*, *17*(2), 239. https://doi.org/10.33225/jbse

Chen, M. (2015). An examination of the value-belief-norm theory model in predicting pro-environmental behaviour in Taiwan. *Asian Journal of Social Psychology*, *18*(2), 145–151. https://doi.org/10.1111/ajsp.12096

Creswell, J. W., & Creswell, J. D. (2017). *Research design: qualitative, quantitative, and mixed methods approaches*. Sage publications. ISBN: 978-1-4129-6557-6.

Erdogan, M., & Ozsoy, A. (2007). Graduate students' perspectives on the human-environment relationship. *Journal of Turkish Science Education*, *4*(2), 21–30.

Farrukh, M., Raza, A., Mansoor, A., Khan, M. S., & Lee, J. W. C. (2022). Trends and patterns in pro-environmental behaviour research: a bibliometric review and research agenda. *Benchmarking: An International Journal*. https://doi.org/10.1108/BIJ-10-2020-0521

Fawehinmi, O., Yusliza, M. Y., Mohamad, Z., Noor Faezah, J., & Muhammad, Z. (2020). Assessing the green behaviour of academics: the role of green human resource management and environmental knowledge. *International Journal of Manpower*, *41*(7), 879–900. https://doi.org/10.1108/IJM-07-2019-0347

Fettahlıoğlu, P., & Aydoğdu, M. (2020). Developing environmentally responsible behaviours through the ımplementation of argumentation-and problem-based learning models. *Research in Science Education*. https://link.springer.com/article/10.1007/s11165-018-9720-0

Gifford, R., & Nilsson, A. (2014). Personal and social factors that influence pro-environmental concern and behaviour: A review. *International Journal of Psychology*, *49*(3), 141–157. https://doi.org./10.1002/ijop.12034

Hair, J. F., Howard, M. C., & Nitzl, C. (2020). Assessing measurement model quality in PLS-SEM using confirmatory composite analysis. *Journal of Business Research*, *109*, 101–110. https://doi.org/10.1016/j.jbusres.2019.11.069

Hair, J. F., Matthews, L. M., Matthews, R. L., & Sarstedt, M. (2017). PLS-SEM or CB-SEM: updated guidelines on which method to use. *International Journal of Multivariate Data Analysis*, *1*(2), 107–123. https://doi.org/10.1504/IJMDA.2017.087624

Hassan, A., & Pudin, S. (2011). The ınformal environmental education value practices among adults in Sabah, Malaysia. *Journal of Turkish Science Education*, *8*(1), 19–28.

Hoy, W. K., & Adams, C. M. (2015). *Quantitative research in education: A primer* (Second Edi). Sage Publications. https://doi.org/10.4135/9781452272061

Iswari, N., & Kusuma, A. B. (2022). Analysis of the factors that influence the environmental quality index in Bekasi Regency. *Jurnal Pengelolaan Sumber Daya Alam dan Lingkungan*, *12*(4), 720–728. http://dx.doi.org/10.29244/jpsl.12.4.720–728

Janmaimool, P., & Khajohnmanee, S. (2019). Roles of environmental system knowledge in promoting university students' environmental attitudes and pro-environmental behaviors. *Sustainability*, *11*(16), 4270. https://doi.org/10.3390/su11164270

Jensen, B. B. (2002). Knowledge, action and pro-environmental behaviour. *Environmental Education Research*, *8*(3), 325–334. https://doi.org/10.1080/13504620220145474

Jurdi-Hage, R., Hage, H. S., & Chow, H. P. H. (2019). Cognitive and behavioural environmental concern among university students in a Canadian city: Implications for institutional interventions. *Australian Journal of Environmental Education*, *35*(1), 28–61. https://doi.org/10.1017/aee.2018.48

Kaiser, F. G., Hübner, G., & Bogner, F. X. (2005). Contrasting the theory of planned behavior with the value-belief-norm model in explaining conservation behavior. *Journal of Applied Social Psychology*, *35*(10), 2150–2170. https://doi.org/10.1111/j.1559-1816.2005.tb02213.x

Kaiser, F. G., Ranney, M., Hartig, T., & Bowler, P. A. (2006). Ecological behavior, environmental attitude, and feelings of responsibility for the environment. *European Psychologist*, *4*(2), 59–74. https://doi.org/10.1027//1016-9040.4.2.59.

Kaiser, F. G., Wölfing, S., & Fuhrer, U. (1999). Envıronmental attıtude and ecologıcal behavıour. *Journal of Environmental Psychology*, *19*(1), 1–19. https://doi.org/10.1006/JEVP.1998.0107

Kennedy, E. H., Beckley, T. M., McFarlane, B. L., & Nadeau, S. (2009). Why we don't" walk the talk": understanding the environmental values/behaviour gap in Canada. *Human Ecology Review*, 151–160. http://www.jstor.org/stable/24707539

Kennedy, E. H., & Kmec, J. (2018). Reinterpreting the gender gap in household pro-environmental behaviour. *Environmental Sociology*, *4*(3), 299–310. https://doi.org/10.1080/23251042.2018.1436891

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, *8*(3), 239–260. https://doi.org/10.1080/13504620220145401

Kurisu, K. (2015). *Pro-environmental behaviors*. Springer. ISBN : 978-4-431-55832-3.

Larson, L. R., Stedman, R. C., Cooper, C. B., & Decker, D. J. (2015). Understanding the multi-dimensional structure of pro-environmental behavior. *Journal of Environmental Psychology*, *43*, 112–124. https://doi.org/10.1016/j.jenvp.2015.06.004

Latif, S. A., Omar, M. S., Bidin, Y. H., & Awang, Z. (2013). Role of environmental knowledge in creating pro-environmental residents. *Procedia-Social and Behavioral Sciences*, *105*, 866–874. https://doi.org/10.1016/j.sbspro.2013.11.088

Liobikienė, G., & Poškus, M. S. (2019). The importance of environmental knowledge for private and public sphere pro-environmental behavior: modifying the value-belief-norm theory. *Sustainability*, *11*(12), 3324. https://doi.org/10.3390/su11123324

Liu, P., Teng, M., & Han, C. (2020). How does environmental knowledge translate into pro-environmental behaviors?: The mediating role of environmental attitudes and behavioral intentions. *Science of the Total Environment*, *728*, 138126. https://doi.org/10.1016/j.scitotenv.2020.138126

Liu, S.-C., & Lin, H. (2015). Exploring undergraduate students' mental models of the environment: Are they related to environmental affect and behavior? *The Journal of Environmental Education*, *46*(1), 23–40. https://doi.org/10.1080/00958964.2014.953021

Liu, S., & Guo, L. (2018). Based on environmental education to study the correlation between environmental knowledge and environmental value. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(7), 3311–3319. https://doi.org/10.29333/ejmste/91246

Liu, X., Zou, Y., & Wu, J. (2018). Factors influencing public-sphere pro-environmental behavior among Mongolian college students: A test of value–belief–norm theory. *Sustainability*, *10*(5), 1384. https://doi.org/10.3390/su10051384

Lozano, M., & Vallés, J. (2007). An analysis of the implementation of an environmental management system in a local public administration. *Journal of Environmental Management*, *82*(4), 495–511. https://doi.org/10.1016/j.jenvman.2006.01.013

Mahat, H., Hashim, M., Saleh, Y., Nayan, N., & Norkhaidi, S. B. (2020). Transformation of education for sustainable development through low carbon schools community program. *Journal of Turkish Science Education*, *17*(3), 429–442. https://doi.org/10.1016/j.jclepro.2015.10.133

Meyer, A. (2016). Heterogeneity in the preferences and pro-environmental behavior of college students: The effects of years on campus, demographics, and external factors. *Journal of Cleaner Production*, *112*, 3451–3463. https://doi.org/10.1016/j.jclepro.2015.10.133

Mulyana, R. (2009). Instilling environmental ethics through schools that care and have an environmental culture. *Jurnal Tabularasa*, *6*(2), 175–180.

Neolaka, A. (2020). The ınfluence of pro envıronmental knowledge on envıronmentally frıendly behavıor. *Prosiding Seminar Nasional Pascasarjana*, *1*(01), 14–21.

Oreg, S., & Katz-Gerro, T. (2006). Predicting proenvironmental behavior cross-nationally: values, the theory of planned behavior, and value-belief-norm theory. *Environment and Behavior*, *38*(4), 462–483. https://doi.org/10.1177/0013916505286012

Otto & Pensini P, S. (2017). Nature-based environmental education of children: environmental knowledge and connectedness to nature, together, are related to ecological behaviour. *Global Environmental Change*, *47*, 88–94. https://doi.org/10.1016/j.gloenvcha.2017.09.009

Özalemdar, L. (2021). The effect on environmental attitude of the active learning method applied in teaching the biology topic "current environmental ıssues and human" for 10th grade students. *Journal of Turkish Science Education*, *18*(2), 276–289. https://doi.org/10.36681/tused.2021.65

Ramos, T. B., Caeiro, S., Van Hoof, B., Lozano, R., Huisingh, D., & Ceulemans, K. (2015). Experiences from the implementation of sustainable development in higher education institutions: environmental management for sustainable universities. *Journal of Cleaner Production*, *106*, 3–10. https://doi.org/10.1016/j.jclepro.2015.05.110

Rasoolimanesh, S. M. (2022). Discriminant validity assessment in PLS-SEM: a comprehensive composite-based approach. *Data Analysis Perspectives Journal*, *3*(2), 1–8.

Scannell, L., & Gifford, R. (2010). The relations between natural and civic place attachment and pro-environmental behavior. *Journal of Environmental Psychology*, *30*(3), 289–297. https://doi.org/10.1016/j.jenvp.2010.01.010

Singh, N., & Gupta, K. (2013). Environmental attitude and ecological behaviour of Indian consumers. *Social Responsibility Journal*, *9*(1), 4–18. https://doi.org/10.1108/17471111311307787/FULL/XML

Soares, J., Miguel, I., Venâncio, C., Lopes, I., & Oliveira, M. (2021). Public views on plastic pollution: knowledge, perceived impacts, and pro-environmental behaviours. *Journal of Hazardous Materials*, *412*, 125227. https://doi.org/10.1016/j.jhazmat.2021.125227

Sontay, G., Gokdere, M., & Usta, E. (2015). A comparative ınvestigation of sub-components of the environmental literacy at the secondary school level. *Journal of Turkish Science Education*, *12*(1), 19–28. https://doi.org/10.12973/tused.10130a

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology*, *29*(3), 309–317. https://doi.org/10.1016/j.jenvp.2008.10.004

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Human Ecology Review*, 81–97. http://www.jstor.org/stable/24707060

Usaini, M. I., Abubakar, N. B., & Bichi, A. A. (2015). Influence of school environment on academic performance of secondary school students in Kuala Terengganu, Malaysia. *The American Journal of Innovative Research and Applied Sciences*, *1*(6), 203–209.

Whitley, C. T., Takahashi, B., Zwickle, A., Besley, J. C., & Lertpratchya, A. P. (2018). Sustainability behaviors among college students: an application of the VBN theory. *Environmental Education Research*, *24*(2), 245–262. https://doi.org/10.1080/13504622.2016.1250151

Yusliza, M. Y., Amirudin, A., Rahadi, R. A., Nik Sarah Athirah, N. A., Ramayah, T., Muhammad, Z., Dal Mas, F., Massaro, M., Saputra, J., & Mokhlis, S. (2020). An investigation of pro-environmental behaviour and sustainable development in Malaysia. *Sustainability*, *12*(17), 7083. https://doi.org/10.3390/su12177083

Yüzüak, A. V., & Erten, S. (2022). Teachers' views about turkey's zero waste project (TZWP). *Journal of Turkish Science Education*, *19*(1), 71–81. https://doi.org/10.36681/tused.2022.110

Zareie, B., & Navimipour, N. J. (2016). The impact of electronic environmental knowledge on the environmental behaviors of people. *Computers in Human Behavior*, *59*, 1–8. https://doi.org/10.1016/j.chb.2016.01.025

Zilahy, G., & Huisingh, D. (2009). The roles of academia in regional sustainability initiatives. *Journal of Cleaner Production*, *17*(12), 1057–1066. https://doi.org/10.1016/j.jclepro.2009.03.018

Zsóka, Á., Szerényi, Z. M., Széchy, A., & Kocsis, T. (2013). Greening due to environmental education? environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students. *Journal of Cleaner Production*, *48*, 126–138. https://doi.org/10.1016/j.jclepro.2012.11.030

Zürich, F., Zingg, Æ. A., Biber, Æ. P., Zimmerman, D. L., Zimble, D. a., Evans, D. L., Carlson, G. C., Parker, R. C., Grado, S. C., Gerard, P. D., Zianis, D., Muukkonen, P., Mäkipää, R., Zhao, Y., Krzic, M., Bulmer, C. E., Schmidt, M. G., Simard, S. W., Zhao, D., … Leuven, K. U. (2005). A structural equation model analysis of postfire plant diversity. *Forest Ecology and Management*, *10*(1). https://doi.org/10.1890/1051-0761(2006)016[0503:ASEMAO]2.0.CO;2

Journal of Turkish Science Education, 2024, *21*(1), 118-133.
DOI no: 10.36681/tused.2024.007

Effect of science process skills and entry grades on academic scores of student teachers

Anthony Koomson[1], Christopher Yaw Kwaah[2], Christine Adu-Yeboah[3]

[1]*University of Cape Coast, Ghana, anthony.koomson@ucc.edu.gh, Corresponding author, ORCID ID:* 0000-0001-9613-0755
[2]*University of Cape Coast, Ghana, ORCID ID: 0000-0002-4890-9761*
[3]*University of Cape Coast, Ghana, ORCID ID:* 0000-0003-2006-7336

ABSTRACT
The development and acquisition of science process skills (SPS) in science education are closely linked to the development of 21st-century skills and improvements in academic performance. To help facilitate the development of SPS in learners, teachers should acquire and exhibit SPS. This study assesses the SPS acquired by final-year students in a college of education who are pursuing a bachelor's degree in education, using regression correlation to find relationships between their acquired SPS, entry qualifications and academic performance. A parametric achievement test was used to assess the SPS acquired by the student teachers and extant data were used to construct their entry qualifications and academic performance. The data for the study were collected from 236 student teachers in four science colleges affiliated with the University of Cape Coast in Ghana. The results indicated that SPS contributed more to better academic performance than did students' entry qualifications. However, the nature of assessment of academic performance was such that basic SPS was a better influencer of academic performance than integrated SPS. It is recommended that, aside from entry qualifications, SPS acquired by candidates aspiring to pursue science programmes in tertiary institutions should be considered for admissions, and academic assessment instruments should be improved to encourage acquisition and development of integrated SPS.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 26.08.2022
Accepted: 16.11.2023

KEYWORDS:
Science process skills, entry grades, student teachers, academic scores.

To cite this article: Koomson, A., Kwaah, C.Y., & Adu-Yeboah, C. (2024). Effect of science process skills and entry grades on academic scores of student teachers. *Journal of Turkish Science Education*, *21*(1), 118-133. DOI: 10.36681/tused.2024.007

Introduction

The aim of science education is to build skills in students that equip them with the ability to apply those skills in their everyday life in a scientific manner (Opulencia, 2011). Curricular documents for science education in Ghana at various levels share this view (Ministry of Education [MoE], 2007a, 2007b, 2010a, 2010b, 2019). For example, MoE 2019 (p. 5) states, among other things, that: 'The science curriculum is designed to help learners to (a) develop a sense of curiosity, creativity, innovation and critical thinking for investigating and understanding their environment; (b) develop skills, habits and attitudes necessary for scientific inquiry; (c) communicate scientific ideas effectively; and (d) use scientific concepts in explaining their own lives and the world around them.

In science education, skills that allow one to function in a scientific manner (Padilla, 1990) and also help solve scientific problems like the ones espoused in the curricular documents incorporate science process skills (SPS; Akinbobola & Afolabi, 2010; Harlen, 1999; Nwosu & Okeke, 1995). Mushani (2021) asserted that SPS still supports the development of other skills individuals are supposed to possess for use in daily life. SPS are grouped into basic SPS (BSPS) and integrated SPS (ISPS; Ango, 1992; Padilla, 1990). BSPS include observing, communicating, measuring, inferring and predicting, while ISPS comprises data interpreting, controlling variables, hypothesising and experimenting. The BSPS are known to help with science learning and concepts formation, while the ISPS are notable for solving scientific problems (Akinbobola & Afolabi, 2010).

SPS have been linked to the development of 21st-century skills (Baran et al., 2021; Ergül et al., 2011; Opara, 2011; Osman & Vebrianto, 2013). Learners whose SPS are well developed possess better abilities to meet the demands of 21st-century life (Osman & Vebrianto, 2013). Ergül et al. (2011) also asserted that when learners acquire and develop SPS, they are able to better solve problems, think critically, make decisions, find answers and satisfy their concerns. An aim of science education is to inculcate the acquisition and development of SPS and to offer learners the ability to describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge and communicate their ideas to others (Opara, 2011).

Kayange and Msiska (2016) viewed 21st-century learning as the type of education that, although appreciating the acquisition of content knowledge, transcends mastering content into respecting and understanding cultural diversity and enabling learners to produce, synthesise and evaluate information that emerges from different subjects and sources. For science education to be relevant to the 21st-century era, science learning should put an emphasis on interactions between theory and practice, individuals and communities, formal and informal learning, learners and meta-cognitive brokers (Lee & Hung, 2012). It is obvious that SPS is an essential factor that influences the aspirations of the 21st-century era. Learners who acquire and develop SPS are likely to contribute more positively to the socioeconomic developments of this 21st-century era and future life.

Integrating SPS acquisition and development into the teaching and learning process to make learning relevant in the 21st century involves the participation of school systems and the abilities of teachers. Evidence from several studies suggests that schools do make a noticeable impact on learners' skill development and that teachers are an important part of learners' development (Darling-Hammond & Bransford, 2005; Dembélé & Lefoka, 2007; Rice, 2003; Tsui, 2009). It therefore becomes apparent that teachers must exhibit such dispositions as effective learners who are reflective in their practice, able to think critically and evaluate different points of view (Flores & Day, 2006). The need for teachers to acquire and develop SPS is necessary on two grounds. First, teachers are professionals with certain ethical, as well as technical, expectations placed upon them, and secondly, education must serve democratic purposes (Darling-Hammond & Bransford, 2005). Democratic perspectives held by professional teachers implies that they are multi-perspective thinkers, innovative, evaluative and have effective interactions with learners and curriculum content.

The need to develop SPS and 21st-century skills in not only students but also in teachers coincides with the recommendations made by the Presidential Committee on the Review of Education Reform in Ghana. The Presidential Committee recommended that the objective of teacher education should be the training and development of the right type of teachers, who are competent, committed and dedicated (Republic of Ghana, 2002). The need for relevant skills and knowledge for the present era brought about policies to upgrade teacher training institutions to Colleges of Education (CoE), with degree awarding status. The aim of the upgrade included training teachers who are capable of applying, extending and synthesising various forms of knowledge; developing attitudes, values and dispositions that create an environment that is conducive to quality teaching and learning in schools; facilitating learning and motivating individual learners to fully realise their potentials; and adequately preparing the learner to participate fully in the national development (Republic of Ghana, 2002). The recommended upgrading of teacher training institutions to CoE in Ghana happened with the first batch of CoE students, who are currently in the final year of their 4-year programme. Since the

introduction of the Bachelor of Education programme in the CoE, no studies have been conducted to assess student teachers acquired SPS and its influence on their academic performance. It has therefore become imperative to assess their acquired SPS and how it impacts their academic performance in the CoE.

Literature Review

Research reviews of SPS in both the developed and developing worlds have indicated an inequality of SPS inclusion in science curricular documents (Akinbobola & Afolabi, 2010; Koomson, 2020; Mushani, 2021; Ongowo & Indoshi, 2013). Lack of appropriate evaluation of science curricular documents for SPS inclusion and development and acquisition of SPS have been blamed as the main factors affecting the progress of science education (Downing & Gifford, 1996; Duruk et al., 2017; Patonah et al., 2018; Siachibila & Banda, 2018). The basic science process skills are also known to be a basis for acquiring and developing the integrated science process skills (Padilla, 1990). Unfortunately, acquisition and development of SPS has been found to emphasize BSPS at the expense of ISPS (Akinbobola & Afolabi, 2010; Duruk et al., 2017; Koomson, 2020, 2021; Ongowo & Indoshi, 2013).

An analysis of the Turkish secondary school curriculum (Duruk et al., 2017) showed that the representation rate of SPS varied with grade level and unit, although the BSPS were generally more emphasised. An analysis of West African and Kenyan secondary school examinations (Akinbobola & Afolabi, 2010; Koomson, 2020; Ongowo & Indoshi, 2013) showed a similar trend of emphasis in curricula for chemistry, biology and physics, respectively. Koomson (2021) also found that while chemistry students in their final year of secondary education in Ghana had acquired mainly BSPS, including observing and communicating, and ISPS, including interpreting, SPS of classifying, hypothesising, controlling variables and experimenting were only minimally developed or acquired.

Evidence has indicated that a variety of teaching approaches during the science learning process impacts SPS development (Rauf et al., 2013). Some studies have also revealed that there is a positive relationship between SPS and academic success in science courses (Beaumont-Walters & Soyibo, 2001; Farsakoğlu et al., 2012). However, such studies in Africa and in Ghanaian CoE, in particular, are limited. Very little is known about the development and acquisition of SPS among student teachers who are expected to teach science at the primary and junior high schools in Ghana. Taale et al. (n.d.) explored science student teachers' views on the kind of practical activities and skills they engage in when teaching in Ghanaian CoE. Yaayin et al. (2021) also explored the use of the jigsaw model as an alternative to traditional practical approaches in organic functional group compounds. While the study linked their approach to improvement in performance, there was no reference to skills development. Taale et al. (n.d.) also indicated the student teachers' perceptions of the frequency of engagement in practical activities and skills, but the link to academic performance was not made. Beaumont-Walters and Soyibo (2001) assessed the performance of 164 students from Jamaican Reform of Secondary Education (ROSE) project high schools and 141 students from non-ROSE high schools. The six-way analysis of variance (ANOVA) conducted revealed, among other things, that the ROSE schools outperformed the non-ROSE schools. The link between the acquisition of SPS and academic performance was inferred rather than determined, however. The inference was based on the known fact that the ROSE schools were academically better than the non-ROSE schools. Similarly, Farsakoğlu et al. (2012) measured SPS acquired by students in Turkey and analysed the result against different grade levels with the expectation of linearity. The assumption was that increasing grade levels would accompany increasing academic ability, but a linear progression in acquisition of SPS was not realised in the study.

Harlen (1999) linked SPS to understanding scientific concepts with the assertion that SPS have a central role in learning with understanding. Countries that scored high in the Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) assessment frameworks, which assess mainly SPS, are touted as high achievers in science, and these assessments have compelled many to include SPS in their curricula. For example, a conclusion from

the analysis of TIMSS 2019 was encouragement to involve pupils in field trips and to allow them design and conduct experiments (Sabah et al, 2023) in order to develop SPS. Investigations from Abungu et al. (2014), Hiğde and Aktamış (2022), Kasuga et al (2022), Koksal and Berberoglu (2014) and Uzun and Sen (2023) have aimed to justify the place of SPS in curricula. Usually, interventions with frameworks of SPS are incorporated into a controlled experimental approach involving pre- and post-tests. Reports in the literature have demonstrated various levels of effects. However, a limitation of such approaches is that quasi-experiments (QE) in social research usually lack randomisation and are replete with confounding factors that are typically difficult to identify and minimise (Andrade, 2021). The confounding effect is even more pronounced when univariate analysis is used in QE designs. The recommendation was made for the use of multi-variance regression analysis to limit confounding factors (Andrade, 2021).

For instance, Sacķes (2013) undertook longitudinal studies involving 8731 kindergarten children (5–6 years old). The aim was to relate the factorial structure of the children's mathematics and SPS with an impact on their performance on mathematics and science achievement tests in the third grade (8–9 years old). The multilevel structural equation modelling tool used to analyse the data revealed that both mathematics and SPS are among the key determinants of children's success in the third grade. The results of the study indicated that mathematics and SPS together accounted for 27% of the variance in children's mathematics achievement in third grade and 22% of the variance in children's science achievement in third grade. The study used three instruments: a mathematics achievement test, science achievement test and survey questionnaire. The questionnaire collected information about teachers' backgrounds, classroom practices and ratings of children's skills. Although a standard scheme could be used to objectively assess the achievement test, they found that objectivity and standardization were likely compromised to a significant extent in the rating of the process skills of participants, particularly considering the number of assessors with diverse knowledge and skills who were involved in the study. This critique has footing in the observation that early childhood teachers' competencies at evaluating mathematics and SPS tend to vary considerably. Also, some teachers have fewer opportunities to observe children using SPS. These observations limit the accuracy of the procedure used to assess SPS in the study (Early et al., 2010; Sacķes et al., 2011).

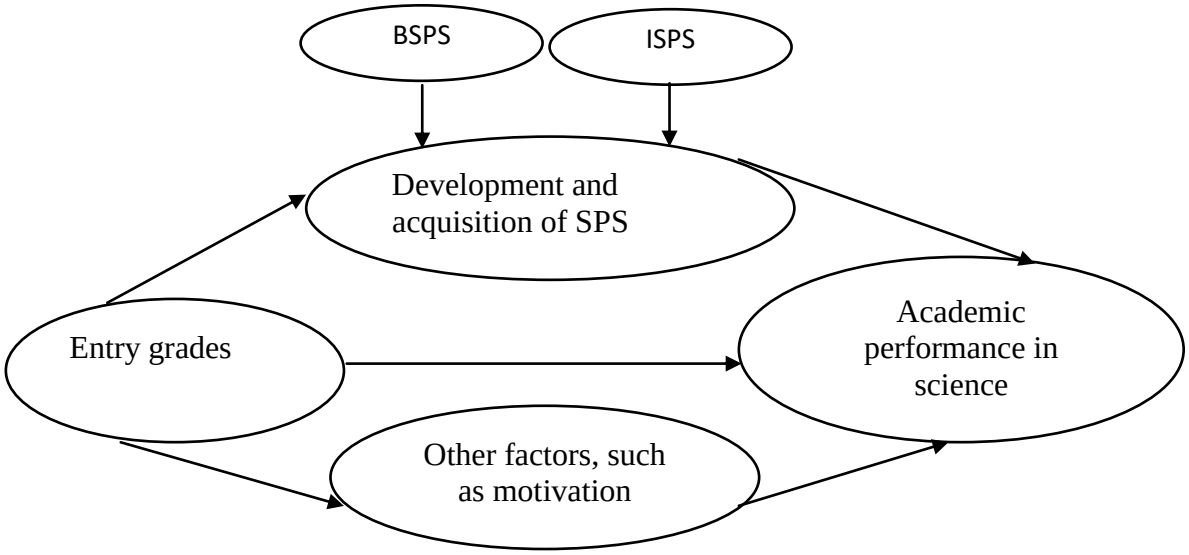
The present study aimed to improve objectivity in relating acquired SPS and academic performance of student teachers by using different data collection and analytical approaches. The study is unique in comparing the contribution of SPS to academic achievement with that of entering grades. Studies that relate entering grades to academic achievements include Spahr (1995), Hoskins et al. (1997), Zezekwa and Mudavanhu (2011) and Wambugu and Emeke (2013). In their assessment of the performance of students studying at the University of Plymouth, Hoskins et al. (1997) identified the key variables affecting student performance to be age, gender, discipline studied and entering grades. Entering grades (prior qualifications) is a key selection criterion for admission to most tertiary institutions. Spahr (1995) investigated the effect of entering grades on the graduating status of some 255 students admitted to a nursing programme, using multiple regression analysis to determine the contribution of the students' grade point average (GPA) and grades in three prerequisite support courses (biology, chemistry and algebra) on graduation status. The analysis showed that while contributions of the selected variables were significant, their effects on academic success were rather low. GPA was the greatest determinant, with about a 4.4% effect, followed by biology (0.33%), then chemistry (0.18%), with algebra being the lowest (0.02%). Many of the studies reviewed used students in primary and secondary schools and other tertiary students; however, only a limited number of studies have looked at preservice teachers' academic performance in relation to their SPS and entry grades. Wambugu and Emeke (2013) used regression analysis to study the effect of entry grades on achievements in biology, chemistry and physics and found that the effect of entry grades, while statistically significant, had a low contributory effect. Wambugu and Emeke (2013) called for alternative criteria for admitting students into tertiary programmes, particularly science-related programmes.

Conceptual Framework

The preceding review of the literature shows that SPS influences academic performance in science (Beaumont-Walters & Soyibo, 2001; Farsakoğlu et al., 2012). Lewin & Stuart (2003) asserted that effective teacher education relies on motivation and other characteristics of the student teacher. The issue of motivation and other learner characteristics is evidenced by the fact that the academic success of student teachers depends not only on content knowledge but also on the ability to learn how to learn and to regulate the learning process (Dembo, 2001). Studies such as Anane (2018, 2020), Wambugu and Emeke (2013) and Ogunleye and Agoro (2013) have related entry grades of student teachers in the CoE to their academic success.

Figure 1

Hypothetical Model of Influence of SPS Development and Acquisition, Entry Grades and Other Factors on Academic Performance in Science



The study, therefore, made the assumption that the development of SPS, entry grades and other factors, including motivation (Anane, 2020), influence academic performance in science, as hypothesized in Figure 1, and aimed to explore the relationship (if any) among SPS, entry grades and academic science course in CoE in Ghana. In line with the stated aim, the study focused on three research questions and two hypotheses.

Research Questions

Research Question 1: What is the emphasis of the SPS acquired by student teachers in the CoE science programmes?

Research Question 2: What contributions do SPS and entry grades make to subsequent academic performance?

Research Question 3: How does acquisition of SPS relate to contribution to academic performance?

Hypotheses

***HO1*:** There is no significant difference between the apparent effect of SPS and entry grades on subsequent academic scores.

***HO2* :** There is no significant difference between the apparent effect of BSPS and ISPS on subsequent academic performance.

Methods

Design

The study was a correlational study employing an achievement test and document analysis as means of collecting quantitative data to understand the relationships among process skills, entry grades and academic performance. The study assumed that SPS and entry grades of student teachers might contribute to their academic performance.

Measures

The achievement test, which was adapted from Koomson (2020, 2021), contained two parts The instrument is named the Students' Development of SPS Index Test (SDSPS). Part A collects biodata, such as index numbers, with the intent to access extant data in the form of entry grades and academic scores of the participants. Part B of the SDSPS is a parametric achievement test comprising 36 questions that assess nine higher order SPS. There are four questions for each SPS. The SPS under examination included observation (questions 1–4), measurement (questions 5–8), classification (questions 9–12), inference/prediction (questions 13–16), communication (questions 17–20), controlling variables (questions 21–24), data interpretation (questions 25–28), hypothesis (questions 29–32) and experimentation (questions 33–36). These skills were based on the Ghanaian senior high school curriculum (MOE, 2010a) and are relevant to student teachers because completion of senior high school is a prerequisite for admission to the CoE. The instrument was modelled on SPS instruments used with science attitude questionnaires to determine relationships of the SPS with science attitudes among Palestinian secondary school students (Zeidan & Jayosi, 2015). Although the style of construction of the test was modelled on that of Zeidan and Jayosi (2015), the content was based on the Ghanaian curriculum. The index numbers of the participants were used to retrieve their entry qualification and scores in a particular science course that was common and compulsory to all of the participants. The accessed result was used as a measure of their academic performance.

Reliability of Instrument

Koomson (2020, 2021) reported a reliability of 0.7 using two science groups (A and B) in similar environments. Both groups A and B, each comprising 21 participants, were tested with SDSPS, and the results were analysed using Cronbach's alpha reliability test. The reliability test was conducted after proofreading and validation by chemistry teachers. The reliability of the current study was checked by testing and retesting using 40 students selected from one CoE outside of the sampled population after 4 weeks, and the retesting was conducted using the same items. The Cronbach's alpha reliability test of the two results was 0.84.

Sample

The participants for the study were all science student teachers in the four science CoE affiliated with the University of Cape Coast who were willing and available at the time of data collection. All students in the population frame were requested to participate. A few students opted

out, and others were absent on the day of data collection. In the end, 236 students, which comprised about 80% of the expected population, took part in the study. The participants were between 20 and 28 years old, with 48% being female and 52% male. Only 110 out of 236 participants willingly wrote their index numbers to access extant data for further analysis

Data Analysis

The result of the achievement test was analysed by assigning 1 to the correct answer and 0 to incorrect answers. Participants were scored for the overall SPS, BSPS and ISPS and all 10 subcategories of SPS, and the scores were converted into percentages. The academic scores were extracted from the extant data as percentages, with entry grade extracted as numbers, from a minimum of 6 to a maximum of 36, with the best entry grade being 6. These numbers and percentages allowed further analysis, including regression correlation and ANOVA.

Findings

Emphasis of Acquired Process Skills among College Student Teachers in Science Programmes

Research Question 1

What is the emphasis of the SPS acquired by student teachers in the CoE science programmes? Table 1 shows that participants who willingly gave their index numbers to access their academic and entry grades had mean scores better than the mean scores of the entire group of participants in all components of the SPS examined except the skill of observing.

Table 1

Descriptive Statistics of All Participants Compared to Those Providing Index Numbers for Follow-Up

Variable	Total Participants (*N*=236)			Participants Providing Index Number (*N*=110)		
	Mean	Std. Err.	Std. Dev.	Mean	Std. Error	Std. Dev.
SPS	45.3	1.1	16.6	50.7	1.7	17.7
BSPS	50.2	1.2	17.8	55.7	1.8	18.5
ISPS	39.3	1.4	21.2	44.4	2.1	21.6
Observing	60.4	1.7	25.4	59.1	2.5	25.7
Communicating	57.6	2.3	35.4	71.4	3.4	36.0
Data Interpreting	55.0	2.4	37.2	63.6	3.6	37.3
Measuring	52.0	1.7	26.8	55.2	1.9	20.3
Classifying	44.8	1.7	25.5	52.3	2.3	24.5
Inferring	39.2	2.0	30.9	45.0	3.0	31.7
Hypothesizing	35.3	2.4	36.3	37.1	2.2	22.9
Controlling Variables	35.1	1.8	27.3	41.8	2.9	30.3
Predicting	32.6	2.2	33.2	36.8	3.1	33.0
Experimenting	32.0	1.6	24.7	36.1	2.3	23.8
Entry Grade				23.5	0.4	4.3
Acad. Score				70.3	1.1	11.0

Note. SPS = Science process skills; BSPS = basic SPS; ISPS = integrated SPS

For example, the mean score for SPS was 45.3 for the entire group of participants ($N = 236$), but the group of participants who provided their index numbers ($n = 110$) had a mean SPS score of 50.7. Table 1 shows that student teachers in the CoE science programmes had acquired more BSPS (50.2%) than ISPS skills (39.3%). The top five acquired SPS in descending order of emphasis were observing (60.4%), communicating (57.6%), data interpreting (55%), measuring (52%) and classifying (44.8). Six of the acquired SPS fell below the passing mark of 50%: classifying (44.8%), inferring (39.2%), hypothesising (35.3%), controlling variables (35.1%), predicting (32.6%) and experimenting (32.0%). The only ISPS that scored higher than 50% was data interpreting.

Contributions of SPS and Entry Grades to Academic Performance

Research Question 2

What contributions do SPS and entry grades make to academic scores? Table 2 shows how the data in the study conform to assumptions made in using regression.

Table 2

Pearson's Correlation of the Dependent and Independent Variables

Variable	ISPS	BSPS	SPS	Academic Score	Entry Grade
ISPS					
BSPS	0.583*				
	0.000				
SPS	0.881*	0.897*			
	0.000	0.000			
Academic Score	0.313*	0.473*	0.445*		
	0.001	0.000	0.000		
Entry Grade	−0.073	−0.092	−0.093	−0.286*	
	0.447	0.338	0.332	0.002	

Note. *Correlation is significant at $p < .01$. SPS = Science process skills; BSPS = basic SPS; ISPS = integrated SPS

Table 2 shows that the data do not violate the assumption of multicollinearity. The independent variables, BSPS, ISPS and entry grades, correlate well with the dependent variable, academic score. The correlations among the independent variables, however, are not high (< .6) enough to violate the assumption of multicollinearity. Nevertheless, ISPS and BSPS correlated highly ($R > 0.8$ with SPS. Therefore, SPS was not included with either of them as a dependent variable in the same model. The consistency in the sustenance of the assumption of multicollinearity is also revealed by the tolerance and variance inflation factor (VIF) values of more than .1 and less than 10, respectively, for all variables, as shown in Table 4. Table 3 shows the regression model using SPS and entry grades as predictors of academic scores.

Table 3

Summary Model of Influence of Process Skills and Entry Grades on Academic Scores

Model	*R*	R^2	Adjusted R^2	Std. Error of the Estimate
1	.508	.258	.244	9.591

The *R* value in Table 3 indicates .508 with R^2 of .258. This shows that the two variables, SPS and entry grades, contribute 25.8% to academic scores.

HO1

There is no significant difference between process skills and entry grades on academic scores.Table 4 contains the regression coefficients of various predictors of academic scores.

Table 4

Regression Coefficients of the Variants

Variable	Standardized Coefficients	Sig.	Correlation	Collinearity Statistics	
	Beta		Part	Tolerance	VIF
SPS	0.445	0.000	0.445	1.000	1.000
BSPS	0.440	0.000	0.358	0.661	1.514
ISPS	0.056	0.592	0.046	0.661	1.514
Entry Grades	−0.246	0.004	−0.245	0.991	1.009

Note. VIF = Variance inflation factor; SPS = science process skills; BSPS = basic SPS; ISPS = integrated SPS.

Table 4 shows the part correlation coefficients of process skills and entry grades as .445 and .245, respectively. This shows that SPS and entry grades had unique contributions (part square) of 19.9% and 6%, respectively. Table 5 shows that the contributions from the two predictors (19.9% and 6%) are significant at $F(2, 107) = 18.6$, at $p < .0001$.

HO1 is, therefore, rejected. Acquired SPS is a significantly better predictor of academic performance than entry grades.

Table 5

ANOVA of Contributions of Process Skills and Entry Grades to Academic Scores

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3420.993	2	1710.496	18.594	0.000
	Residual	9843.380	107	91.994		
	Total	13264.373	109			

Contribution of Basic Skills and Integrated Skills to Academic Performance

HO2

There is no significant difference between contributions of basic and integrated skills on academic performance.

Table 6 shows the summary of the regression model using basic skills, integrated skills and entry grade as independent variables against academic scores as the dependent variable.

Table 6

Summary Model of Contributions of Process Skills and Entry Grades to Academic Scores

Model	*R*	R^2	Adjusted R^2	Std. Error of the Estimate
1	.533	.285	.264	9.462

The model shows that basic skills, integrated skills and entry grades contributed 28.5% to academic performance. Table 7 shows that the contributions made by the three independent variables were statistically different and significant at $F(3, 106) = 14.05$, at $p < .001$.

Table 7

ANOVA of Contribution of Process Skills and Entry Qualification to Academic Performance

	Model	Sum of Squares	df	Mean Square	F	Sig.
	Regression	3774.312	3	1258.104	14.052	.000
1	Residual	9490.061	106	89.529		
	Total	13264.373	109			

The beta value of .422 (Table 4) indicates that BSPS is the best predictor and significantly increases the dependent variable by .422, with an increase of a unit of standard deviation. The part correlation coefficient of .358 shows that BSPS uniquely contributes about 12.8% to performance. Entry grades is the second predictor of performance and decreases the dependent variable by .246 at any increase of a unit of standard deviation. The ISPS makes the least contribution at beta value of .049. Thus, HO2 is rejected. The contribution of BSPS to academic scores is significantly different and better than that of ISPS.

Contributions and Acquisitions of Subcategories of SPS

Research Question 3

How does acquisition of SPS relate to contribution to academic performance? Table 8 contains the mean scores for the subcategory of process skills and the contributions (R^2) each make to academic performance.

Table 8

Relationship between Development of Process Skills and Contribution to Academic Performance

Process Skills	M	SE	R^2	F	Sig.
Communicating	71.30	2.5	.200	26.93	<.001
Data Interpreting	63.60	1.9	.122	14.94	<.001
Predicting	36.80	2.3	.114	13.84	<.001
Measuring	55.20	3.0	.076	8.85	<.001
Classifying	52.30	3.1	.061	7.01	.01
Inferring	45.00	3.4	.060	6.88	.01
Controlling Variables	41.80	2.9	.056	6.44	.01
Observing	59.10	3.6	.053	6.06	.02
Hypothesising	37.10	2.2	.047	5.29	.02
Experimenting	36.10	2.3	.014	1.59	.21
Correlation			.7		

Table 8 shows the skills in descending order in terms of contributions to academic performance. For instance, the skill of communicating (M = 71.30; SE = 2.5) contributes more (20%) at F = 26.93, $p < .0001$ than the contribution (12.2%) of the skill of data interpreting (M = 63.60; SE = 1.9) at F = 14.94, $p < .0001$. The R^2 values show descending order of contribution to academic performance, as are the mean values, from communicating to experimenting skills. The only exceptions are predicting and observing skills. The correlation between the M and the contributions (R^2) was positive and strong at $R = .7$. This implies that the skills acquired by students relate to skills required to perform on academic assessments.

Discussion

In this study, 46.7% (110 out of 236) of the participants gave their index numbers to allow for further collection of data to answer all the research questions and hypotheses. The results showed that this group of participants (46.7% of the sampled population) had higher mean scores for process skills. Analysis of the data provided by Anane (2020) indicated that the mean entry grades for students in the CoE is about 28. The mean entry grade of the 46.7% of participants was 23.5 (Table 1). The higher grades of the group perhaps explain their boldness with making their index numbers available and their subsequent higher scores in the SPS achievement test.

Contrasting this study to Koomson (2021), it can be seen that, in general, students' acquisition of SPS drops from senior high school chemistry education to CoE science programmes. Senior high school chemistry students' acquired skills were 51.1%, 44.7% and 48% for BSPS, ISPS and SPS, respectively (Koomson, 2021) as against 50.2%, 39.2% and 45.3% for the respective skills acquired in this study. This drop can be partly explained by the nature of the admission of students into tertiary institutions in Ghana. Generally, students who enrol in traditional universities have higher grades than their counterparts who enter CoE (Anane, 2018). However, the 46.7% of CoE respondents' acquired skills were found to be higher than even the senior high school chemistry students. They scored 55.7%, 44.4% and 50.7% for BSPS, ISPS and SPS, respectively.

Nonetheless, the average SPS for prospective science teachers (teacher trainees) for primary and junior high schools seems low considering the fact that they are required to help develop the SPS in their students. The acquired SPS in the CoE were consistent with those found among senior high schools concluding that skills such as observing, communicating, measuring and data interpreting

were fairly well developed, but skills such as classifying, inferring, predicting, controlling variables, hypothesising and experimenting were underdeveloped. SPS of inferring, predicting and controlling variables interact between theory and practice to evaluate and synthesize new knowledge. Lack of these skills implies that student teachers are likely to lack the 21st-century skills espoused by Kayange and Msiska (2016) and Lee and Hung (2012).

What was significantly different from Koomson (2021) was that the classifying skill was found to be the least developed at the senior high school level, but it was found to be the fifth most prominent skill acquired at the CoE level, with the mean increased from 34% to 44%. This may be due to increases in practical activities involving classification at the CoE. Taale et al. (n.d.) indicated that student teachers identified classification and identification as the third most prominent practical activity among eight other skills in the CoE. This observation shows that SPS development and acquisition is dependent on a variety of teaching approaches during the science learning process (Rauf et al., 2013). The observed low score in acquired SPS is consistent in the literature, particularly in curricula where a teacher-centred approach to teaching is dominant. For example, Beichumila et al. (2022) found that the mean acquired SPS in a Tanzania school was 42.28%, which increased to 62.79% after a treatment of adding computer simulations and animations.

The study is, unique in demonstrating that acquired SPS contribute significantly better to academic performance than entry grades. Saçkes (2013) found that 22% of children's achievement in science is explained by acquired SPS. The present study found that 19.9% of the student teachers' achievement in science is explained by their acquired SPS. The difference may be due to the effects of confounding factors in Saçkes' (2013) methodological approach, as raised in the literature review. Spahr (1995) used multiple regression to analyse the effects of entry grades among scores in biology, chemistry and physics on students' grade point averages. The reported contribution of 4.4% for entry grades is similar to the 6.6% realized in this study. Wambugu and Emeke (2013) asserted that an alternative to entry grades should be sought as admission criterion because entry grades contribute less than 50% to academic achievement, as they reported that entry grades contributed to 43.7%, 22.5% and 3%, respectively, to academic achievements in biology, chemistry and physics. Unlike Spahr (1995) and the present study, Wambugu and Emeke (2013) used univariate regression analysis. According to Andrade (2021), the confounding effect is more pronounced when univariate analysis is used. Although we do not agree that entry grade should be discontinued as admission criterion because its contribution is below 50%, we agree that a better alternative should be sought. Acquired SPS may therefore satisfy the alternative that Wambugu and Emeke (2013) seek as admission criteria to tertiary institutions.

The present study also found that BSPS contributed significantly more to academic performance than ISPS. If BSPS, which demands lower cognitive ability than ISPS, is higher contributing, then it can be inferred that the academic assessment tool used requires mainly lower cognitive skills. If this is the case, then the emphasis of the academic assessment at the CoE is not so different from that of secondary schools, which is organised by the Kenyan and West African examination bodies (Akinbobola & Afolabi, 2010; Koomson, 2020; Ongowo & Indoshi, 2013). The examinations conducted by theses bodies in the area of chemistry, biology and physics are found to emphasise BSPS, with a significant level of recalling factual knowledge (Akinbobola & Afolabi, 2010; Koomson, 2020; Ongowo & Indoshi, 2013). The positive relationship found between the acquired SPS and contributions made to academic performance also seems to suggest that learners adjust their development and acquisition of SPS to the demands of academic assessments. In other words, acquisition and development of SPS depends not only on the variety of teaching approaches used during the science learning process but also on the nature of assessment tools used to give summative marks for the academic process. The analysis in this study therefore confirms Harlen's (1999) observation that the nature of assessment practice influences the development and acquisition of SPS.

Conclusion and Implications

The emphasis placed on acquiring and developing SPS in science education is as important as the emphasis on developing 21st-century skills in education in general. These skills, such as problem solving, critical thinking and decision-making, among others, are related to SPS, including observing, inferring, predicting, classifying, evaluating, experimenting and others classified as SPS in science education. The observation that these important skills are inadequately acquired and developed among teacher trainees, who are required to be future facilitators of these skills among basic school learners, needs immediate attention. The present study showed that using achievement in SPS to select candidates for science-related programmes, particularly at the tertiary level, is perhaps more appropriate than relying on their grades at the secondary level of education. The basis for this assertion is the evidence that acquired SPS contributes more to the success of candidates in science programmes than do entry grades. The authors recommend that in addition to entry qualifications, admissions into tertiary levels, particularly for science-based programmes, should be based on competencies in SPS. This move will compel development of these essential skills to not only understand science better but also to encourage innovation and creativity. Also, examinations of students at both the secondary and tertiary levels should be focused on testing these skills rather than emphasising factual recall of knowledge.

References

Abungu, H. E., Okere, M. I., & Wachanga, S. W. (2014). Effect of science process skills teaching strategy on boys' and girls' achievement in chemistry in Nyando district, Kenya. *Journal of Education and Practice*, *5*(15), 42-48.

Akinbobola, A. O., & Afolabi, F. (2010). Analysis of science process skills in West African senior secondary school certificate physics practical examinations in Nigeria. *American-Eurasian Journal of Scientific Research*, *5*(4), 234–240.

Andrade, C. (2021). The limitations of quasi-experimental studies, and methods for data analysis when a quasi-experimental research design is unavoidable. *Indian Journal of Psychological Medicine*, *43*(5), 451-452.

Anane, E. (2018). Examining the relationship between pre-service teachers' entry characteristics and their academic achievement. *Journal of Educational Sciences & Psychology*, *8*(1), 56–67.

Anane, E. (2020). A multiple mediation analysis of the effect of prior performance on academic achievement through student teachers' motivational orientations. *Higher Education Research*, *5*(4), 118. https://doi.org/10.11648/j.her.20200504.12

Ango, M. L. (1992). Issues in technology education for national development. In P. O. Awotunde (Ed.), *Issues in technology education for national development* (1st ed., Vol. 1, pp. 92–104). National Association of Teachers of Technology.

Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The influence of project-based STEM (PjbL-STEM) applications on the development of 21st century skills. *Journal of Turkish Science Education*, *18*(4), 798-815.

Beaumont-Walters, Y., & Soyibo, K. (2001). An analysis of high school students' performance on five integrated science process skills. *Research in Science and Technological Education*, *19*(2), 133–145. https://doi.org/10.1080/02635140120087687

Beichumila, F., Bahati, B., & Kafanabo, E. (2022). Students' acquisition of science process skills in chemistry through computer simulations and animations in secondary schools in Tanzania. *International Journal of Learning, Teaching and Educational Research*, *21*(3), 166–195.

Darling-Hammond, L., & Bransford, J. (Eds.). (2005). *Preparing teachers for a changing world: What teachers should learn and be able to do*. Jossey-Bass.

Dembélé, M., & Lefoka, P. (2007). Pedagogical renewal for quality universal primary education: Overview of trends in sub-Saharan Africa. *International Review of Education*, *53*(5–6), 531–553. https://doi.org/10.1007/s11159-007-9066-8

Dembo, M. H. (2001). Learning to teach is not enough—Future teachers also need to learn how to learn. *Teacher Education Quarterly*, *28*(4), 23–35.

Downing, J. E., & Gifford, V. (1996). An investigation of preservice teachers' science process skills and questioning strategies used during a demonstration science discovery lesson. *Journal of Elementary Science Education*, *8*(1), 64. https://doi.org/10.1007/BF03173741

Duruk, U., Akgün, A., Doğan, C., & Gülsuyu, F. (2017). Examining the learning outcomes included in the Turkish science curriculum in terms of science process skills: A document analysis with standards-based assessment. *International Journal of Environmental and Science Education*, *12*(2), 117–142.

Early, D. M., Iruka, I. U., Ritchie, S., Barbarin, O. A., Winn, D. M. C., Crawford, G. M., ... & Pianta, R. C. (2010). How do pre-kindergarteners spend their time? Gender, ethnicity, and income as predictors of experiences in pre-kindergarten classrooms. *Early Childhood Research Quarterly*, *25*(2), 177-193.

Ergül, R., Şimşekli, Y., Çalış, S., Özdilek, Z., Göçmençelebi, Ş., & Şanlı, M. (2011). The effects of inquiry-based science teaching on elementary school students' science process skills and science attitudes. *Bulgarian Journal of Science and Education Policy*, *5*(1), 48–68.

Farsakoğlu, Ö. F., Şahin, Ç., & Karsli, F. (2012, June). Comparing science process skills of prospective science teachers: A cross-sectional study. In *Asia-Pacific Forum on Science Learning and Teaching* (Vol. 13, No. 1, pp. 1-21). The Education University of Hong Kong, Department of Science and Environmental Studies.

Flores, M. A., & Day, C. (2006). Contexts which shape and reshape new teachers' identities: A multi-perspective study. *Teaching and Teacher Education*, *22*(2), 219–232.https://doi.org/10.1016/j.tate.2005.09.002

Harlen, W. (1999). Purposes and procedures for assessing science process skills. *Assessment in Education: Principles, Policy & Practice*, *6*(1), 129–144. https://doi.org/10.1080/09695949993044

Hiğde, E., & Aktamış, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. *Thinking Skills and Creativity*, *43*, 101000

Hoskins, S. L., Newstead, S. E., & Dennis, I. (1997). Degree performance as a function of age, gender, prior qualifications and discipline studied. *Assessment & Evaluation in Higher Education*, *22*(3), 317-328.

Kasuga, W., Maro, W., & Pangani, I. (2022). Effect of Problem-Based Learning Approach on Developing Students' Science Process Skills on the topic of Safety in our Environment. *Journal of Turkish Science Education*, *19*(3). 10.36681/tused.2022.154

Kayange, J. J., & Msiska, M. (2016). Teacher education in China: Training teachers for the 21st century. *The Online Journal of New Horizons in Education*, *6*(4), 204–210.

Koksal, E. A., & Berberoglu, G. (2014). The effect of guided-inquiry instruction on 6th grade Turkish students' achievement, science process skills, and attitudes toward science. *International Journal of Science Education*, *36*(1), 66-78.

Koomson, A. (2020). *An investigation into development of science process skills by senior high school chemistry students* [doctoral dissertation, University of Cape Coast]. University of Cape Coast Institutional Repository.

Koomson, A. (2021). Assessing acquired science process skills of senior high schools in central region, Ghana. *Advances in Social Sciences Research Journal*, *8*(11), 438–451. https://doi.org/10.14738/assrj.811.11291

Lee, L. S.-S., & Hung, D. (2012). Is there an instructional framework for 21st century learning? *Creative Education*, *3*(4), 461–470. https://doi.org/10.4236/ce.2012.34071

Lewin, K. M., & Stuart, J. S. (2003). *Researching teacher education: New perspectives on practice, performance and policy* (Education Papers series). Policy Division of the Department for International Development, Sussex, UK.

Ministry of Education (MoE). (2007a). *Science syllabus for junior high schools*. Curriculum Research and Development Division (CRDD).

Ministry of Education (MoE). (2007b). *Teaching syllabus for primary schools*. Curriculum Research and Development Division (CRDD).

Ministry of Education (MoE). (2010a). *Chemistry syllabus for junior high schools*. Curriculum Research and Development Division (CRDD).

Ministry of Education (MoE). (2010b). *Integrated science syllabus for senior high schools*. Curriculum Research and Development Division (CRDD).

Ministry of Education (MoE). (2019). *Science curriculum for primary schools (basic 1–3)*. National Council for Curriculum and Assessment (NaCCA).

Mushani, M. (2021). Science process skills in science education of developed and developing countries: Literature review. *Unnes Science Education Journal*, *10*(1), 12–17. https://doi.org/10.15294/usej.v10i1.42153

Nwosu, A. A., & Okeke, E. A. C. (1995). The effect of teacher sensitization of students' acquisition of science process skills. *Journal of Science Teachers Association of Nigeria*, *30*(1 & 2), 39–45.

Ogunleye, B. O., & Agoro, A. A. (2013). Reflective-reciprocal teaching and mode of entry as determinants of pre-service teachers' science process skills. *Journal of Applied Education and Vocational Research*, *10*(2), 151–164.

Ongowo, R. O., & Indoshi, F. C. (2013). Science process skills in the Kenya certificate of secondary education biology practical examinations. *Creative Education*, *4*(11), 713–717. https://doi.org/10.4236/ce.2013.411101

Opara, J. A. (2011). Some considerations in achieving effective teaching and learning in science education. *Journal of Educational and Social Research*, *1*(4), 85–89.

Opulencia, L. M. (2011). *Correlates of science achievement among grade VI pupils in selected elementary schools San Francisco District, Division of San Pablo City*. Laguna State Polytechnic University.

Osman, K., & Vebrianto, R. (2013). Fostering science process skills and improving achievement through the use of multiple media. *Journal of Baltic Science Education*, *12*(2), 191–204. https://doi.org/10.33225/jbse/13.12.191

Padilla, J. M. (1990). *The science process skills. Research matters—to the science teacher* (Research matters, no. 9004). National Association for Research in Science Teaching.

Patonah, S., Nuvitalia, D., & Saptaningrum, E. (2018). Content analysis of science material in junior school-based inquiry and science process skills. *Journal of Physics: Conference Series*, *983*, Article 012167. https://doi.org/10.1088/1742-6596/983/1/012167

Rauf, R. A. A., Rasul, M. S., Mansor, A. N., Othman, Z., & Lyndon, N. (2013). Inculcation of science process skills in a science classroom. *Asian Social Science*, *9*(8), 47–57. https://doi.org/10.5539/ass.v9n8p47

Republic of Ghana (2002). *Meeting the challenges of education in the twenty-first century: Report of the President's Committee on Review of Education Reforms in Ghana*. Adwinsa Publications.

Rice, J. K. (2003). Investing in teacher quality: A framework of estimating the cost of teacher professional development. In W. Hoy & C. Miskel (Eds.), *Theory and research in educational administration* (2nd ed.). Information Age Publishing, Inc.

Sabah, S., Akour, M. M., Hammouri, H. (2023). Implementing next generation science practices in classrooms: Findings from TIMSS 2019. *Journal of Turkish Science Education*, *20*(2), 309-319. https://doi.org/10.36681/tused.2023.017

Saçkes, M. (2013). Children's competencies in process skills in kindergarten and their impact on academic achievement in third grade. *Early Education & Development*, *24*(5), 704-720.

Saçkes, M., Trundle, K. C., Bell, R. L., & O'Connell, A. A. (2011). The influence of early science experience in kindergarten on children's immediate and later science achievement: Evidence

from the early childhood longitudinal study. *Journal of Research in Science Teaching*, *48*(2), 217-235.

Siachibila, B., & Banda, A. (2018). Science process skills assessed in the Examinations Council of Zambia (ECZ) Senior Secondary School Chemistry—5070/3 practical examinations. *Chemistry and Materials Research*, *10*(5), 17–23. www.iiste.org

Spahr, A. E. (1995). Predicting graduation status of nursing students using entering GPA and grades in algebra, biology, and chemistry.

Taale, K. D., Hanson, R., & Antwi, V. (n.d.). *Practical skills of science teacher–trainees in science and mathematics colleges of education in Ghana*. University of Education, Winneba.

Tsui, A. B. M. (2009). Distinctive qualities of expert teachers. *Teachers and Teaching*, *15*(4), 421–439. https://doi.org/10.1080/13540600903057179

Uzun, S., & Sen, N. (2023). The Effects of a STEM-based intervention on middle school students' science achievement and learning motivation. *Journal of Pedagogical Research*, *7*(1), 228-242.

Wambugu, L., & Emeke, A. (2013). Relationship between entry qualification and academic performance in undergraduate science courses at the University of Nairobi, Kenya. *Proceedings of the Pan-Commonwealth Forum*, Article 85.

Yaayin, B., Oppong, E. K., & Hanson, R. (2021). Efficacy of jigsaw model in improving pre-service teachers' performance in selected functional group organics compounds. *Science Education International*, *32*(3), 191–196.

Zeidan, A. H., & Jayosi, M. R. (2015). Science process skills and attitudes toward science among palestinian secondary school students. *World journal of Education*, *5*(1), 13-24.

Zezekwa, N., & Mudavanhu, Y. (2011). The Effects of entry qualifications on student's performance in university science courses: The case of Bindura University of science education. *African Journal of Education and Technology*, *1*(3), 32-39.

Journal of Turkish Science Education, 2024, *21*(1), 134-152.
DOI no: 10.36681/tused.2024.008

The impact of emerging technology in physics over the past three decades

Binar Kurnia Prahani[1], Hanandita Veda Saphira[2], Budi Jatmiko[3], Suryanti[4], Tan Amelia[3]

[1]*Faculty of Mathematics and Natural Science, Universitas Negeri Surabaya, Indonesia, binarprahani@unesa.ac.id, Corresponding author, 0000-0002-5606-6629*
[2] *Faculty of Mathematics and Natural Science, Universitas Negeri Surabaya, Indonesia, 0000-0002-3609-952X*
[3] *Faculty of Mathematics and Natural Science, Universitas Negeri Surabaya, Indonesia, 0000-0002-0713-9078*
[4] *Faculty of Science Education, Universitas Negeri Surabaya, Indonesia, 0000-0003-0341-2716*
[5] *Faculty of Information Systems, Universitas Dinamika, Indonesıa 0000-0003-1083-7552*

ABSTRACT
As humanity reaches the 5.0 industrial revolution, education plays a critical role in boosting the quality of human resources. This paper reports bibliometric research on emerging TiP during 1993-2022 in the educational field to analyse its development on any level of education during the last three decades. This study employed a Scopus database. The findings are that the trend of TiP publication in educational fields has tended to increase every year during the past three decades and conference paper became the most published document type, the USA is the country which produces the most publications; 'Students' being the most occurrences keyword and total link strength. The publication of the TiP is ranked to the Quartile 1, which implies that a publication with the cited performance is a publication with credibility because the publisher has a good reputation. Researchers can find the topics most relevant to other metadata sources such as Web of Science, Publish, and Perish.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
01.04.2023
Accepted:
26.09.2023

KEYWORDS:
Bibliometric, education, Educational, physics, technology.

To cite this article: Prahani, B.K., Saphira, H.V., Jatmiko, B., Suryanti, & Amelia, T. (2024). The impact of emerging technology in physics over the past three decades. *Journal of Turkish Science Education, 21*(1), 134-152. DOI: 10.36681/tused.2024.008

Introduction

As humanity enters the 5.0 age, education will be critical in boosting human capital quality. Society 5.0 is a stage of civilisation that addresses various technical and social problems using advanced technologies produced during the industrial revolution's 4.0, including Artificial Intelligence (A.I.), robots, internet of Things (IoT), and Big Data (large amounts of data) to improve the quality of human life (Kahar et al., 2021). Society 5.0 is human-centered but technologically based (Hamdani et al., 2019; Islam et al., 2020). However, technology-based platform's influence differed since pupils viewed the constructed elements variously (Christopulos & Sprangers, 2021).

Physics is one of the subjects with a high opportunity for implementing technology in its teaching and learning. The digitisation of critical thinking skills in physics learning is an on-going trend (Jatmiko et al., 2021). Since it needs innovative learning in applying IT-based learning (Koç & Büyük, 2021; Morales et al., 2022; Negoro et al., 2023), IT-based physics education can stimulate pupils' active participation, as well as the findings demonstrate a considerable boost in physics (TiP) learning (Aswal et al., 2019; Ferty et al., 2019; Tetep & Dahlena, 2021; Wijaya et al., 2021). The benefit of emerging TiP learning is that pupils may interact with high-quality, actual data like experts do (Damar & Turkey, 2022; Ellermeijer & Tran, 2019; Iatsyshyn et al., 2020; Karim et al., 2020). Physics education using technological devices is similar to practising in interaction with the present study effort (Deveci, 2023; Jumini et al., 2022). Investigations using technological tools are described as demanding, complicated, open-ended, requiring a substantial commitment and a diverse set of abilities (Khan et al., 2022; Van den Beemt et al., 2020; Vesikivi et al., 2020; Wang et al., 2022). However, there are still obstacles and challenges in implementing emerging technology in physics learning (Mwambela, 2019).

Organisations are paying particular attention to advancements in A.I. and robotics because they promise eventual efficiency improvement (Schweikl & Obermaier, 2020), especially in educational fields (Papadopoulos et al., 2020; Raman et al., 2022). Previous research involving a bibliometric investigation has focused on emerging e-books (Dawana et al., 2022), e-module (Dewantara et al., 2021) in physics learning, augmented reality (A.R.)-based in the laboratory of physics (Putri et al., 2021), Prezi mind mapping as media in physics learning (Zakhiyah et al., 2021), and online physics learning in Indonesia (Yani et al., 2021). However, in previous studies, there has yet to be a publication of the bibliometric in emerging technology in physics. This research conducted bibliometric research on publications **(Prahani et al., 2022)** of emerging technology in the physics education field to analyze its actual impact in any level of education during 1993 to 2022.

Research Objectives

This research identifies bibliometrics on TiP keywords in educational fields. The publications indexed by Scopus were used to collect the metadata. This research was to compare trends, patterns, novelty, and future research in TiP over the past three decades. Specifically, the objectives of this research were as follows:

1. To compare trends in research on the TiP publications during 1993-2022.
2. To identify the various type ot TiP publications during 1993-2022.
3. To identify the most used language in TiP publications during 1993-2022.
4. To identify the top 10 most productive countries in terms of TiP publications during 1993-2022.
5. To detect any trend in mapping of TiP keywords network publications during 1993-2022 to finding the novelty, recommendation and implication for further research.
6. To identify the promenint of the sponsorship finding, affiliation and authors during 1993-2022 as recommendation or futher collaboration in TiP research for further researcher.
7. To identify the main subject areas of TiP publications during 1993-2022.
8. To identify the distribution of top cited publication TiP during 1993-2022.
9. To identify the top 5 cited publications in TiP publication research during 1993-2022 as further recommendation to develop the TiP research.
10. To identify the research route in TiP to educational fields for future research

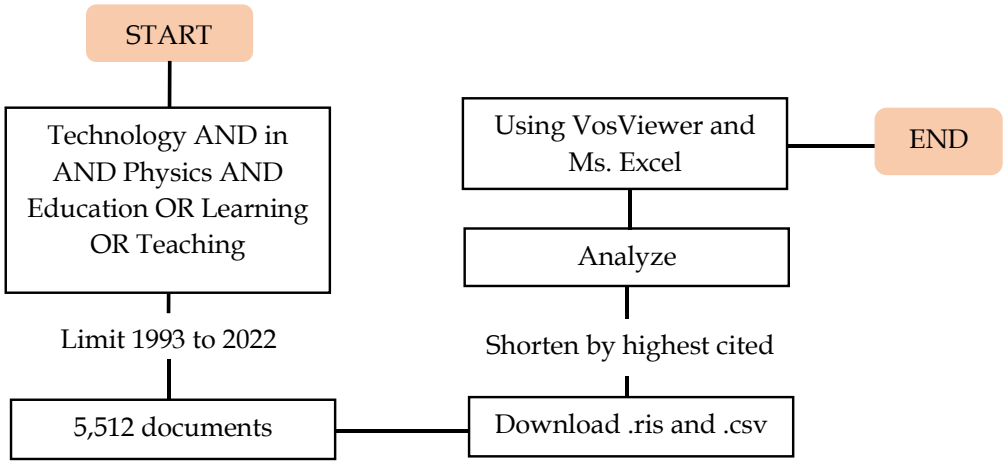
Methods

This study employed a Scopus database (http://www.scopus.com/) since it contains more linked records than other sources (Phuong et al., 2022). Bibliometric analysis assists researchers in determining long-term trends (Schöbel et al., 2021; **Abdullah, 2022**). Furthermore, bibliometric analysis scientists' contributions, interactions, and the annual increase in publications and citations

(Do et al., 2021; Prahani et al., 2022; Yanniris & Huang, 2018). The steps of this research were as follows: (1) developed a research plan, (2) acquired information examination objectives, (3) data processed, and (4) summarised and presented information (Moral-Muñoz et al., 2020; Prahani et al., 2022). The flowchart of this research to determine the emerging technology in educational physics fields is as in Figure 1.

Figure 1

Research Flowchart



Data were gathered on February 8th, 2023, yielding 6,042 publications, reduced to 5,512 by restricting the timeframe to 1993-2022 by highest to lowest citation. The data was imported to external software for descriptive analysis (Kamarrudin et al., 2022; Marulanda-Grisales & Vera-Acevedo, 2022).

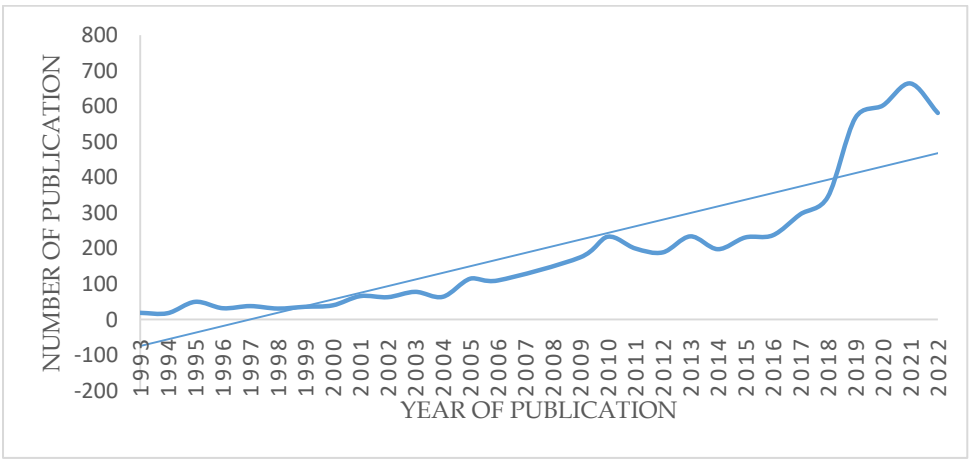
Findings

Types of Documents, and Most Used Language in TiP Publications 1993-2022

Figure 2 depicts the trend in physics (TiP) education during 1993-2022.

Figure 1

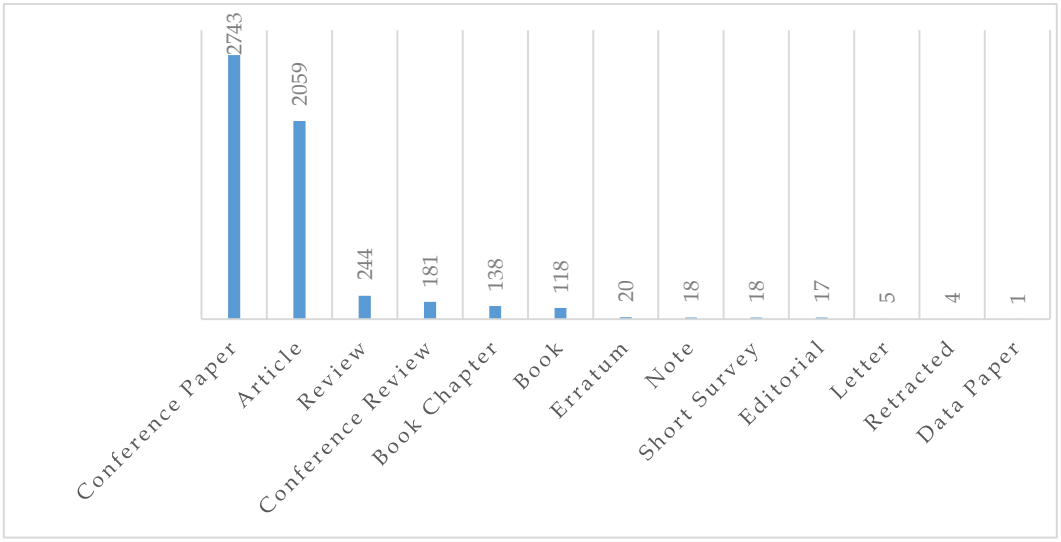
Number Publications of TiP in Educational Fields



The trend of publications in TiP consists of various available documents. Whether all documents were open access or not in any journal website, proceeding, book, book chapters, lecture notes, or more (Kousha & Thelwall, 2020), based on the data gathered, it can be known the various types of documents published from 1993 to 2022 as a deliberation for future researchers. Figure 3 shows the various types of published documents on TiP.

Figure 3

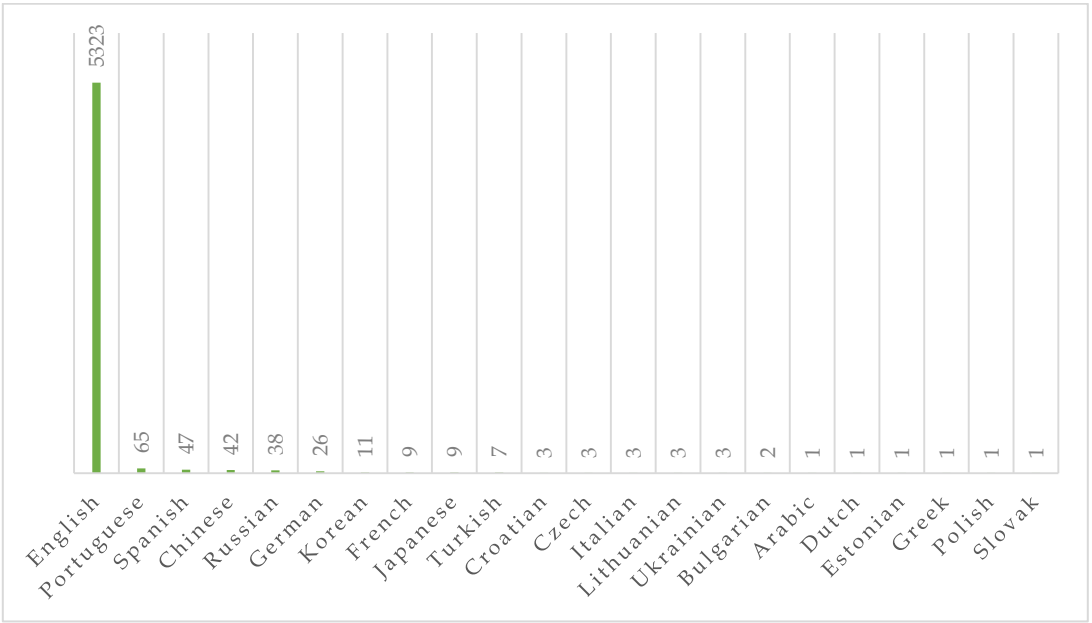
Various Types of TiP Publications in Educational Fields



Based on Figure 3, the conference paper (C.P.) is the most widely used with 2,743 documents. An 'article' is the second most common form of publication in the TiP study, accounting for 2,059 publications. 'C.P.' displayed at a summit for many specialists from various disciplines to see (Gass et al., 2021; Papadakis, 2021). Figure 4 shows the most used language in TiP publication.

Figure 4

The Most Used Langauge in TiP Publication



Top Countries in TiP Publications During 1993-2022

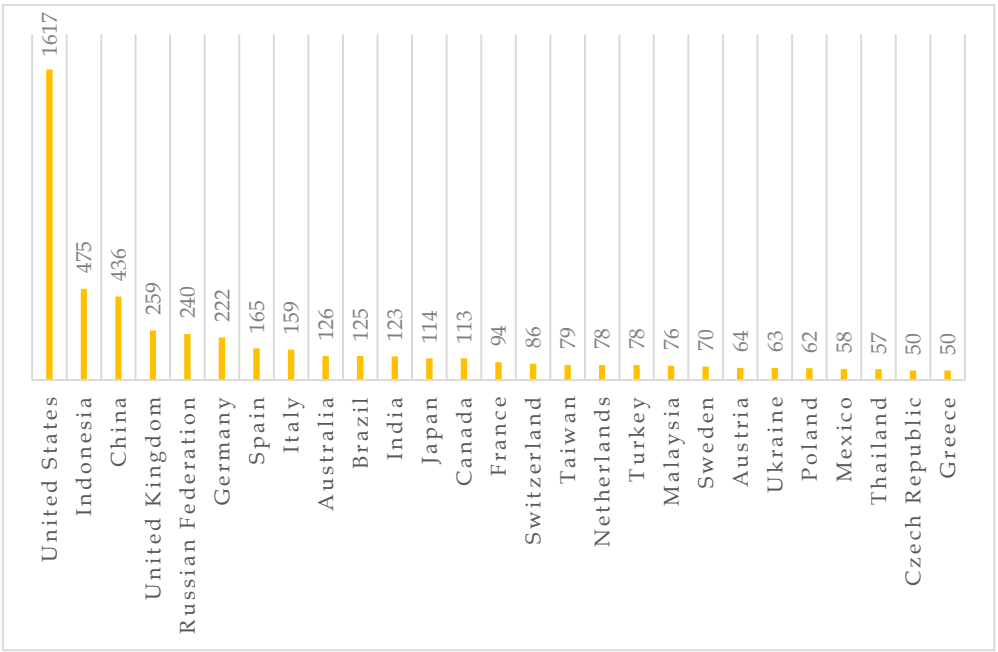
Figures 5 and **6** show the most productive countries in TiP publications can be analyzed using metadata. It is known that 122 countries are being recorded in Scopus.

Figure 5

World Contribution Countries to TiP Publications

Figure 6

Top Countries in TiP Publications



Based on Figures 5 and **6,** in line with the most used language, the United States (1,617) is the most productive country for TiP publications from 1993 to 2022.

Trend Mapping Visualisation of TiP in Educational Fields During 1993 to 2022

The most occurrence keywords are analyzed before mapping out the occurances keywords of TiP publications during 1993-2022, as shown in Table 1. It can be seen that the highest total link strength (3,420) and the most frequently occurring keywords (441) are "Students."

Table 1

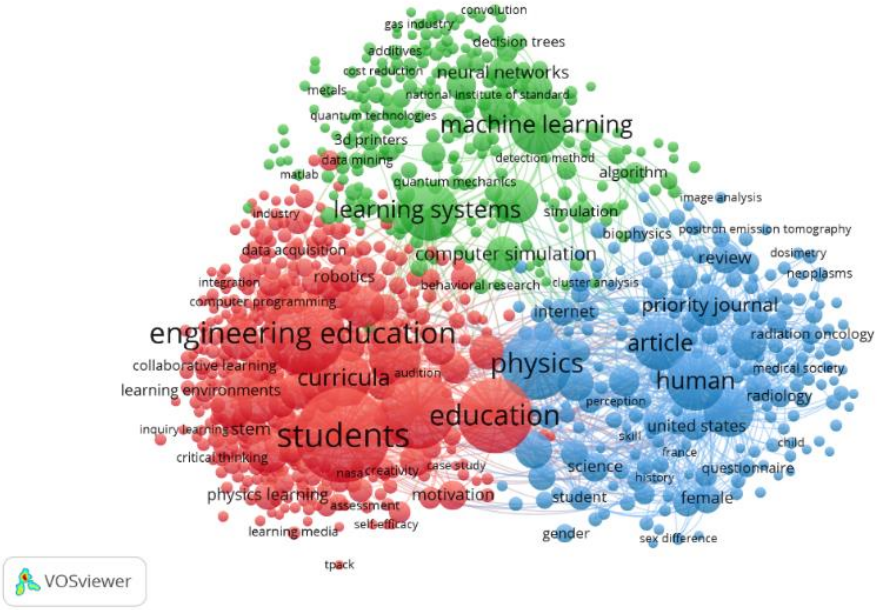
Top 20 Most Occurring Keyword in TiP Publications

Keyword	Occurences	Total Link Strength	Keyword	Occurences	Total Link Strength
Students	441	3,420	Curricula	149	1,258
Education	276	2,713	Machine learning	155	1,131
Teaching	279	2,511	e-learning	129	1,117
Engineering education	322	2,346	Medical learning	64	1,077
Human	166	2,338	STEM (Science, Technology, Engineering and Mathematics)	98	811
Article	142	2,076	Artificial intelligence (AI)	94	763
Physics	242	2,067	Virtual reality (VR)	89	743
Humans	125	1,875	Education computing (EC)	81	695
Learning systems	170	1,405	Curriculum	47	687
Priority journal	84	1,345	Educational technology	59	668

The metadata keywords are mapped to identify the TiP publication's recommendation in using techonology-based learning. To find a recommendation of the research based on the mapping results, look at the relationships between smaller or fewer keywords (Al-Husaeni & Nandiyanto, 2022; Escher, 2020; Nandiyanto et al., 2022). As in Figure 8 are all linked keywords.

Figure 7

Keyword Mapping Visualisation of TiP Publications during Three Decades



Hence, to find the novelties for future research of TiP publications in educational fields, the keywords are detailed to the fewest and most significant links, as in Figures 7 and 8 The mapping visualization of the metadata that presumably looks at the relationships between minor or fewer keywords to identify a novelty of the research based on the mapping results.

Figure 8

The Most Linked Keyword

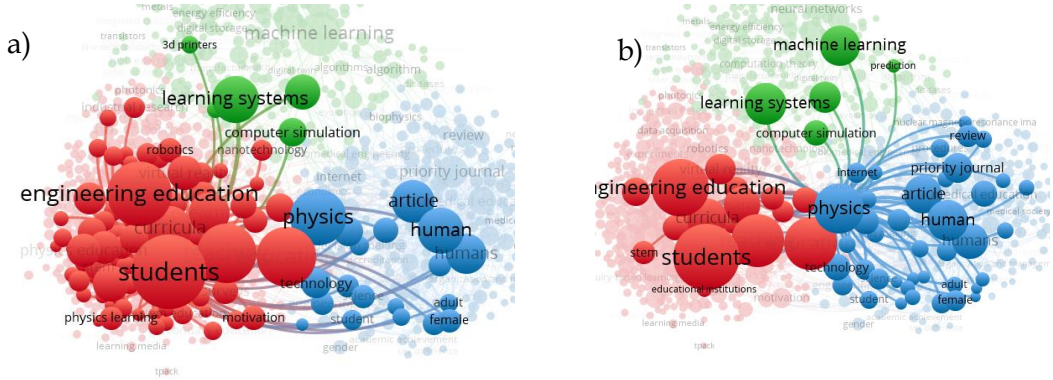
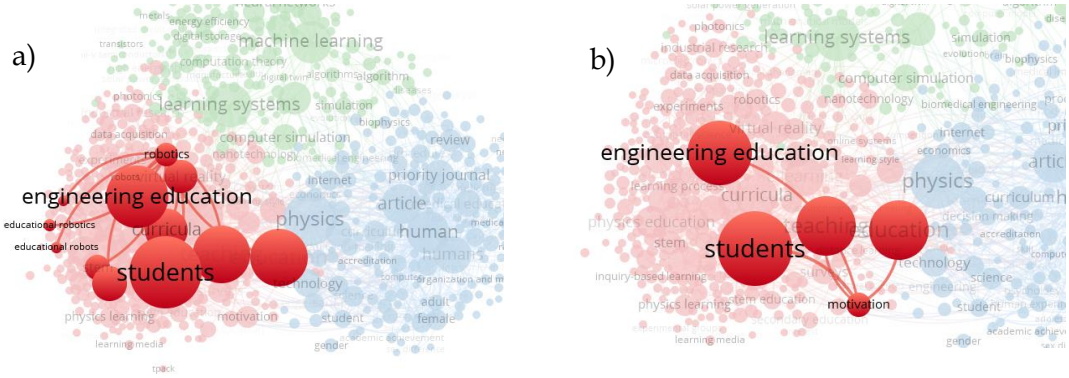


Figure 9

The Least Linked Keyword



Sponsorship Funding, Authors and Their Affiliations

Table 2 shows the lists of top sponsorship funding, affiliation, and authors of TiP in educational fields from 1993 to 2022 as references for further researchers to conduct, collaborate or elaborate research. The relationships between authors can be analyzed using Vosviewer, as in Figure 11.

Table 2

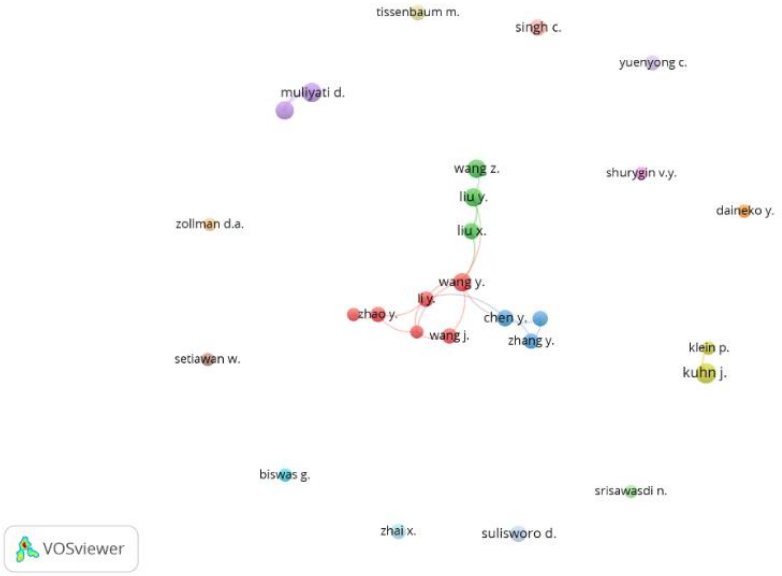
Top Sponsorship Funding, Affiliation and Authors in TiP Publications

Sponsorship Funding	Total	Affiliation	Total	Authors	Total
National Science Foundation	225	University of Indonesia	56	Bakri, F.	21
National Natural Science Foundation of China	94	Jakarta State University	54	Muliyati, D.	16
U.S. Department of Energy	55	State University of Padang	47	Romaniuk, R.S.	14
Horizon 2020 Framework Programme	34	Purdue University	44	Yuenyong, C.	14
European Commission	24	Yogyakarta State University	44	Kuhn, J.	12
Japan Society for the Promotion of Science	23	Stanford University	39	Wibowo, F.C.	12
Bundesministerium für Bildung und Forschung	19	Massachusetts Institute of Technology	38	Daineko, Y.	11

Sponsorship Funding	Total	Affiliation	Total	Authors	Total
National Institutes of Health	19	Texas University	31	Sprawls, P.	11
Office of Science	19	Arizona State University	28	Sulisworo, D.	11
Engineering and Physical Sciences Research Council	18	University of Michigan, Ann Arbor	27	Jumadi	10

Figure 10

The Mapping Visualisation of Authors in TiP Publication



Top Subject Areas and Sources of TiP

The top subject areas and source titles are being analysed to open the possible subject areas that can be developed in TiP and subject areas that still need to be correlated with TiP so that they can develop. Table 3 shows the top subject areas and source titles of TiP publications in educational fields from 1993 to 2022.

Table 3

The Top Subject Area and Source Title to TiP Publications

Subject Area	Total	Source Title	Total
Engineering	1,921	Journal Of Physics Conference Series	601
Physics and Astronomy	1,708	ASEE Annual Conference and Exposition Conference Proceedings	204
Social Sciences	1,529	Aip Conference Proceedings	150
Computer Science	1,526	Proceedings Of SPIE The International Society for Optical Engineering	150
Mathematics	519	Medical Physics	80
Materials Science	431	ASEE Annual Conference Proceedings	75
Medicine	355	Physics Education	59
Energy	278	Proceedings Frontiers in Education Conference	53
Earth and Planetary Sciences	208	Ceur Workshop Proceedings	51

Distribution of Top Cited Publication TiP During 1993 to 2022

Table 4 shows the distribution of publications on TiP publication during 1993-2022. ACPP is known as Average Citation Per Paper, the highest rank of the paper distribution noted by the *.

Table 4

Paper Distribution of TiP Publications 1993-2022

Year	Paper	Cited	ACPP	ACPPY	Citable Years	Year	Paper	Cited	ACPP	ACPPY	Citable Years
1993	19	220	11.58	0.39	30	2009	175	1,641	9.38	0.67	14
1994	18	52	2.89	0.10	29	2010	233	2,359	10.12	0.78	13
1995	50	68	1.36	0.05	28	2011	200	2,509	12.55	1.05	12
1996	32	351	10.97	0.41	27	2012	189	1,181	6.25	0.57	11
1997	38	282	7.42	0.29	26	2013	234	851	3.64	0.36	10
1998	31	24	0.77	0.03	25	2014	198	6,602*	33.34*	3.70*	9
1999	36	323	8.97	0.37	24	2015	231	1,462	6.33	0.79	8
2000	40	282	7.05	0.31	23	2016	237	2,252	9.50	1.36	7
2001	66	1,147	17.38	0.79	22	2017	296	1,782	6.02	1.00	6
2002	63	337	5.35	0.25	21	2018	345	3,289	9.53	1.91	5
2003	78	440	5.64	0.28	20	2019	567	2,250	3.97	0.99	4
2004	64	978	15.28	0.80	19	2020	602	1,964	3.26	1.09	3
2005	115	1,874	16.30	0.91	18	2021	664*	1,281	1.93	0.96	2
2006	110	985	8.95	0.53	17	2022	581	74	0.13	0.13	1
Year	Paper	Cited	ACPP	ACPPY							
Total	5,512	36,860	235.86	20.86	-						

Publication Review and State of The Art of TiP 1993-2022

Table 5 reviews previous research filtered by the highest citation of TiP publication from 1993 to 2022. The chosen publication is identified as publications related to educational fields with specific titles, abstracts, or other keywords.

Table 5

Publication Review of TiP Publication in Educational Fields During 1993-2022

Author(s)	Citation	SJR-CiteScore (2021)-Percentile to Education (2020)	Findings	Recommendations
(Deslauriers et al., 2011)	715	14.589 (Q1)-57.8-(98th)	In different instructional approaches, there is an increase in student attendance, high engagement using research-based instruction.	For subsequent research, it can use more diverse research subjects so that results tend to be generalized in certain schools
(Potkonjak et al., 2016)	442	3.68 (Q1)-19.8-(99th)	Advances in computer graphics, virtual reality, and cyber technology can accelerate the use of virtual laboratory-based system applications so as to reduce the real needs of laboratories.	It is recommended that the use of virtual lab simulators be applied in deep learning with real original equipment.
(Dori & Belcher, 2009)	332	2.52 (Q1)-9.8-(98th)	The Active Learning Project uses Technology (TEAL) at the Massachusetts Institute of Technology (MIT) to analyze students' cognitive and affective outcomes.	Based on the assessment results, subsequent research is recommended adding active learning, technology-based components from the TEAL course to the basic undergraduate mechanics course as well.

Author(s)	Citation	SJR-CiteScore (2021)-Percentile to Education (2020)	Findings	Recommendations
(Hwang et al., 2009)	284	3.68 (Q1)-19.8-(99th)	The use of Context-aware ubiquitous learning (u-learning) as an innovative approach that integrates wireless, mobile, and context-awareness (u-computing) technologies to detect real-world learner situations and provide appropriate adaptive support or guidance for students.	It is recommended that "graphic illustration" can make the u-computing PDA interface more attractive with the u-computing system having to record many learning patterns based on the experience of each learner.
(Akçayir et al., 2016)	281	2.17 (Q1)-1.2-(24th to neuroscience)	AR technology improves students' laboratory skills and helps them build a positive attitude towards physics labs	It is recommended that the use of virtual lab simulators be applied in deep learning with real original equipment.

Discussion

Based on Figure 2, research number on TiP educational fields from 1993 to 2022 are increasing every year. In early 2023, 43 documents had been published. It shows that interest in TiP continues to increase (Azlan et al., 2020; Fahmi et al., 2022; Vandenberghe et al., 2020). This is because TiP is considered capable of becoming a learning medium that covers many aspects of physics learning that contains many abstract and complex materials (Astuti et al., 2019; Hahn & Klein, 2022; Rahardja et al., 2019; Sudarsana et al., 2019; Syakroni et al., 2019). Especially in 21st-century learning, it is an alternative to enhance the pupil's motivation to study physics, which is considered difficult by many pupils (Abdurrahman et al., 2019; Novitra et al., 2021; Rizaldi et al. al., 2021; Sari et al., 2022). English is the most widely used language (5,523), followed by Portuguese (65), Spanish (47), Chinese (42), and Russian (38). English is a universal global language (Davidson & Liu, 2020; Sari & Aminatun, 2021; Sofyan, 2021). As a result, the circulation of publications will have to be more significant and much more extensively utilized or read as a reference point among many individuals (Hussain, 2019; Ramírez-Castañeda, 2020).

TiP implementation and development have been actively undertaken in the United States at every institutional level during these three decades (Borda et al., 2020; Rapanta et al., 2020; Wang et al., 2022; Yik et al., 2022). The US exhibits the greatest link strength (268) and number of citations (26,679). There are 7 clusters, namely Cluster 1 (15 items) including Australia, Belgium, India, Indonesia, Japan, Malaysia and New Zealand; Cluster 2 (15 items) including Cyprus, Czech Republic, Germany, Greece, Iran and Israel; Cluster 3 (8 items) consists of Argentina, Chile, Mexico, Morocco, Portugal, Spain, Sweden, etc. Cluster 4, with yellow node (5 items), consists of China, Hongkong, Saudi Arabia, United Kingdom, and United States. Cluster 5 with lilac node (5 items) consists of Austria, Finlandia, France, Serbia, and Switzerland. Cluster 6 with turquoise nodes (5 items) consists of Canada, Denmark, Ireland, Norway, and Slovenia. Cluster 7 tangerine color node (3 items) consists of Hungary, Italy, and Romania.

Based on Table 1, 'Students' is the main keyword of TiP publications. At the same time, the second place is 'Education' with total link strength of 2,713 and occurrences 276. Followed by Teaching, Engineering Education, Humans, Articles, Physics, Humans, Learning Systems, and others. Based on this pattern, it can be found that the trends of TiP publications during the past three decades are: 1) related to students; 2) implementation of education and teaching-human; 3) primarily used in engineering education or else medical education; 4) Output research by article key words; 5) learning systems; 6) Integrating to curricula; 7) Emerging as STEM education could be A.I., V.R., and so on; 8) Educational technology.

Figure 7 depicts term co-occurrences throughout all TiP articles during the last three decades (1993-2022). The mapping visualization shows that there are three main clusters. Cluster 1, coloured by red node (368 items), consists of abstracting, academic performance, applied physics, Arduino,

augmented reality (A.R.), e-learning, education, educational technology, STEM, physics laboratory, physics learning, physics phenomena, mobile learning, V.R., technology enhance learning and so on. Cluster 2, coloured by a green node (241 items), consists of A.I., atomic physics, biotechnology, deep learning, emerging technologies, energy utilization, machine learning, molecular physics, quantum physics, etc. Cluster 3, coloured by blue node (204 items), consists of academic achievement, biophysics, chemistry, curriculum, C.P., education and training, education, medical, engineering, learning environment, online system, physics, problem-based learning, publication, radiology, science, students, university, and so on. Again, discuss importance/significance. Why should these findings be of interest to us?

Figure 8 is the most linked keywords in TiP publication, whereas Figure 9 is the opposite. Suppose the research study wants to investigate TiP publication on top trends. In that case, there is still any chance to explore because the top trends still have a wide range and various fields of terms such as Figure 9a) 'Students' keyword remains available to discover perform an advancement or modify in educational environments, engineering education, physics or else. However, TiP may help and improve education in a variety of ways. 'Robotics,' may serve as a possible alternative learning media future research field, particularly to investigate TiP prior to merging with robotics (Auyelbek et al., 2022). How TiP can improve motivation in engineering education or for larger classes of all stages of education (Godwin & Kirn, 2020; Hadgraft & Kolmos, 2020; Hernández-de-Menéndez et al., 2019; Qadir & Al-Fuqaha, 2020).

Based on Table 2, the National Science Foundation is in first place as sponsor at 225 publications, followed by the National Natural Science Foundation of China with 94. In third place, followed by the U.S. Department of Energy, Horizon 2020 Framework Programme. Sponsorship activities for most of the world's largest audiences are critical. Most of them make investments to carry out sponsorship activities to achieve the desired goals or results. Sponsorship funding usually chooses many goals, one of which is to help improve the reputation of article publications. Top sponsorship funding mapping project as a consideration of publication reputation (Phuong et al., 2022).

Based on Figure 10, Bakri, F. is the leading author by total link strength, followed by Muliyati, D. with the same total link strength. However, the most cited author is Kuhn, J., with 11 documents and total link strength of 4. Many authors are not linked to each other. It shows the author's loyalty to TiP (Dangaiso et al., 2022). Furthermore, the Indonesian University of Education occupies the first top affiliation place, with 56 publications, followed by Jakarta State University, with 54 full publications. Subsequent positions are occupied by the State University of Padang, Purdue University, Yogyakarta State University, Stanford University, Massachusetts Institute of Technology, Texas University, Arizona State University, and University of Michigan, Ann Arbor. The form of cooperation between colleagues and TiP publications can be seen through mapping data. Various top universities are affiliated with TiP publications that demonstrate the quality of good cooperation in education (Stoner et al., 2019).

Based on Table 3, the most common subject areas are Engineering, totaling 1,921. Physics and Astronomy are second, followed by Social Sciences, Computer Science, Mathematics, Materials Science, Medicine, and Energy. The top source title, namely the Journal of Physics Conference Series as many as 601 then followed by ASEE Annual Conference and Exposition Conference Proceedings, AIP Conference Proceedings, Proceedings of SPIE The International Society for Optical Engineering, Medical Physics, ASEE Annual Conference Proceedings, Physics Education, Proceedings Frontiers in Education Conference, Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics, Ceur Workshop Proceedings. The mapping of the subject area and source title was carried out to analyze the strategic location of TiP publications' novelty in the education field (Olusola et al., 2022).

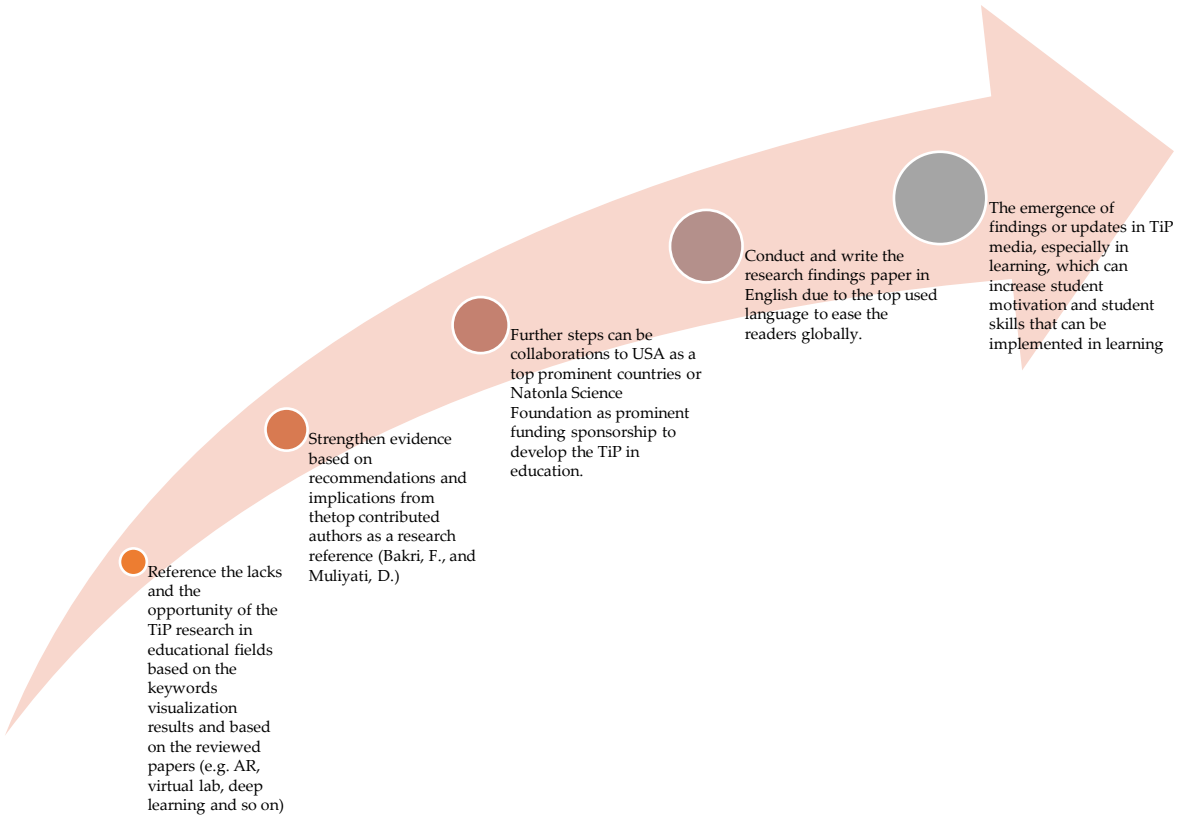
Based on Table 4, the year with the most papers is 2021 (664). In comparison, the most cited (6,602) papers are in the year 2014, followed by ghe highest ACPP (33.34) and ACPPY (3.70). İn contrast, 1994 is the year with the fewest papers (18), but 2007 and 2008 are years with no publications at all, and hence there is no ACPP and ACPPY. The total number of papers through the three decades

is 5,512, with 36,860 citations and 235.86 ACPP, 20.86 ACPPY. Based on Table 5, the results of the study and analysis of the publication review of TiP during 1993-2022 is the use of learning media result from, which can identify students' cognitive and affective results as innovations in physics learning. Adaptive guidance is also needed for students to recognise and build attitudes toward physics. The involvement of technology was instrumental in familiarising students with detecting real-world learning situations with a range of support over three decades. Hence, the emergence of technology plays an essential role in research from publications cited (Chang & Hwang, 2019; Jabbour et al., 2020).

Based on the research findings the research route for TiP in educational fields are emerged technology such as engineering education based on the main keyword to adapt. Otherwise, the further term is linked TiP education to the integrating of robotics to enhance the students' incitement of physics learning (Godwin & Kirn, 2020; Hadgraft & Kolmos, 2020). The research of the TiP in educational fields to future research are likely in Figure 11.

Figure 9

Rsearch Route to TiP Education for Future Research



Based on the Figure 10, further research are recommended to conduct the research of TiP in English based on the most used language to ease reader all around the world. This is line with the finding of the most prominent country to developed TiP publication being the United States with the most linked strength. Otherwise, further researchers can refer to Bakri, F. and Muliyati, D. of the TiP in fields education especially to AR technology, due to finding of the top prominent authors in English language. Based on the Table 5 likely it is recommended that the use of virtual lab simulators be applied in deep learning with real original equipment and Akçayir et al., (2016) recommended that the use of virtual lab simulators be applied in deep learning with real original equipment. However, the reviewed paper are listed in the top quartile ranked and filtered by the top cited paper on the Scopus,

it is implying that a publication with the mentioned achievement is published with unquestionable reliability since the publisher has a high reputation. Hence, the future study can be confident in the references that have been reviewed, and use the findings (e.g. further development of AR, implement of virtual lab, integrating of deep learning, and so on) as opportunities for TiP in the education sector.

Conclusion and Implication

In summary, the fundamental findings derived from the extensive bibliometric analysis of Technology in Pedagogy (TiP) publications in educational fields over the past three decades (1993-2022) through the Scopus database and VOSviewer application offer crucial insights and lay the groundwork for future research endeavors. The identified trends, including the consistent rise in TiP publications, the prevalence of C.P. as the most published document type, and the dominance of English in these publications, underscore the enduring global significance of TiP in education. Moreover, the recognition of key contributors, such as the National Science Foundation and prominent authors like Bakri, F., along with their affiliations, sheds light on the collaborative nature of TiP research. The subject-wise distribution highlights the prominence of engineering in TiP publications, signaling its central role in shaping educational practices.

Based on these findings, several recommendations for future research emerge. First and foremost, researchers are encouraged to explore emerging trends identified in this study, such as the integration of robotics and the application of AR technology. These represent promising avenues for advancing TiP's impact on educational practices and student outcomes. Additionally, the identified temporal patterns and the high reliability of TiP publications suggest the need for continued collaboration and exploration of niche topics. Collaborative efforts across institutions and countries can further enrich the discourse, while focusing on specific themes, like deep learning with real equipment using virtual lab simulators, can contribute to the continued evolution of TiP in education.

In conclusion, these fundamental findings and recommendations provide a comprehensive foundation for researchers, educators, and policymakers to deepen their understanding of TiP in educational fields, guiding future endeavors towards innovative and impactful contributions to the intersection of technology and pedagogy.

Acknowledgement

The author's gratitude goes to Direktorat Jenderal Pendidikan Tinggi, Riset, dan Teknologi; Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi, Indonesia who has supported funding in Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) – DRTPM 2023.

References

Abdullah, K. H. (2022). Publication trends in biology education: A bibliometric review of 63 years. *Journal of Turkish Science Education*, *19*(2), 465–480. https://doi.org/10.36681/tused.2022.131

Abdurrahman, A., Ariyani, F., Maulina, H., & Nurulsari, N. (2019). Design and validation of inquiry-based STEM learning strategy as a powerful alternative solution to facilitate gifted students facing 21st-century challenging. *Journal for the Education of Gifted Young Scientists*, *7*(1), 33–56. https://doi.org/10.17478/jegys.513308

Akçayir, M., Akçayir, G., Pektaş, H. M., & Ocak, M. A. (2016). Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Computers in Human Behavior*, *57*, 334–342. https://doi.org/10.1016/j.chb.2015.12.054

Al-Husaeni, D. F., & Nandiyanto, A. B. D. (2022). Bibliometric computational mapping analysis of publications on mechanical engineering education using vosviewer. *Journal of Engineering Science and Technology*, *17*(2), 1135–1149.

Astuti, D. P., Leonard, Bhakti, Y. B., & Astuti, I. A. D. (2019). Developing adobe flash-based mathematics learning media for 7th-grade students of junior high school. *Journal of Physics: Conference Series*, *1188*(1), 1-7. https://doi.org/10.1088/1742-6596/1188/1/012098

Aswal, A., Hunaidah, H., & Erniwati, E. (2019). Development of lesson plan (L.P.) with software lectora inspires assisted problem-based learning in improving learning outcomes for senior high school. *Indonesian Review of Physics*, *2*(2), 40-51. https://doi.org/10.12928/irip.v2i2.1177

Auyelbek, M., Ybyraimzhanov, K., Andasbayev, E., Abdykerimova, E., & Turkmenbayev, A. (2022). Analysis of studies in the literature on educational robotics. *Journal of Turkish Science Education*, *19*(4), 1267–1290. https://doi.org/10.36681/tused.2022.174

Azlan, C. A., Wong, J. H. D., Tan, L. K., Shahrun, M. S. N., Ung, N. M., Pallath, V., Tan, C. P. L., Yeong, C. H., & Ng, K. H. (2020). Teaching and learning of postgraduate medical physics using Internet-based e-learning during the COVID-19 pandemic – A case study from malaysia. *Physica Medica*, *80*(July), 10–16. https://doi.org/10.1016/j.ejmp.2020.10.002

Borda, E., Schumacher, E., Hanley, D., Geary, E., Warren, S., Ipsen, C., & Stredicke, L. (2020). Initial implementation of active learning strategies in large, lecture STEM courses: Lessons learned from a multi-institutional, interdisciplinary STEM faculty development program. *International Journal of STEM Education*, *7*(1), 1-10. https://doi.org/10.1186/s40594-020-0203-2

Deveci, İ. (2023). Bibliometric analysis of published documents on entrepreneurship in basic sciences (physics, chemistry, biology). *Journal of Turkish Science Education*, *20*(1), 211–240. https://doi.org/10.36681/tused.2023.012

Chang, C. Y., & Hwang, G. J. (2019). Trends in digital game-based learning in the mobile era: A systematic review of journal publications from 2007 to 2016. *International Journal of Mobile Learning and Organisation*, *13*(1), 68–90. https://doi.org/10.1504/IJMLO.2019.096468

Christopoulos, A., & Sprangers, P. (2021). Integration of educational technology during the Covid-19 pandemic: An analysis of teacher and student receptions. *Cogent Education*, *8*(1), 1–27. https://doi.org/10.1080/2331186X.2021.1964690

Cruz, R. A., Manchanda, S., Firestone, A. R., & Rodl, J. E. (2020). An examination of teachers' culturally responsive teaching self-efficacy. *Teacher Education and Special Education*, *43*(3), 197–214. https://doi.org/10.1177/0888406419875194

Damar, M., & Turkey, I. (2022). What the literature on medicine, nursing, public health, midwifery, and dentistry reveals: An overview of the rapidly approaching metaverse. *Journal of Metaverse*, *2*(2), 62–70. https://doi.org/10.57019/jmv.1132962

Dangaiso, P., Makudza, F., & Hogo, H. (2022). Modeling perceived e-learning service quality, student satisfaction and loyalty: A higher education perspective. *Cogent Education*, *9*(1). https://doi.org/10.1080/2331186X.2022.2145805

Davidson, R., & Liu, Y. (2020). Reaching the world outside: Cultural representation and perceptions of global citizenship in Japanese elementary school English textbooks. *Language, Culture and Curriculum*, *33*(1), 32–49. https://doi.org/10.1080/07908318.2018.1560460

Dawana, I. R., Dwikoranto, D., Setiani, R., & Marsini, M. (2022). E-Book learning research in physics education during the last five years: A review and bibliometric study. *Journal of Physics: Conference Series*, *2392*(1), 1-6. https://doi.org/10.1088/1742-6596/2392/1/012016

Deslauriers, L., Schelew, E., & Wieman, C. (2011). Improved learning in a large-enrollment physics class. *Science*, *332*(6031), 862–864. https://doi.org/10.1126/science.1201783

Dewantara, D., Sofianto, E. W. N., Misbah, M., & Munawaroh, D. (2021). Physics e-module: A review and bibliometric analysis. *Journal of Physics: Conference Series*, *2104*(1), 1-7. https://doi.org/10.1088/1742-6596/2104/1/012008

Do, T. T., Thi Tinh, P., Tran-Thi, H. G., Bui, D. M., Pham, T. O., Nguyen-Le, V. A., & Nguyen, T. T. (2021). Research on lifelong learning in Southeast Asia: A bibliometrics review between 1972 and 2019. *Cogent Education*, *8*(1), 1-20. https://doi.org/10.1080/2331186X.2021.1994361

Dori, Y. J., & Belcher, J. (2009). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *Journal of the Learning Sciences*, *14*(2), 243–279. https://doi.org/10.1207/s15327809jls1402_3

Ellermeijer, T., & Tran, T. B. (2019). Technology in teaching physics: Benefits, challenges, and solutions. In *Upgrading physics education to meet the needs of society*. Spring Nature Switzerland.

Escher, I. (2020). Sustainable development in sport as a research field: A bibliometric analysis. *Journal of Physical Education and Sport*, *20*(October), pp. 2803–2812. https://doi.org/10.7752/jpes.2020.s5381

Fahmi, F., Chalisah, N., & Istyadji, M. (2022). Scientific literacy on the topic of light and optical instruments in the innovation of science teaching materials. *Jurnal Pendidikan IPA*, *8*(2), 154–163. http://dx.doi.org/10.21831/jipi.v8i2.41343

Ferty, Z. N., Wilujeng, I., Jumadi, J., & Kuswanto, H. (2019). Enhancing students' critical thinking skills through physics education technology simulation assisted of scaffolding approach. *Journal of Physics: Conference Series*, *1233*(1), 1-7. https://doi.org/10.1088/1742-6596/1233/1/012062

Gass, S., Loewen, S., & Plonsky, L. (2021). Coming of age: The past, present, and future of quantitative SLA research. *Language Teaching*, *54*(2), 245–258. https://doi.org/10.1017/S0261444819000430

Godwin, A., & Kirn, A. (2020). Identity-based motivation: Connections between first-year students' engineering role identities and future-time perspectives. *Journal of Engineering Education*, *109*(3), 362–383. https://doi.org/10.1002/jee.20324

Hadgraft, R. G., & Kolmos, A. (2020). Emerging learning environments in engineering education. *Australasian Journal of Engineering Education*, *25*(1), 3–16. https://doi.org/10.1080/22054952.2020.1713522

Hahn, L., & Klein, P. (2022). Eye tracking in physics education research: A systematic literature review. *Physical Review Physics Education Research*, *18*(1), 13102. https://doi.org/10.1103/PhysRevPhysEducRes.18.013102

Hamdani, N. A., Herlianti, A. O., & Amin, A. S. (2019). Society 5.0: Feasibilities and challenges of implementing fintech in small and medium industries. *Journal of Physics: Conference Series*, *1402*(7), 5–10. https://doi.org/10.1088/1742-6596/1402/7/077053

Hartshorn, K. J., & Mcmurry, B. L. (2020). The effects of the COVID-19 pandemic on ESL learners and TESOL practitioners in the united states. *International Journal of TESOL Studies*, *pp. 2*, 140–156. https://doi.org/10.46451/ijts.2020.09.11

Hernández-de-Menéndez, M., Vallejo-Guevara, A., Tudón Martínez, J. C., Hernández Alcántara, D., & Morales-Menendez, R. (2019). Active learning in engineering education. A review of fundamentals, best practices, and experiences. *International Journal on Interactive Design and Manufacturing*, *13*(3), 909–922. https://doi.org/10.1007/s12008-019-00557-8

Hussain, S. (2019). The importance of speaking skills in English classrooms. *Alford Council of International English & Literature Journal*, *2*(2), 6–18.

Hwang, G. J., Yang, T. C., Tsai, C. C., & Yang, S. J. H. (2009). A context-aware ubiquitous learning environment for conducting complex science experiments. *Computers and Education*, *53*(2), 402–413. https://doi.org/10.1016/j.compedu.2009.02.016

Iatsyshyn, A. V., Kovach, V. O., Romanenko, Y. O., Deinega, I. I., Iatsyshyn, A. V., Popov, O. O., Kutsan, Y. G., Artemchuk, V. O., Burov, O. Y., & Lytvynova, S. H. (2020). Application of augmented reality technologies for preparation of specialists of new technological era. *CEUR Workshop Proceedings*, *2547*, 181–200.

Islam, A., Islam, M., Hossain Uzir, M. U., Abd Wahab, S., & Abdul Latiff, A. S. (2020). The panorama between the COVID-19 pandemic and Artificial Intelligence (A.I.): Can it catalyze Society 5.0? *International Journal of Scientific Research and Management*, *8*(12), 2011–2025. https://doi.org/10.18535/ijsrm/v8i12.em02

Jabbour, C. J. C., Fiorini, P. D. C., Ndubisi, N. O., Queiroz, M. M., & Piato, É. L. (2020). Digitally-enabled sustainable supply chains in the 21st century: A review and a research agenda. *Science of the Total Environment*, *725*, 138177. https://doi.org/10.1016/j.scitotenv.2020.138177

Jatmiko, B., Sunarti, T., Prahani, B. K., Hariyono, E., Dwikoranto, D., Wibowo, F. C., Mahtari, S., Misbah, & Asy'Ari, M. (2021). Critical thinking skills on physics learning during COVID- 19 Pandemic: A bibliometric analysis using VOS viewer. *Journal of Physics: Conference Series*, *2110*(1), 1-7. https://doi.org/10.1088/1742-6596/2110/1/012020

Jumini, S., Madnasri, S., Cahyono, E., & Parmin, P. (2022). Article review: Integration of science, technology, entrepreneurship in learning science through bibliometric analysis. *Journal of Turkish Science Education*, *19*(4), 1237–1253. https://doi.org/10.36681/tused.2022.172

Kahar, M. I., Cika, H., Afni, N., & Wahyuningsih, N. E. (2021). Pendidikan era revolusi industri 4.0 menuju era society 5.0 di masa pandemi COVID-19. *Moderasi: Jurnal Studi Ilmu Pengetahuan Sosial*, *2*(1), 58–78. https://doi.org/10.24239/moderasi.vol2.iss1.40

Kamarrudin, H., Talib, O., Kamarudin, N., Ismail, N., & Zamin, A. A. M. (2022). Examining the trend of research on active engagement in science education: Bibliometric analysis. *Journal of Turkish Science Education*, *19*(3), 937–957. https://doi.org/10.36681/tused.2022.157

Karim, A., Campbell, M., & Hasan, M. (2020). A new method of integrating project-based and work-integrated learning in postgraduate engineering study. *Curriculum Journal*, *31*(1), 157–173. https://doi.org/10.1080/09585176.2019.1659839

Khan, R. M. I., Ali, As., Alourani, A., Kumar, T., & Shahbaz, M. (2022). An investigation of the educational challenges during COVID-19: A case study of Saudi students' experience. *European Journal of Educational Research*, *11*(1), 1–16.

Koç, A., & Büyük, U. (2021). Effect of robotics technology in science education on scientific creativity and attitude development. *Journal of Turkish Science Education*, *18*(1), 54–72. https://doi.org/10.36681/tused.2021.52

Kousha, K., & Thelwall, M. (2020). COVID-19 publications: Database coverage, citations, readers, tweets, news, Facebook walls, Reddit posts. *Quantitative Science Studies*, *1*(3), 1068–1091. https://doi.org/10.1162/qss_a_00066

Marulanda-Grisales, N., & Vera-Acevedo, L. D. (2022). Intellectual capital and competitive advantages in higher education institutions: An overview based on bibliometric analysis. *Journal of Turkish Science Education*, *19*(2), 525–544. https://doi.org/10.36681/tused.2022.135

Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. *El Profesional de La Informa-Ción*, *29*(1), 1–20. https://doi.org/10.3145/epi.2020.ene.03

Morales, M. P. E., Avilla, R. A., Sarmiento, C. P., Anito, J. C., Elipane, L. E., Palisoc, C. P., Palomar, B. C., Ayuste, T. O. D., & Ramos-Butron, B. (2022). Experiences and practices of STEM teachers through the lens of TPACK. *Journal of Turkish Science Education*, *19*(1), 233–252. https://doi.org/10.36681/tused.2022.1120

Mwambela, C. (2019). Challenges in using ICT in Teaching secondary school physics and the effect of teaching using ICT on students' physics academic achievement in mombasa county, Kenya. *Journal of Education and Practice*, *10*(22), 67–73. https://doi.org/10.7176/jep/10-22-08

Nandiyanto, A. B. D., Fatimah, S., Ragadhita, R., & Husaeni, D. N. Al. (2022). Particle size and pore size of rice husk ash on the resin-based brake pads performance: Experiments and Bibliometric literature review. *Journal of Engineering Science and Technology*, *17*(6), 4065–4081.

Negoro, R. A., Rusilowati, A., & Aji, M. P. (2023). Scratch-assisted waves teaching materials: ICT Literacy and students' critical thinking skills. *Journal of Turkish Science Education*, *20*(1), 189–210. https://doi.org/10.36681/tused.2023.011

Novitra, F., Festiyed, Yohandri, & Asrizal. (2021). Development of online-based inquiry learning model to improve 21st-century skills of physics students in senior high school. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(9), 1–20. https://doi.org/10.29333/ejmste/11152

Olusola, A. S., Olaleke Oluseye, O., Menyene Saviour, U., Joy Iember, K., & Olamilekan Ayomiposi, D. (2022). A content analysis of the vision and mission statements of top ten leading universities in africa. *Cogent Education*, *9*(1), 1–15. https://doi.org/10.1080/2331186X.2022.2143648

Papadakis, S. (2021). The impact of coding apps to support young children in computational thinking and computational fluency: A literature review. *Frontiers in Education*, *6*, 1–12. https://doi.org/10.3389/feduc.2021.657895

Papadopoulos, I., Lazzarino, R., Miah, S., Weaver, T., Thomas, B., & Koulouglioti, C. (2020). A systematic review of the literature regarding socially assistive robots in pre-tertiary education. *Computers and education*, p. *155*, 103924. https://doi.org/10.1016/j.compedu.2020.103924

Phuong, T. T. T., Danh, N. N., Le, T. T. T., Phuong, T. N., Thanh, T. N. T., & Le Minh, C. (2022). Research on the application of ICT in Mathematics Education: Bibliometric analysis of scientific bibliography from the Scopus database. *Cogent Education*, *9*(1), 1–14. https://doi.org/10.1080/2331186X.2022.2084956

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers and Education*, *95*(1), 309–327. https://doi.org/10.1016/j.compedu.2016.02.002

Prahani, B. K., Amiruddin, M. Z. B., Jatmiko, B., Suprapto, N., & Amelia, T. (2022). Top 100 cited publications for the last thirty years in digital learning and mobile Learning . *International Journal of Interactive Mobile Technologies (iJIM)*, *16*(08), 18–33. https://doi.org/10.3991/ijim.v16i08.29803

Prahani, B. K., Alfin, J., Fuad, A. Z., Saphira, H. V., Hariyono, E., & Suprapto, N. (2022). Learning management system (LMS) research during 1991-2021: How technology affects education. *International Journal of Emerging Technologies in Learning (iJET)*, *17*(17), 28–49. https://doi.org/10.3991/ijet.v17i17.30763

Prahani, B. K., Saphıra, H. V., Wıbowo, F. C., Mısbah, & Sulaeman, N. F. (2022). Trend and visualization of virtual reality & augmented reality in physics learning from 2002-2021. *Journal of Turkish Science Education*, *19*(4), 1096–1118. https://doi.org/10.36681/tused.2022.164

Putri, C. R., Soleh, S. M., Saregar, A., Anugrah, A., & Susilowati, N. E. (2021). Bibliometric analysis: Augmented reality-based physics laboratory with VOSviewer software. *IOP Conference Series: Earth and Environmental Science*, *1796*(1). https://doi.org/10.1088/1742-6596/1796/1/012056

Qadir, J., & Al-Fuqaha, A. (2020). A student primer on how to thrive in engineering education during and beyond COVID-19. *Education Sciences*, *10*(9), 1–22. https://doi.org/10.3390/educsci10090236

Rahardja, U., Aini, Q., Graha, Y. I., & Tangkaw, M. R. (2019). Gamification framework design of management education and development in industrial revolution 4.0. *Journal of Physics: Conference Series*, *1364*(1), 0–13. https://doi.org/10.1088/1742-6596/1364/1/012035

Raman, R., Achuthan, K., Nair, V. K., & Nedungadi, P. (2022). Virtual laboratories- A historical review and bibliometric analysis of the past three decades. In *Education and Information Technologies, 27*(8), 11055-11087. https://doi.org/10.1007/s10639-022-11058-9

Ramírez-Castañeda, V. (2020). Disadvantages in preparing and publishing scientific papers caused by the dominance of the English language in science: The case of colombian researchers in biological sciences. *PLoS ONE*, *15*, 1–15. https://doi.org/10.1371/journal.pone.0238372

Rapanta, C., Botturi, L., Goodyear, P., & Guàrdia, L. (2020). Online university teaching during and after the COVID-19 crisis : Refocusing teacher presence and learning activity. *Postdigital Science and Education*, *2*, 923–945.

Rizaldi, D. R., Fatimah, Z., Doyan, A., & Makhrus, M. (2021). Efforts to familiarize literacy culture in students: Orientation in the madrasa environment. *International Journal of Social and Humanities Extension(IJSHE), 1*(1), 20–24.

Sari, S. N., & Aminatun, D. (2021). Students' perception on the use of english movies to improve vocabulary mastery. *Journal of English Language Teaching and Learning*, *2*(1), 16–22.

Sari, S. Y., Rahim, F. R., Sundari, P. D., & Aulia, F. (2022). The importance of e-books in improving students' skills in physics learning in the 21st century: A literature review. *Journal of Physics: Conference Series*, *2309*(1), 1-8. https://doi.org/10.1088/1742-6596/2309/1/012061

Schöbel, S., Saqr, M., & Janson, A. (2021). Two decades of game concepts in digital learning environments – A bibliometric study and research agenda. *Computers and Education*, *173,* 1-23. https://doi.org/10.1016/j.compedu.2021.104296

Schweikl, S., & Obermaier, R. (2020). Lessons from three decades of I.T. productivity research: towards a better understanding IT-induced productivity effects. In *Management review quarterly*. Springer International Publishing.

Sofyan, N. (2021). The role of english as a global language. *Edukasi*, *19*(1), 65-80. https://doi.org/10.33387/j.edu.v19i1.3200

Sudarsana, I. K., Pusparani, K., Selasih, N. N., Juliantari, N. K., & Wayan Renawati, P. (2019). Expectations and challenges of using technology in education. *Journal of Physics: Conference Series*, *1175*(1), 1–5. https://doi.org/10.1088/1742-6596/1175/1/012160

Stoner, O., Economou, T., & Marques da Silva, D. G. (2019). A hierarchical framework for correcting under-reporting in count data. *Journal of the American Statistical Association*, *114*(528), 1481–1492. https://doi.org/10.1080/01621459.2019.1573732

Syakroni, A., Zamroni, Muali, C., Baharun, H., Sunarto, M. Z., Musthofa, B., & Wijaya, M. (2019). Motivation and learning outcomes through the internet of things; Learning in pesantren. *Journal of Physics: Conference Series*, *1363*(1), 1-7. https://doi.org/10.1088/1742-6596/1363/1/012084

Tetep, T., & Dahlena, A. (2021). Fun pattern-based learning approach for social studies learning during the COVID-19 pandemic. *AL-ISHLAH: Jurnal Pendidikan*, *13*(3), 1571–1580. https://doi.org/10.35445/alishlah.v13i3.1025

Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of Engineering Education*, *109*(3), 508–555. https://doi.org/10.1002/jee.20347

Vandenberghe, S., Moskal, P., & Karp, J. S. (2020). State of the art in total body PhET. *EJNMMI Physics*, *7*(1), 1-33. https://doi.org/10.1186/s40658-020-00290-2

Vesikivi, P., Lakkala, M., Holvikivi, J., & Muukkonen, H. (2020). The impact of project-based learning curriculum on first-year retention, study experiences, and knowledge work competence. *Research Papers in Education*, *35*(1), 64–81. https://doi.org/10.1080/02671522.2019.1677755

Wang, C., Shen, J., & Chao, J. (2022). Integrating computational thinking in STEM education: A literature review. *International Journal of Science and Mathematics Education*, *20*(8), 1949–1972. https://doi.org/10.1007/s10763-021-10227-5

Wang, Q., Wen, Y., & Quek, C. L. (2022). Engaging learners in synchronous online learning. *Education and Information Technologies*, 1-24. https://doi.org/10.1007/s10639-022-11393-x

Wijaya, R. E., Mustaji, M., & Sugiharto, H. (2021). Development of mobile learning in learning media to improve digital literacy and student learning outcomes in physics subjects: Systematic literature review. *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, *4*(2), 3087–3098. https://doi.org/10.33258/birci.v4i2.2027

Yani, A. D., Wati, M., & Misbah. (2021). Bibliometric analysis: Physics online learning in indonesia (2020-2021). *Online Learning in Educational Research*, *1*(1), 25–36.

Yanniris, C., & Huang, Y. S. (2018). Bibliometric evidence point to LOCI of empirical knowledge production in environmental education. *Cogent Education*, *5*(1), 1–14. https://doi.org/10.1080/2331186X.2018.1542961

Yik, B. J., Raker, J. R., Apkarian, N., Stains, M., Henderson, C., Dancy, M. H., & Johnson, E. (2022). Evaluating the impact of malleable factors on percent time lecturing in gateway chemistry, mathematics, and physics courses. *International Journal of STEM Education*, *9*(1), 15–38. https://doi.org/10.1186/s40594-022-00333-3

Zakhiyah, I., Suprapto, N., & Setyarsih, W. (2021). Prezi mind mapping media in physics learning: A bibliometric analysis. *Journal of Physics: Conference Series*, *2110*(1), 1-7. https://doi.org/10.1088/1742-6596/2110/1/012015

Zuparova, S., & Shegay, A. (2020). Approaches to learning English as the source of all subjects. *European Journal of Research and Reflection in Educational Sciences*, *8*(6), 102–107.

Journal of Turkish Science Education, 2024, *21*(1), 153-174.
DOI no: 10.36681/tused.2024.009

Comprehensive science mapping of STEM studies in gifted education

M. Davut Gül[1], Zekai Ayık[2]

[1]*Tokat Gaziosmanpasa University, Türkiye, mdavutgul1@gmail.com, Corresponding author, ORCID ID: 0000-0003-0437-5865*
[2]*Harran University, Türkiye, ORCID ID: 0000-0002-3562-6543*

ABSTRACT
The integration of gifted learners into STEM education has raised two key issues: providing suitable learning experiences for them and utilising their potential to contribute to the ultimate goals of STEM education. Hence, research in this area is essential for both researchers and practitioners in gifted education. The purpose of this study was to examine pertinent trends in recent years as revealed by the bibliometric analysis of published studies on STEM in gifted education. A total of 170 publications on gifted and STEM education obtained from Web of Science and Scopus databases were examined. The PRISMA model was used for data collection. RStudio was employed for data analysis. The results of the study revealed that 59 different journals, 170 articles, and 332 authors had contributed to the field of STEM in gifted education. The most frequently used keywords in research in both databases were "STEM", "gifted students", "gifted education", and "talent development". The most productive journals on STEM-related studies in gifted education were Rooper Review and Gifted Child Quarterly. The most relevant authors were C. June Maker and Paula Olszewski-Kubilius. The most productive institutions were the Northwestern University and the University of North Texas. Trending topics have evolved from gender differences to enrichment and science mathematically focused subjects, and then technology and engineering focused stem and talent development.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received:
25.06.2023
Accepted:
25.03.2024

KEYWORDS:
Gifted education, STEM, bibliometric analysis.

To cite this article: Gül, M.D., & Ayık, Z. (2024). Comprehensive science mapping of STEM studies in gifted education. *Journal of Turkish Science Education, 21*(1), 153-174. DOI: 10.36681/tused.2024.009

Introduction

In the knowledge-based global economy of the 21st century, the need for scientific and technological advances and associated professionals has been steadily increasing (Wu et al., 2019). Integrating Science, Technology, Engineering and Mathematics (STEM) in schools has been a major attempt to address this need. It has been noted that there is a scarcity of persons demonstrating exceptional aptitude in STEM fields in the ever-evolving realm of technology (U.S. Department of Commerce, 2017), while demand for STEM employment is expected to rise between 2010 and 2020 in the USA. Thus, the forthcoming cohort should be equipped and nurtured with science, technology, engineering and mathematics (STEM) education as a national priority (Steenbergen-Hu & Olszewski-Kubilius, 2017). It is important that learners' dispositions towards STEM and their STEM education should be prioritised as a policy in many countries.

As stated by Wu et al. (2019) and Maker (2020), identifying learners who exhibit exceptional talent (gifted learners) in STEM and providing enrichment programmes to improve their skills to the highest level of their capability is also critical to each nation's future. In this sense, the National Science Board (NSB) (2012) established a core goal for the domain of gifted education to identify and nurture gifted learners who would become the world's pioneering STEM professionals. To do this, the NSB proposed eight policy actions –including accelerated and well-designed enrichment programmes and accessing formal and informal education opportunities such as out-of-school programmes- to promote STEM education for gifted learners.

In this respect, since the curricula implemented at school may be restricting in terms of advanced nurturing of gifted students in STEM fields (Adams et al., 2008), it is recommended that a differentiated curriculum including enriched syllabi and challenging activities should be implemented (Ericsson, 2014). Many efforts have been made to create challenging STEM activities such as advanced placement programmes, summer enrichment programmes, extracurricular academic competitions, and dual-enrolment programmes. Numerous studies propose the use of STEM as an optimal learning environment to nurture gifted learners' abilities, to be interested in complex problems in line with their interests, to make novel discoveries (Schroth & Helfer, 2017; Steenbergen-Hu & Olszewski-Kubilius, 2017; Stoeger et al., 2017; Tofel-Grehl & Callahan, 2017; Ulger & Çepni, 2020; Yoon & Mann, 2017).

Although gifted learners tend to exhibit high motivation and high achievement (Tofel-Grehl & Callahan, 2017), there is a paucity of research on STEM studies in gifted education. And there is no unified viewpoint on the optimal STEM education programme for gifted pupils in either school or out-of-school systems. Accordingly, the current investigation endeavoured to amalgamate extant literature on STEM studies in the realm of gifted education. The results of this study furnish a comprehensive outline of the field and proffer recommendations for future research studies. It sought to explore the following research questions:

1. How does scientific production, the productivity of sources, authors, and countries vary per year?
2. What is the relationship between sources, authors, and keywords?
3. What is the distribution of the publications in terms of their authors, year of publication, type of publication, the country and institution where they are published, and journals?
4. What is the most relevant sources, authors, intuitions, and countries?
5. How the collaborations among scholars, intuitions, and countries are constructed?
6. What are the publication charts of the most published journals on the subject?
7. Which studies are the most cited in the field of gifted STEM education?
8. What is the historiography of STEM-gifted oriented studies?
9. What are the most used keywords and the co-occurrence networks of the keywords in the subject area, among the list of keywords?
10. What are the changing and up-to-date trends in the studies carried out in this field and how does the thematic evolution take place?

Theoretical Framework

Characteristics of Gifted Students

According to the Marland Report (1972), gifted individuals are the ones who show superior performance to their peers in the fields of general cognitive skills, special academic talent, visual or performance-based artistic talent, creativity, leadership or psychomotor skills. While IQ had been seen as a single measure of giftedness for a long time, it has of late been considered a multidimensional construct including creativity and socioemotional attributes (Kaufman & Sternberg, 2008). For example, the Triarchic Theory of Intelligence developed by Sternberg (2005), Gagné's (2004) Differentiated Model of Giftedness and Talent (DMGT) or Renzulli's (1986) Three-Ring Model of

giftedness views including multiple factors and variables. The concept of giftedness is confused with many concepts. Renzulli et al. (1982) tried to tackle the confusion by distinguishing between schoolhouse giftedness and creative-productive giftedness. Due to their unique and distinct characteristics, gifted learners are more advanced and superior to their peers in areas such as the cognitive, social, emotional and creative (Renzulli, 1986). They are at an advantage regarding physical, perceptual, analysis, synthesis, problem-solving, abstract thinking, logical process, language skills, and creativity (Kurup et al., 2015). In regular schools, these learning characteristics and advantages generally turn into disadvantages because the general curriculum and classroom instruction are inadequate for creating cognitive, creative, and affective challenges for gifted learners. For this reason, many efforts for meeting the educational needs of gifted learners have been made through differentiation of curriculum components (content, process, learning products, and the physical and social environment) (Tomlinson, 2017).

Given the apparent learner differences, gifted learners need content delivery through a variety of instructional and learning methods. Siegle et al. (2014) reported that some enjoy authentic learning experiences such as labs or field trips, while others prefer classroom discussions and Socratic dialogue; for these, discussions motivate them to come to class prepared after reading major literary works. Vanderbrook (2006) noted that gifted learners preferred active discussion to passive activities such as watching film renditions of literary works because discussion allowed valuable time for analysis. In accordance with this trend of active learning found in other subjects, Gavin et al. (2013) noted that to develop a deeper understanding of mathematics, gifted learners needed to grapple with challenging problems, try different strategies, engage in dialogue with peers and teachers, find new ways of solving problems, and explain their reasoning to others. Challenging and meaningful content motivate gifted learners to excel.

STEM Education

The STEM approach is the integration of four different disciplines including science, technology, engineering and mathematics with respect to real-life course content (Moore et al., 2014). The use of science, technology, engineering and mathematics disciplines together provides the opportunity for learners to gain more permanent and deeper learning and to have the opportunity to apply what they have learned (Wicklein & Schell, 1995). Those educated through STEM are expected to exhibit 21st-century skills such as creative thinking, problem-solving, self-confidence, logical thinking, communication, using technology at a high level, competitiveness and critical thinking. STEM education uses a student-centred approach to provide learners with these skills (Kocaman, 2022; Stehle & Peters-Burton, 2019).

STEM is an integral part of people's lives every day. Creative problem-solving in the areas of STEM has become increasingly critical. For example, STEM-based learning via real-world applications can help learners design environmentally friendly transportation systems that reduce the detrimental effects of climate pollution. Thus, through STEM, students find solutions to real-world problems, make designs, and ultimately develop products for the problem (Margot & Kettler, 2019). Based on various sources, it can be stated that this approach contributes greatly to their acquisition of high-level cognitive skills (Haryadi et al., 2021), the development of their affective characteristics (Blaique et al., 2023), and their career planning (Cheng et al., 2021). In this way, learners can eventually contribute to the world where technology and science develop with STEM.

Giving the necessary importance to STEM education can improve learners' interests, attitudes and future goals involving STEM fields. Their positive attitudes toward STEM fields will enable them to be willing to plan their careers in these fields (Ihrig et al., 2018). In the literature, there are many studies showing that school students' STEM attitudes (Vossen et al., 2021) and career interests (Cheng et al., 2021) are formed during the secondary school years.

STEM Education for Gifted Students

Due to their distinct cognitive, affective, and learning characteristics, gifted learners need differentiated learning experiences which generally include methods like acceleration, grouping and enrichment (Tomlinson, 2017). In order for better integration of gifted students into STEM education, the instructional practices in STEM education must be differentiated accordingly (Morris et al., 2021). Drawing upon the long-term research and practical experiences gained during the DISCOVER assessment development projects funded by the U.S. Department of Education (Maker, 2005; Maker & Schiever, 2010), the research team defined exceptional talent in STEM as consisting of two essential aspects: a highly integrated and interconnected knowledge structure, and the ability to solve a variety of types of problems, from well-structured and known to ill-structured and novel, in science, technology, engineering, and mathematics in the most effective, efficient, original or economical ways.

Gifted pupils need early experiences in science that serve to increase their interest and engagement in the discipline (VanTassel-Baska, 2003), and STEM can provide these opportunities. For example, enjoying learning, analytical thinking, problem solving, creative and critical thinking, high career goals, ability to work both independently and collaboratively, and using mathematics and sciences to solve problems are common characteristics of both engineers and gifted students (Mann et al., 2011). There are many studies showing that STEM is one of the important approaches that can be used to develop the skills of gifted learners in an effective learning environment (Schroth & Helfer, 2017; Sen et al., 2021). STEM is a suitable education model to provide gifted learners with the necessary skills, develop creative and original solutions to problems, and direct them to STEM-related professions (Stoeger et al., 2017). Yoon and Mann (2017) determined that gifted students are more likely to pursue a career in STEM.

Cultivating exceptional talent not only requires the development of a domain-specific, integrated knowledge structure but also the development of domain-general, creative problem-solving abilities. Particularly in STEM, knowledge and conceptual understanding in specific domains (content), problem-solving skills (process), and the ability to apply knowledge and understanding to novel situations (application) are essential elements (English, 2017). It was reported that when academic skills are taught within the context of real-world, open-ended problem-solving, diverse, underrepresented pupils experience greater success in school. Furthermore, STEM-based laboratory experiences have offered important benefits and impacts because such activities promote students' logical and problem-solving skills if constructed appropriately (Porter, 2017).

In brief, the relationship between gifted education and STEM education is mutual. On one hand, STEM education provides a good opportunity for gifted learners if they are supported in their skills, productivity, creativity, encouraged in interest, and demonstrate their potential. On the other hand, STEM education could be more effective and successful in reaching its eventual purposes mentioned above if gifted learners are well integrated into STEM education since they are considered as most capable learners regarding the abovementioned skills (Morris et al., 2021). In this respect, investigating the various aspects of STEM education for gifted students mentioned above poses importance for both researchers and practitioners in the field.

Methodology

Research Design

Bibliometric research methodology was employed in this study (Moreno-Guerrero et al., 2020). Bibliometric analysis is a powerful tool which enables measuring the impact and influence of research journals, articles, authors, institutions, and countries in a subject-specific area. It provides valuable insights into trends and patterns. This approach works by analysing the publications included in certain databases precisely. In this way, the researchers easily identify emerging research areas, evaluate research productivity, and track research trends. The current study focuses on analysing and interpreting educational research on STEM-related studies in gifted education.

Data Collection

In the data scanning process, a rigorous protocol offered by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was followed. The PRISMA guideline is a systematic approach to reviewing studies in the literature (Moher et al., 2007). In this study, the Web of Science and Scopus databases were reviewed (on 1 February, 2023) Table 1 details the inclusion and exclusion criteria for this study.

Table 1

Inclusion and Exclusion Criteria

Inclusion	Exclusion
Must -include STEM studies in gifted education, -be in WoS and Scopus databases -be published before february 2023 -be written in English -be accesible	-Including reviews, editorials, early access articles -Not written in English -Not related to STEM studies in gifted education

Table 2 presents the research query used in both WoS and Scopus.

Table 2

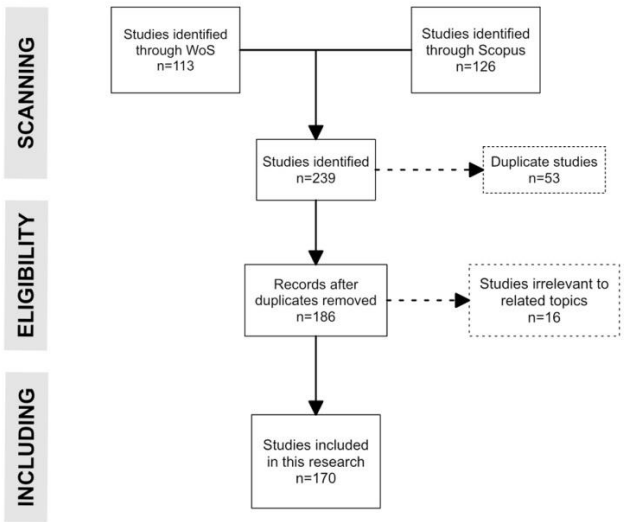
The Research Query Used in WoS and Scopus

Databases	Research query
WoS and Scopus	("gifted" or "giftedness" or "talented" or "highly able" or "intelligent" or "genius") AND ("STEM" or "science and technology" or "science and mathematics" or "science and engineering" and "science and design")

Figure 1 illustrates how the PRISMA guideline was implemented in this study.

Figure 1

Flow Diagram of Studies Selected



Data Analysis

RStudio was employed as a medium for bibliometric analysis. As noted by Gandrud (2013), the integration of this tool with the R programming language makes it highly effective for displaying scientific maps. Data on sources, authors, documents, countries, institutions, conceptual structure, intellectual structure and social structure were examined through the Web application Biblioshiny, which is integrated and synchronised with the R programming language to provide a detailed thematic view: the authors and institutions that have contributed the most to this field; the countries that see this field of study as a priority; which journals are more focused on this field; the cooperation between authors, institutions, and countries; and how the subject has evolved in the historical process have been revealed. For the validity of the study, the findings were examined by two researchers who are experts in R programming language and bibliometrics. For reliability, the data were kept open to the researcher who requested.

Results

When we examine all the data scanned in WoS and Scopus (Table 3), the information being studied was likely gathered between 2000-2023. STEM-oriented studies gradually emerged in the 2000s and became widespread after 2005. During this period there were 59 different sources (journals), 170 documents (articles), and 332 authors that contributed to the field of STEM in gifted education. Although there has not been rapid development over the years, it is evident that work in this field is continuing.

Table 3

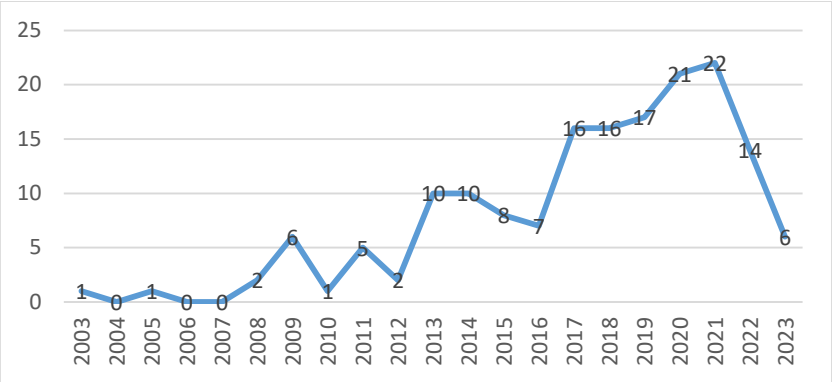
Main Information about Data

Timespan	2000-2023
Sources	59
Documents	170
Authors	332
Annual Growth Rate	4,58 %

When we look at the change in STEM-related research over the years (Figure 2), it is seen that the studies have increased since 2007, reached the highest numbers between 2017 and 2021, while the studies on this subject decreased in 2022 compared to the previous five years. In the years before 2007, it is seen that sporadic efforts were made to bring science and technology and science and engineering to the agenda, although not STEM.

Figure 2

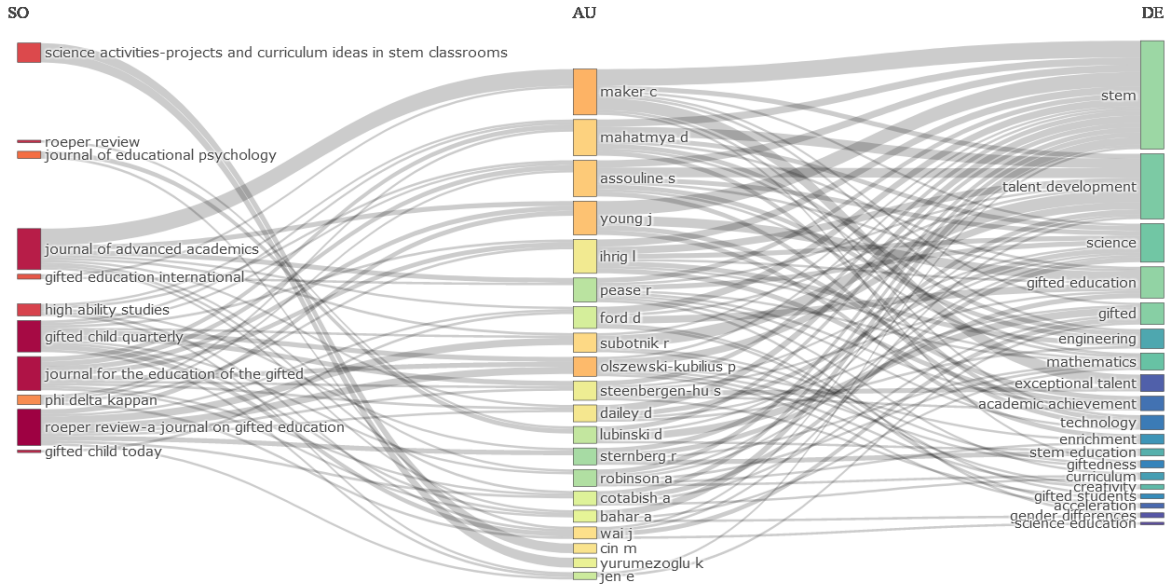
Number of Scientific Publications by Year



When the relationship between the authors, the journals preferred by the authors for publishing and the keywords found in the articles published in these journals were analysed (Figure 3), it is seen that researchers generally focused on talent development, engineering, mathematics, academic achievement technology, enrichment, curriculum, creativity, and acceleration in relation to STEM through the Journal of Advanced Academics, Gifted Child Quarterly, Roeper Review, Journal for the Education of the Gifted, and Science Activities.

Figure 3

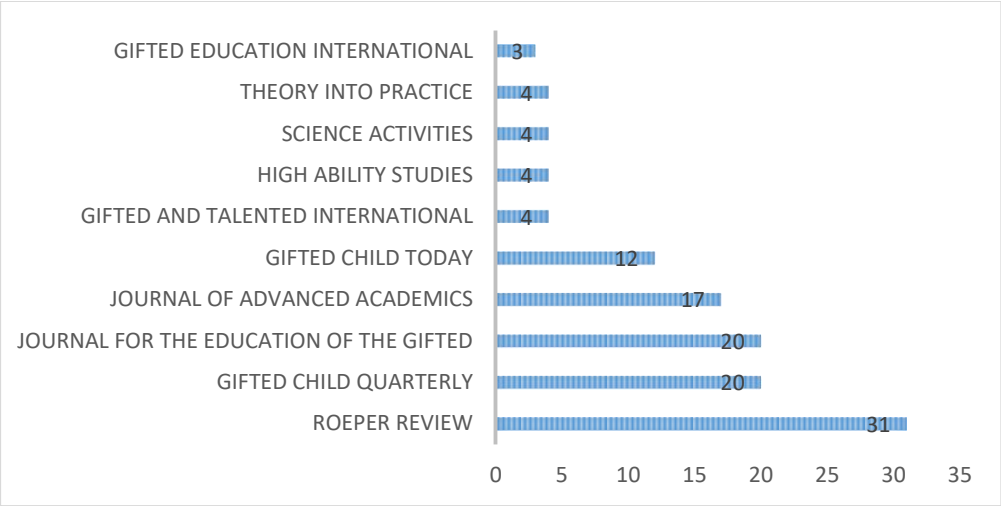
Relationship between Sources, Authors, and Keywords



In Figure 4, it is seen that the most productive journal on stem-related studies in gifted education is Rooper Review, followed by Gifted Child Quarterly, Journal for the Education of Gifted, Journal of Advanced Academics and Gifted Child Today. However, we can assert that other gifted journals (Gifted and Talented International, High Ability Studies, and Gifted Education International) are also interested in this topic, although not in large numbers.

Figure 4

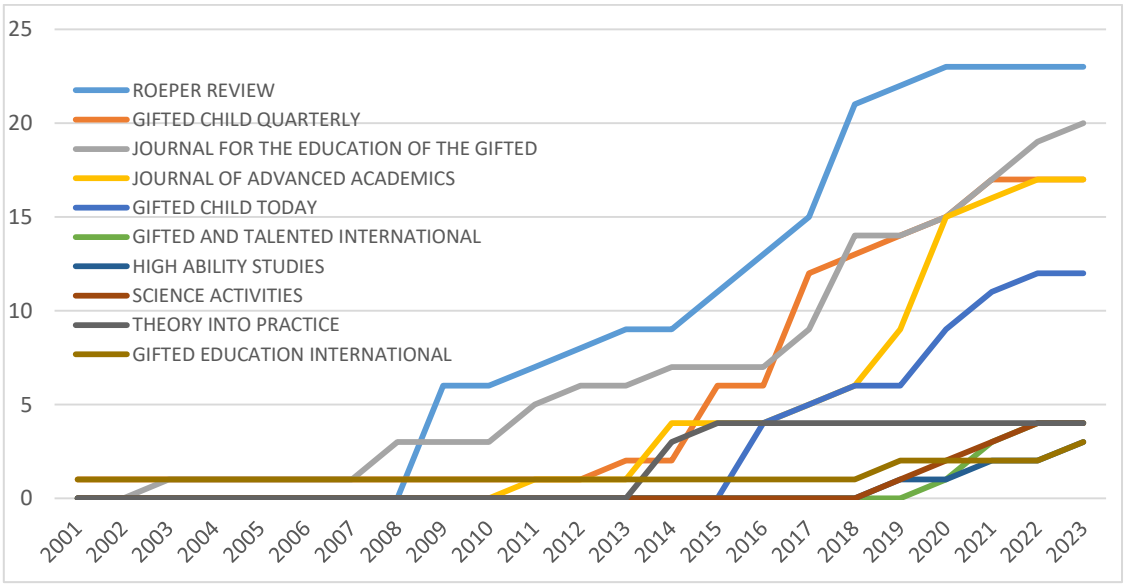
Number of Articles per Sources



When the productivity of the sources over the years was examined (Figure 5), it is seen that the Roeper Review has contributed to this field with increasing interest since 2008. The Journal for the Education of Gifted has been contributing increasingly since 2007, the Journal of Advanced Academics has been contributing increasingly since 2010, the Gifted Child Quarterly has been contributing to this field since 2011 and finally the Gifted Child Today has been contributing to this field since 2015 and continues to be productive.

Figure 5

The Productivity of Sources per Year

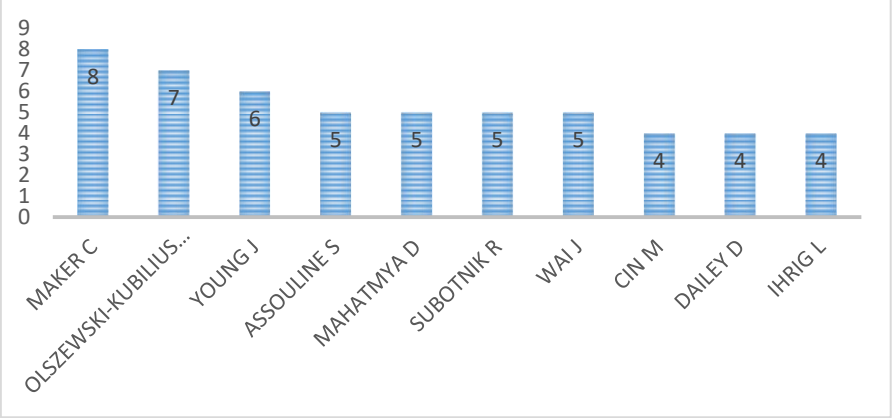


According to Figure 6, the most relevant authors are C. June Maker from The University of Arizona with eight publications, Paula Olszewski-Kubilius from Northwestern University with seven publications, and Jamaal Young from University of North Texas with six publications. These authors are followed by Susan G. Assouline and Duhita Mahatmya from The University of Iowa, Rena F. Subotnik from American Psychological Association and Jonathan Wai from University of Arkansas with five publications each. These authors are followed by Merve Ö. Cin from Republic of Turkey

Ministry of National Education, Debbie Dailey from University of Central Arkansas, and Lori M Ihrig from The University of Iowa with four publications each.

Figure 6

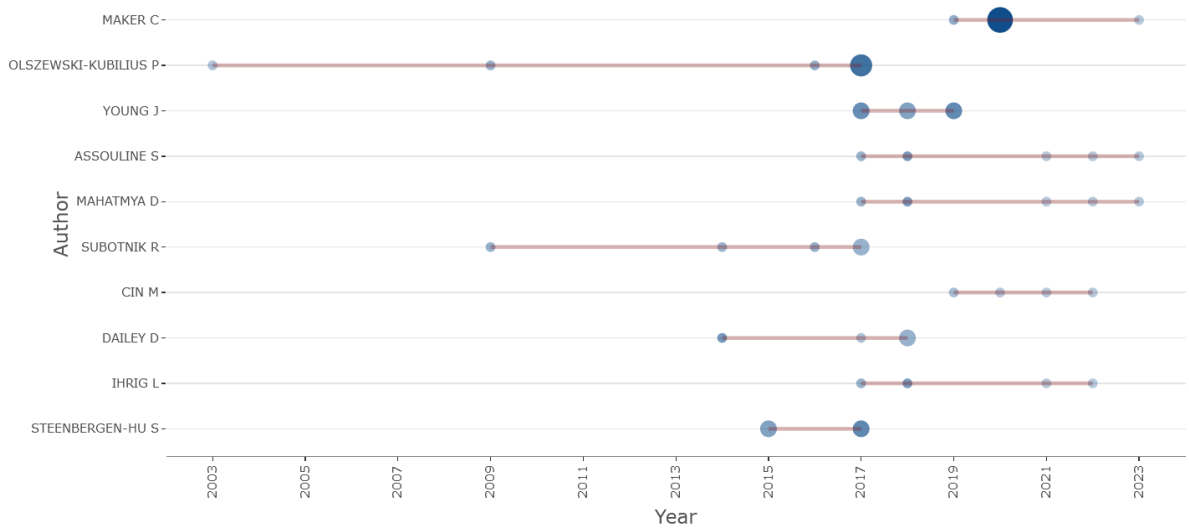
Most Relevant Authors



When we examine the productivity of the authors according to the years (Figure 7), it is seen that four authors continue to work on this issue. Lori M Ihrig, Susan G. Assouline, and Duhita Mahatmya have kept this topic on their agenda since 2017 and C. June Maker since 2019. Paula Olszewski-Kubilius and Rena F. Subotnik are the scientists who have been on this topic the longest. Other authors also emphasized this area at certain intervals.

Figure 7

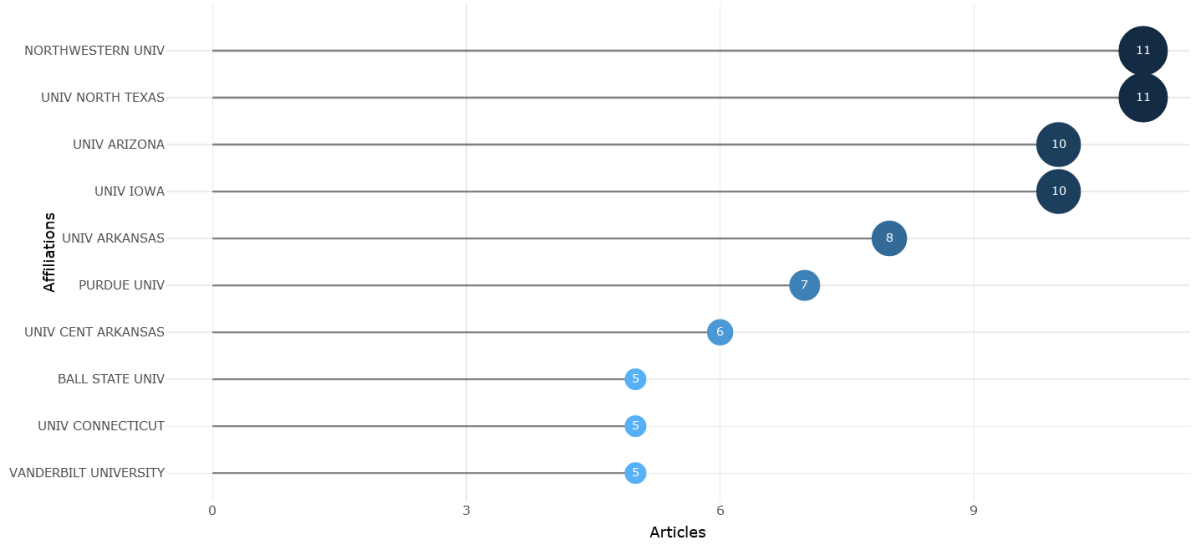
Author's Production over Time



With regard to the most productive institutions that contribute the most to this field (Figure 8), it is seen that Northwestern University and the University of North Texas lead the way, followed by the University of Arizona and the University of Iowa. These institutions are followed by University of Arkansas, Purdue University, and University Central Arkansas.

Figure 8

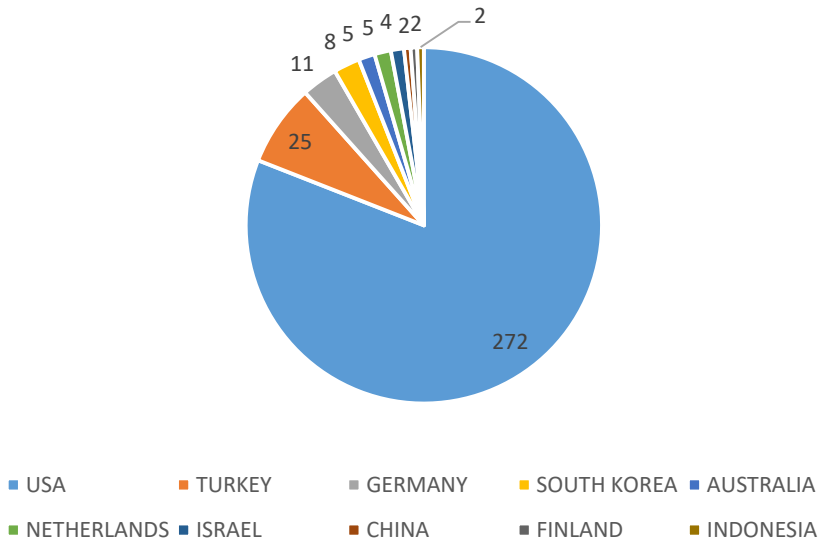
Academic Contribution of Institutions



When the productivity of countries in this field is examined (Figure 9), it is shown that the United States is the dominant country in this field, followed by Turkey, Germany and South Korea. However, Australia, the Netherlands, Israel, China, Finland, and Indonesia are also interested in this field, although not in large numbers.

Figure 9

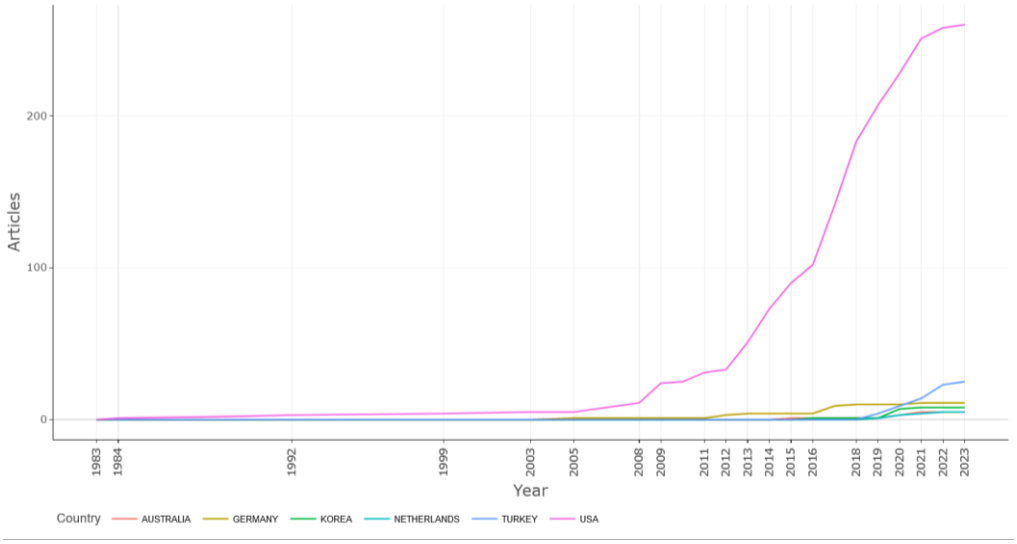
The Scientific Productivity of Countries



The US has focused on this area with a continuous and increasing dynamic since the 2000s, Germany has focused on this issue since 2008, but has not continued to do so, while Turkey has focused on this issue since 2018 and has continued to do so. The Netherlands, Korea and Austria have been focusing on this area since 2019.

Figure 10

The Productivity of Countries by Years



The most cited publications have been published in the last fifteen years. Here, it is seen that the most cited article is a longitudinal study published by Wai et al. (2010). This study is followed by Miller and Halpern's (2013) article on spatial training.

Table 3

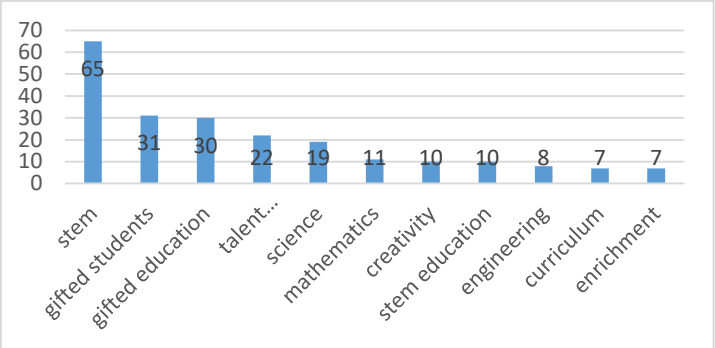
Main Information about Data

Author	Title	Citations
Wai et al. (2010)	Accomplishment in science, technology, engineering, and mathematics (STEM) and its relation to STEM educational dose: A 25-year longitudinal study.	264
Miller & Halpern (2013)	Can spatial training improve long-term outcomes for gifted STEM undergraduates?	84
Heilbronner (2013)	The STEM Pathway for Women: What Has Changed?	53
Park et al. (2013)	When less is more: Effects of grade skipping on adult STEM productivity among mathematically precocious adolescents.	52
Abdurrahman et al. (2019)	Design and Validation of Inquiry-based STEM Learning Strategy as a Powerful Alternative Solution to Facilitate Gift Students Facing 21st Century Challenging	40
Andersen (2014)	Visual–Spatial Ability: Important in STEM, Ignored in Gifted Education	39
Robinson et al. (2014)	The Effects of a Science-Focused STEM Intervention on Gifted Elementary Students' Science Knowledge and Skills	38
Peters-Burton et al. (2014)	Inclusive STEM High School Design: 10 Critical Components	38
Heilbronner (2011)	Stepping Onto the STEM Pathway: Factors Affecting Talented Students' Declaration of STEM Majors in College	36
Root-Bernstein (2015)	Arts and crafts as adjuncts to STEM education to foster creativity in gifted and talented students	35

When we tabulate the most frequently used keywords (Figure 11), STEM, gifted student, science, mathematics, engineering, and gifted education naturally appear to be the most frequently used keywords. We see that talent development, creativity, curriculum, and enrichment are the most frequently used keywords.

Figure 11

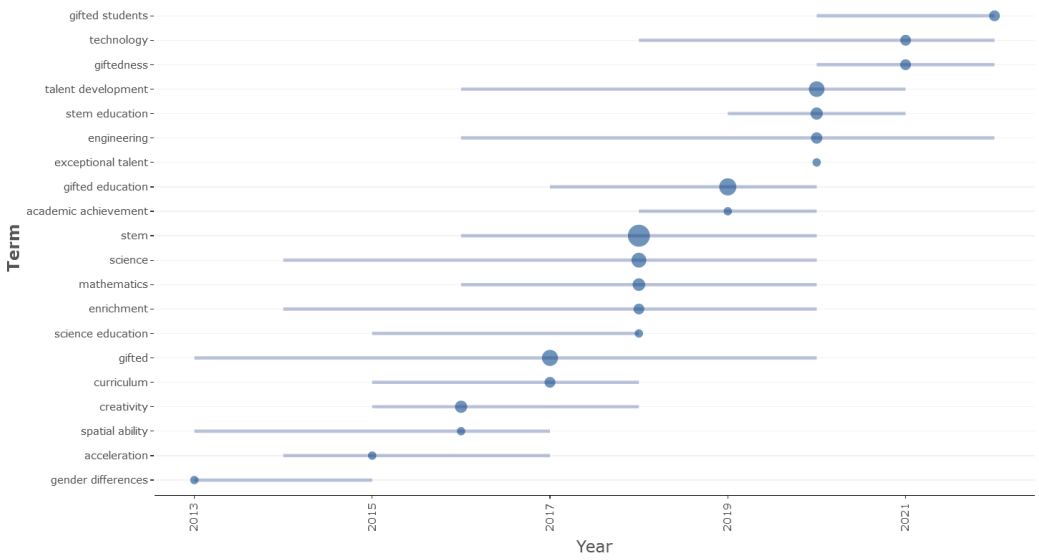
The Most Frequently Used Keywords



When the trending topics in the last ten years are analysed in two-year intervals (Figure 12), it is revealed that gender differences were the trending topic between 2013 and 2015, curriculum, creativity, and spatial ability were the trending topics between 2015-2017, enrichment and science mathematically focused stem were the trending topics between 2017-2019, and technology and engineering focused stem and talent development were the trending topics since 2019.

Figure 12

The Trending Topics in the Last Ten Years

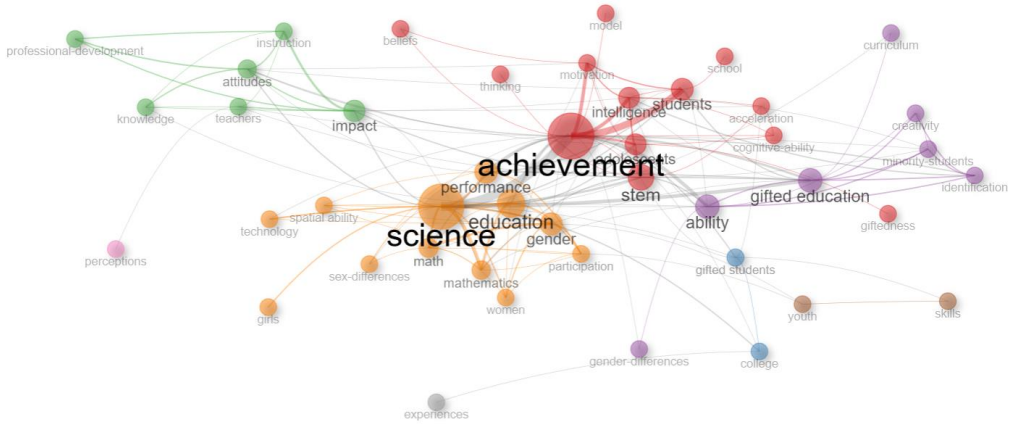


Upon analysing the co-occurrence networks of the keywords (Figure 13), it becomes apparent that they radiate outwards, forming three distinct clusters: one centred on science, another on achievement, and a third on gifted education. In proximity to the cluster centred on achievement, the words intelligence, motivation, thinking, beliefs, acceleration, and cognitive ability were observed to branch out. In close association with the cluster centred on science, the words mat, sex differences, performance, spatial ability, participation, and technology were identified as branching. Finally, in

relation to the cluster centred on gifted education, the words curriculum, minority students, identification, ability, and curriculum were found to branch out.

Figure 13

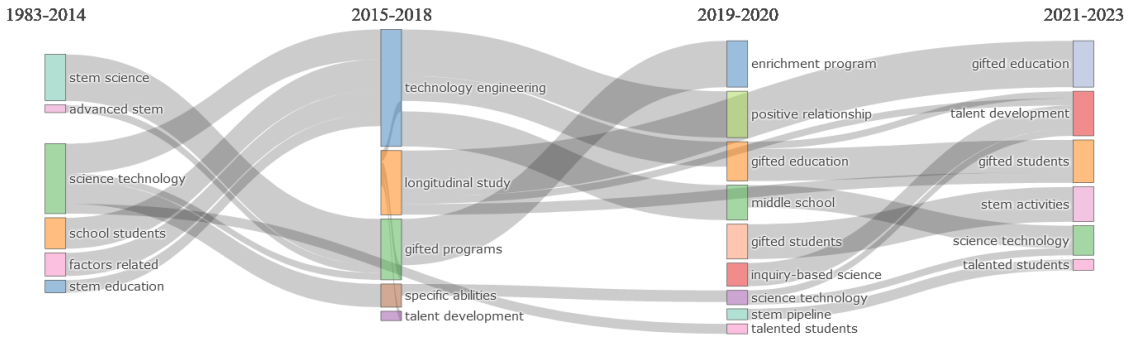
The Co-Occurrence Networks of the Keywords



Considering the thematic evolution divided into four different time periods (Figure 14), an observable transformation is evident within the domain of STEM education, where the trajectory of STEM science and advanced studies is undergoing a progression from foundational curricula towards specialized gifted programs, subsequently transitioning into enrichment initiatives. Concurrently, the landscape of science-technology-related research is undergoing a notable metamorphosis, pivoting towards the realms of technology-engineering studies. The themes focusing on specific abilities through science and technology are then seen to evolve into talent development in parallel with the previous theme through inquiry-based science and science-technology applications.

Figure 14

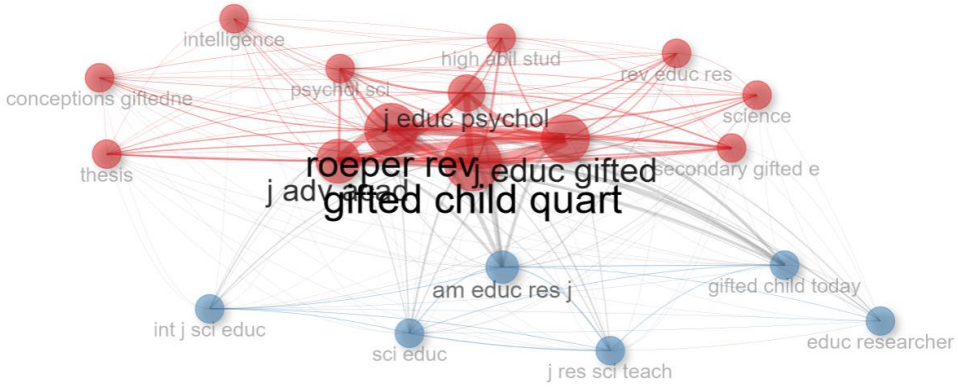
The Thematic Evolution



When the co-citation network between the sources is examined (Figure 15), it is seen that two clusters are formed, and in the first cluster, the network is shaped around the following four sources respectively: Gifted Child Quarterly, Roeper Review, Journal for the Education of Gifted, and Journal of Advanced Academics. Within the second cluster, there appears an interconnectivity among science-oriented journals, although this relationship is not very strong. These journals are the International Journal of Science Education, Science Education, and Journal of Research in Science Teaching.

Figure 15

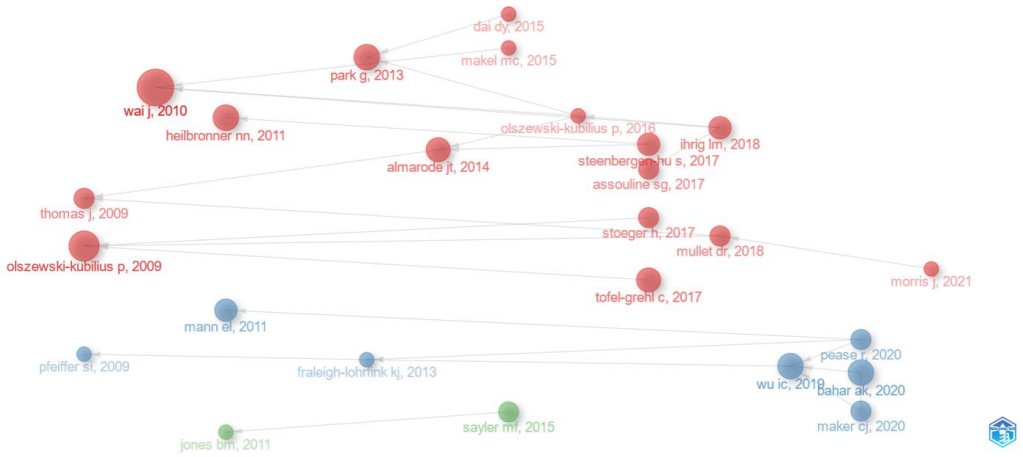
The Co-Citation Network between the Sources



When the historiography of stem and gifted-oriented studies is examined (Figure 16), it is seen that three different clusters are formed, with the strongest and most chronologically connected being the red cluster. Considering that each focal point is related to the introduction of a new topic or problem, there are four main topics in the red cluster and studies on these areas have been continued, sometimes with long periods of time between them. In the blue cluster, it was revealed that there were two main issues and that these issues intersected later. It is seen that there is no sustainable work with the green cluster.

Figure 16

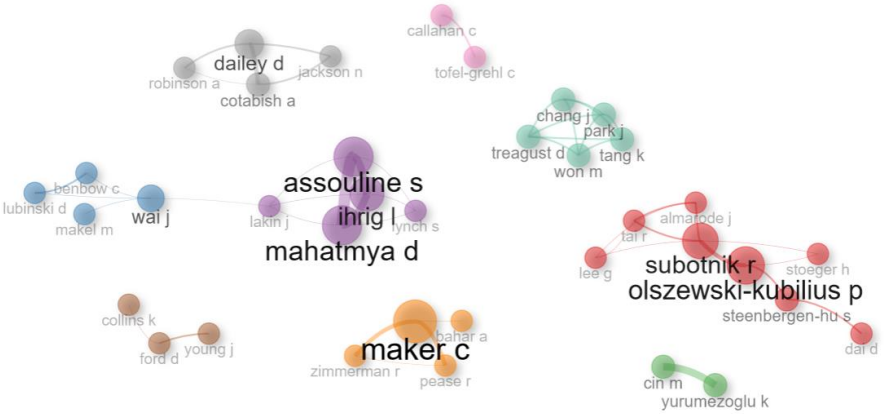
The Historiography of STEM-Gifted Oriented Studies



When we investigate the collaboration between authors (Figure 17), we see that there are many independent groups and that there is not even a slight connection between these groups (except for the blue and purple groups). The group with the strongest and most interaction and collaboration is the red group (Subotnik and Olszewski-Kubilies), followed by the purple group (Assouline, Ihrig and Mahatmya).

Figure 17

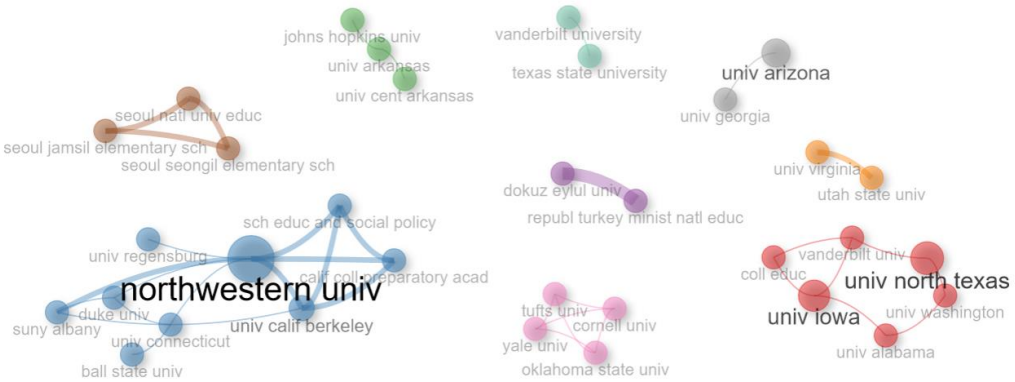
The Collaboration between Authors



In tandem with author collaboration, multiple autonomous groups have been identified in institutional collaborations (Figure 18) Notably, a significant number of institutions engage in cooperative efforts within the blue cluster, with Northwestern University serving as the central nexus. The red cluster also exhibits a relatively high degree of collaboration, while the remaining clusters demonstrate collaboration among two or three institutions.

Figure 18

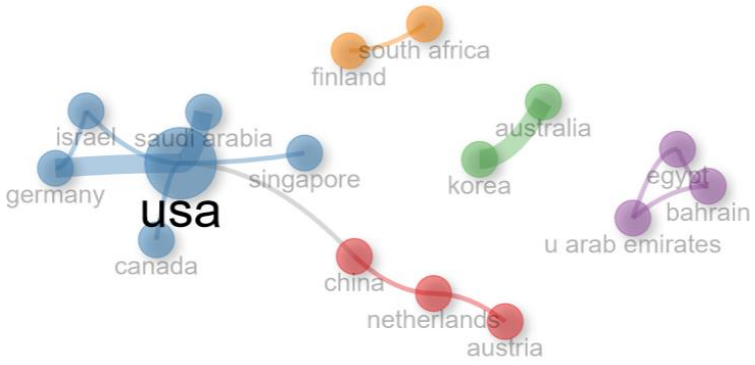
The Collaboration between Intuitions



When we examined the cooperation between countries (Figure 19), it has come to light that those countries demonstrating strong partnerships within the cluster, centred around the United States, consist of Germany, Canada, Singapore, Israel and Saudi Arabia. There is more distant cooperation with China, the Netherlands, and Austria.

Figure 19

The Cooperation between Countries



Discussion and Conclusion

The STEM approach is well suited to guiding and nurturing gifted learners toward STEM-related career pathways, while also equipping them with the scientific process skills, while raising interests towards STEM careers, and competencies for achieving success in those domains (Barış & Ecevit, 2019; Ercan, 2014; Robinson et al., 2014; Yamak et al., 2014). Additionally, as posited by Wu et al. (2019), integrating STEM into gifted curriculum facilitates improvement of creative problem solving skills when dealing with real-world problems (Wu et al., 2019). Furthermore, this teaching approach enables gifted learners to devise authentic and innovative solutions to complicated and multifaceted challenges, as well as encouraging novel discoveries and breakthroughs in the STEM disciplines (Dailey et al., 2018), and increasing their task motivation towards more challenging tasks (Sahin et al., 2014). STEM, in this regard, has begun to play a crucial role in supporting educational programmes for gifted and talented learners. This research has endeavoured to synthesise existing literature pertaining to STEM studies within the realm of gifted education.

170 studies were analysed in terms of bibliometric data. The first study appeared in 2003. After this year, it became apparent that, while there were only two studies published prior to 2007, the number of studies in this particular field has experienced a marked increase, particularly during the period between 2017 and 2021, when the maximum number of studies were published. These studies are generally related to academic achievement. (Tofel-Grehl & Callahan, 2017), positive attitude towards STEM (Ihrig et al., 2018), scientific process skills (Cotabish et al., 2013; Robinson et al., 2014), content and concept knowledge (Robinson et al., 2014), self-efficacy (Almarode et al., 2014), computational thinking skills (Sen et al., 2021), self-confidence and career knowledge (Dieker et al., 2012), creativity (Root-Bernstein, 2015), visual-spatial ability (Andersen, 2014) and etc. There is a paucity of research studies focusing on gifted female learners, gifted learners who reside in rural areas, and learners with twice-exceptionalities. There has been a dearth of studies conducted at the pre-school and primary school levels. It is noteworthy that there are also relatively few studies dedicated to the development of higher-order thinking skills among gifted students, which is one of the primary objectives of differentiation, a strategy often employed in STEM education.

When we examined to which journals the authors sent their studies related to this field, it was determined that these were predominantly gifted-themed journals. It can be stated that journals with the main themes of science, engineering, technology, and mathematics do not focus much on this field. In contrast to the conclusions drawn from the present study, an alternative observation suggests a prevalence of science-themed journals within the domain of STEM studies during the preschool period (Su & Yang, 2023). Again, when STEM teaching is examined in general, it is seen that science-themed journals tend to prevail (Jamali et al., 2023). Upon examining. The primary focus is on journals centred on gifted themes, with a few journals related to science also present, although they do not

hold a significant position. Most of the studies related to this field are published in Rooeper Review, Gifted Child Quarterly and Journal for the Education of Gifted, and at the same time, the articles published by these journals in this field have been increasing for years by year. These journals are prestigious in their field and have a high impact factor and are among the first journals that researchers usually consult. In this respect, their interest in this field is promising for future studies.

C. June Maker, who has contributed the most to this field, works on gifted education and talent development, Paula Olszewski-Kubilius works on gifted and talented development, Jamaal Young works directly on STEM and young learners, Susan G. Assouline and Duhita Mahatmya work on school psychology as does Jonathan Wai. Diverging from this particular finding, alternative studies indicate a prominence of experts operating within the realm of science (Özkaya, 2019; Talan, 2021). In parallel to the researchers publishing in this field, the institutions that contribute the most are the ones to which these authors are affiliated (Northwestern University, University of North Texas, the University of Arizona, and the University of Iowa). These institutions are predominantly located in the United States, with only one institution in Germany and two in Turkey. The study conducted by Taş and Bolat (2022) also reached similar findings. From this point of view, it can be said that the United States continues to work in this field in accordance with the programme but although it is included in the programmes of countries such as Turkey (Dokuz Eylul University and Uludag University), it can be asserted that researchers in these countries and other European countries do not focus much on STEM studies that enable gifted students to work interdisciplinary and develop their abilities in this field.

Upon a thorough examination of the most frequently cited articles in the field, it becomes evident that the majority of these works employ a longitudinal approach (Miller & Halpern, 2013; Wai et al., 2010) and place emphasis on the significance of STEM education for gifted learners (Peters-Burton et al., 2014), the perceptions of students, teachers, and administrators regarding STEM education in the context of gifted education, and the development of customized STEM courses catering to the needs of gifted learners (Heilbronner, 2011). In this regard, it would be prudent to engage in educational design research, causal-comparative, and experimental studies that delve into the specific effects of STEM education on gifted students' scientific process skills, higher-order thinking skills, socio-emotional and affective skills, as well as their overall inclination towards STEM-related careers and interests. The most frequent keywords used in the studies, as well as the distribution of the trending topics in these studies according to certain year intervals, support this conclusion. (see Figure 11 and 12). However, when we look at the co-occurrence map of the keywords (see Figure 13), it becomes apparent that while science, mathematics and technology exhibit strong associations with one another, engineering does not appear to share the same level of emphasis. Similarly, while gifted education is found to co-occur with terms such as curriculum, creativity, and identification, there appears to be a dearth of associations between other essential science process skills such as critical thinking, problem-solving, and design thinking.

When the historiography of stem and gifted-oriented studies is examined, although the studies started in 2003, it was determined that the studies conducted in 2009 and 2010 influenced later researchers. One of these studies is a study by Thomas and Williams (2010) examining the history and impact of STEM-specialised schools, another is a longitudinal evaluation of project excite for minority groups conducted by Olszewski-Kubilius (2010), another is a study by Pfeiffer et al. (2010) about STEM education in state-supported residential academies nationwide, and most recently, a longitudinal study by (Wai et al., 2010). All these indicate that longitudinal and survey studies are taken as reliable reference by researchers.

When the social networks between authors, institutions and countries were examined, there are not very strong ties between all these elements, although authors and institutions within the same country usually cooperate with each other (Domenech et al., 2020). This can be seen as a natural result because each country has different educational policies and educational needs arising from different cultural and social demographic structures. Nevertheless, it can be said that increased cooperation

among all these elements that set the same goals will increase the international validity and reliability of the studies conducted in this field.

Academic research into gifted learners took off in 2003, and accelerated around 2007. Studies are predominantly published in gifted-themed journals, and researchers who specialise in this area are the foremost contributors to this domain. Germany, Turkey and South Korea have also turned to this field, with the United States being the pioneer.

All in all, gifted students demand learning environments that are open-ended, challenging, and geared towards higher-order thinking skills. STEM education has been identified as an effective means of addressing these needs. Studies also indicates that integrating STEM subjects into gifted programmes can significantly enhance the academic, cognitive, social and emotional skills of gifted students, while also fostering positive attitudes and self-confidence towards STEM disciplines (Baum et al., 2014; Kalik & Kırındı, 2022). In the light of these findings, it can be inferred that STEM education not only meet the unique needs of gifted learners, but also holds a promising social benefit, as gifted individuals trained in these fields are well-suited to tackling the complex problems faced by contemporary societies. Hence, the study offers guidance to researchers with an interest in this domain by elucidating the key themes, prevailing trends, institutional affiliations, authorship, and journals that are significant contributors to the field. Additionally, this study highlights gaps in the field for future studies.

As for the limitations of the study, it can be asserted that the data search was conducted only on WoS and Scopus databases, it was conducted in English, and it does not include theses and conference proceedings. Future studies that take these limitations into account may contribute to a more comprehensive picture.

References

Abdurrahman, A., Ariyani, F., Maulina, H., & Nurulsari, N. (2019). Design and validation of inquiry-based STEM learning strategy as a powerful alternative solution to facilitate gifted students facing 21st century challenging. *Journal for the Education of Gifted Young Scientists*, *7*(1), 33–56. https://doi.org/10.17478/jegys.513308

Adams, C., Chamberlin, S., Katherine Gavin, M., Schultz, C., Jensen Sheffield, L., & Subotnik, R. (2008). *The STEM promise: recognizing and developing talent and expanding opportunities for*. www.nagc.org

Almarode, J. T., Subotnik, R. F., Crowe, E., Tai, R. H., Lee, G. M., & Nowlin, F. (2014). Specialized high schools and talent search programs: incubators for adolescents with high ability in stem disciplines. *Journal of Advanced Academics*, *25*(3), 307–331. https://doi.org/10.1177/1932202X14536566

Andersen, L. (2014). Visual-spatial ability: Important in STEM, ignored in gifted education. *Roeper Review*, *36*(2), 114–121. https://doi.org/10.1080/02783193.2014.884198

Baum, S. M., Schader, R. M., & Hébert, T. P. (2014). Through a different lens: Reflecting on a strengths-based, talent-focused approach for twice-exceptional learners. *Gifted Child Quarterly*, *58*(4), 311-327. https://doi.org/10.1177/0016986214547632

Barış, N. ve Ecevit, T. (2019). Özel yetenekli öğrencilerin eğitiminde STEM uygulamaları. *Necatibey Eğitim Fakültesi Elektronik Fen ve Matematik Eğitimi Dergisi, 13*(1), 217-233. https://doi.org/10.17522/balikesirnef.529898

Blaique, L., Pinnington, A. H., Al-Malkawi, H. A., & Aldabbas, H. (2023). The influence of personal skills development and coping self-efficacy on the affective occupational commitment of women in STEM fields. *Equality, Diversity and Inclusion: An International Journal*, *42*(2), 173-192. https://doi.org/10.1108/EDI-10-2021-0264

Cheng, L., Antonenko, P. P., Ritzhaupt, A. D., & MacFadden, B. (2021). Exploring the role of 3D printing and STEM integration levels in students' STEM career interest. *British journal of educational technology*, *52*(3), 1262-1278. https://doi.org/10.1111/bjet.13077

Cotabish, A., Dailey, D., Robinson, A., & Hughes, G. (2013). The effects of a STEM intervention on elementary students' science knowledge and skills. *School Science and Mathematics*, *113*(5), 215–226. https://doi.org/10.1111/ssm.12023

Dailey, D., Cotabish, A. and Jackson, N. (2018). Increasing early opportunities in engineering for advanced learners in elementary classrooms: a review of recent literature. *Journal for the Education of the Gifted*, 41(1), 93 –105. https://doi.org/10.1177/0162353217745157

Dieker, L., Grillo, K., & Ramlakhan, N. (2012). Dieker, L., Grillo, K., & Ramlakhan, N. (2012). The use of virtual and simulated teaching and learning environments: Inviting gifted students into science, technology, engineering, and mathematics careers (STEM) through summer partnerships. *Gifted Education International*, *28*(1), 96-106. https://doi.org/10.1177/0261429411427647

Gil-Doménech, D., Berbegal-Mirabent, J., & Merigó, J. M. (2020). STEM education: A bibliometric overview. In *Modelling and Simulation in Management Sciences: Proceedings of the International Conference on Modelling and Simulation in Management Sciences (MS-18)* (pp. 193-205). Springer International Publishing.

English, L. D. (2017). Advancing elementary and middle school stem education. *International Journal of Science and Mathematics Education*, *15*, 5–24. https://doi.org/10.1007/s10763-017-9802-x

Ercan, S. (2014*). Fen eğitiminde mühendislik uygulamalarinin kullanimi: tasarim temelli fen eğitimi* [Doctoral dissertation, Marmara University].

Ericsson, K. A. (2014). Why expert performance is special and cannot be extrapolated from studies of performance in the general population: A response to criticisms. *Intelligence*, *45*(1), 81–103. https://doi.org/10.1016/j.intell.2013.12.001

Gagné, F. (2004). Transforming gifts into talents: The DMGT as a developmental theory. *High Ability Studies*, *15*(2), 119–147. https://doi.org/10.1080/1359813042000314682

Gandrud, C. (2013). Getting Started with R, RStudio, and knitr. In *Reproducible Research with R and RStudio Second Edition* (pp. 53–84). Chapman and Hall.

Gavin, M. K., Casa, T. M., Firmender, J. M., & Carroll, S. R. (2013). The Impact of advanced geometry and measurement curriculum units on the mathematics achievement of first-grade students. *Gifted Child Quarterly*, *57*(2), 71–84. https://doi.org/10.1177/0016986213479564

Haryadi, R., Situmorang, R., & Khaerudin, K. (2021). Enhancing Students' High-Order Thinking Skills through STEM-Blended Learning on Kepler's Law During Covid-19 Outbreak.lowercase *Jurnal Penelitian Dan Pembelajaran IPA*, *7*(2), 168-192. http://dx.doi.org/10.30870/jppi.v7i2.12029

Heilbronner, N. N. (2011). Stepping onto the STEM pathway: Factors affecting talented students' declaration of STEM majors in college. *Journal for the Education of the Gifted*, *34*(6), 876–899. https://doi.org/10.1177/0162353211425100

Heilbronner, N. N. (2013). The STEM pathway for women: What has changed? *Gifted Child Quarterly*, *57*(1), 39–55. https://doi.org/10.1177/0016986212460085

Ihrig, L. M., Lane, E., Mahatmya, D., & Assouline, S. G. (2018). STEM excellence and leadership program: increasing the level of stem challenge and engagement for high-achieving students in economically disadvantaged rural communities. *Journal for the Education of the Gifted*, *41*(1), 24–42. https://doi.org/10.1177/0162353217745158

Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2023). The role of STEM Education in improving the quality of education: A bibliometric study. *International Journal of Technology and Design Education*, *33*(3), 819-840. https://doi.org/10.1007/s10798-022-09762-1

June Maker, C. (2005). *The national research center on the gifted and talented the discover project: Improving Assessment and Curriculum for Diverse Gifted Learners Senior Scholars Series*.

Kaufman, S. B., & Sternberg, R. J. (2008). Conceptions of giftedness. In S. I. Pfeiffer (Ed.), *Handbook of Giftedness in Children* (pp. 71–93). Springer.

Kalik, G., & Kırındı, T. (2022). Fen bilimleri dersinde okul dışı STEM etkinliklerinin üstün/özel yetenekli öğrencilerin STEM'e karşı tutumlarına ve girişimcilik becerileri üzerine etkisi. *Fen Bilimleri Öğretimi Dergisi*, *10*(1), 38-63. https://doi.org/10.56423/fbod.1058632

Kocaman, B. (2022). Investigation of the effects of STEM activities on STEM attitude in gifted students. *Apuntes Universitarios*, *13*(1), 1–29. https://doi.org/10.17162/au.v13i1.1309

Kurup, A., Chandra, A., & Binoy, V. V. (2015). "Little minds dreaming big science": are we really promoting "children gifted in STEM" in India? *Current Science*, *108*(5), 779–781. http://web.ebscohost.com.ez.sun.

Maker, C. J. (2020). Identifying Exceptional talent in Science, Technology, Engineering, and Mathematics: increasing diversity and assessing creative problem-solving. *Journal of Advanced Academics*, *31*(3), 161–210. https://doi.org/10.1177/1932202X20918203

Maker, C. J., & Schiever, S. W. (2010). *Curriculum development and teaching strategies for gifted learners* (3rd ed.). PRO-ED.

Mann, E. L., Mann, R. L., Strutz, M. L., Duncan, D., & Yoon, S. Y. (2011). Integrating engineering into K-6 curriculum: Developing talent in the STEM disciplines. *Journal of Advanced Academics*, *22*(4), 639–658. https://doi.org/10.1177/1932202X11415007

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. In *International Journal of STEM Education*. Springer. https://doi.org/10.1186/s40594-018-0151-2

Marland, S. P. (1972). *Education of the gifted and talented. Report to congress of the United States Commissioner of Education*.

Miedijensky, S., & Tal, T. (2016). Reflection and assessment for learning in science enrichment courses for the gifted. *Studies in Educational Evaluation*, *50*, 1–13. https://doi.org/10.1016/j.stueduc.2016.05.001

Miller, D. I., & Halpern, D. F. (2013). Can spatial training improve long-term outcomes for gifted STEM undergraduates? *Learning and Individual Differences*, *26*, 141–152. https://doi.org/10.1016/j.lindif.2012.03.012

Moher, D., Tetzlaff, J., Tricco, A. C., Sampson, M., & Altman, D. G. (2007). Epidemiology and reporting characteristics of systematic reviews. *PLoS Medicine*, *4*(3), 65–78.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In Ş. Purzer, J. Strobel, & M. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35-60). Purdue University Press.

Moreno-Guerrero, A. J., Gómez-García, G., López-Belmonte, J., & Rodríguez-Jiménez, C. (2020). Internet addiction in the web of science database: a review of the literature with scientific mapping. *International Journal of Environmental Research and Public Health*, *17*(8), 2753. https://doi.org/10.3390/ijerph17082753

Morris, J., Slater, E., Fitzgerald, M. T., Lummis, G. W., & van Etten, E. (2021). Using Local Rural Knowledge to Enhance STEM Learning for Gifted and Talented Students in Australia. *Research in Science Education*, *51*, 61–79. https://doi.org/10.1007/s11165-019-9823-2

National Science Board. (2012). *Science and Engineering Indicators*.

Olszewski-Kubilius, P. (2010). Special schools and other options for gifted STEM students. *Roeper Review*, *32*(1), 61–70. https://doi.org/10.1080/02783190903386892

Özkaya, A. (2019). Bibliometric analysis of the publications made in STEM education area. *Bartin Üniversitesi Egitim Fakültesi Dergisi*, *8*(2), 590-628. https://doi.org/10.14686/buefad.450825

Park, G., Lubinski, D., & Benbow, C. P. (2013). Park, G., Lubinski, D., & Benbow, C. P. (2013). When less is more: Effects of grade skipping on adult STEM productivity among mathematically precocious adolescents. *Journal of Educational Psychology*, *105*(1), 176.

Peters-Burton, E. E., Lynch, S. J., Behrend, T. S., & Means, B. B. (2014). Inclusive STEM High School Design: 10 Critical Components. *Theory into Practice*, *53*(1), 64–71. https://doi.org/10.1080/00405841.2014.862125

Pfeiffer, S. I., Marguerite Overstreet, J., & Park, A. (2010). The state of science and mathematics education in state-supported residential academies: A nationwide survey. *Roeper Review*, *32*(1), 25–31. https://doi.org/10.1080/02783190903386579

Porter, L. A. (2017). High-Impact Practices in Materials Science Education: Student Research Internships Leading to Pedagogical Innovation in STEM Laboratory Learning Activities. *MRS Advances* , *2*(31–32), 1667–1672. https://doi.org/10.1557/adv.201

Renzulli, J. S. (1986). The three-ring conception of giftedness: A developmental model for creative productivity. In R. J. Sternberg & J. E. Davidson (Eds.), *Conceptions of giftedness* (pp. 55–92). Cambridge University Press.

Renzulli, J. S., Smith, L. H., & Reis, S. M. (1982). Curriculum Compacting: An Essential Strategy for Working with Gifted Students. *The Elementary School Journal*, *82*(3), 185–194. http://www.journals.uchicago.edu/t-and-c

Robinson, A., Dailey, D., Hughes, G., & Cotabish, A. (2014). The effects of a science-focused STEM intervention on gifted elementary students' science knowledge and skills. *Journal of Advanced Academics*, *25*(3), 189-213. https://doi.org/10.1177/1932202X14533799

Root-Bernstein, R. (2015). Arts and crafts as adjuncts to STEM education to foster creativity in gifted and talented students. *Asia Pacific Education Review*, *16*(2), 203–212. https://doi.org/10.1007/s12564-015-9362-0

Sahin, A., Ayar, M. C., & Adiguzel, T. (2014). STEM related after-school program activities and associated outcomes on student learning. *Educational Sciences: Theory and Practice*, *14*(1), 309-322.

Schroth, S. T., & Helfer, J. A. (2017). Gifted & green sustainability/environmental science investigations that promote gifted children's learning. *Gifted Child Today*, *40*(1), 14–28. https://doi.org/10.1177/1076217516675903

Sen, C., Ay, Z. S., & Kiray, S. A. (2021). Computational thinking skills of gifted and talented students in integrated STEM activities based on the engineering design process: The case of robotics and 3D robot modeling. *Thinking Skills and Creativity*, *42*.100931 https://doi.org/10.1016/j.tsc.2021.100931

Siegle, D., Rubenstein, L. D., & Mitchell, M. S. (2014). Honors students' perceptions of their high school experiences: The influence of teachers on student motivation. *Gifted Child Quarterly*, *58*(1), 35-50. https://doi.org/10.1177/0016986213513496

Steenbergen-Hu, S., & Olszewski-Kubilius, P. (2017). Factors that contributed to gifted students' success on stem pathways: the role of race, personal interests, and aspects of high school experience. *Journal for the Education of the Gifted*, *40*(2), 99–134. https://doi.org/10.1177/0162353217701022

Stehle, S. M., & Peters-Burton, E. E. (2019). Developing student 21st Century skills in selected exemplary inclusive STEM high schools. *International Journal of STEM Education*, *6*(1). https://doi.org/10.1186/s40594-019-0192-1

Sternberg, R. J. (2005). The theory of successful intelligence. *Interamerican Journal of Psychology*, *39*, 189–202.

Stoeger, H., Hopp, M., & Ziegler, A. (2017). Online mentoring as an extracurricular measure to encourage talented girls in STEM (science, technology, engineering, and mathematics): An empirical study of one-on-one versus group mentoring. *Gifted Child Quarterly*, *61*(3), 239-249. https://doi.org/10.1177/0016986217702215

Su, J., & Yang, W. (2023). STEM in early childhood education: A bibliometric analysis. *Research in Science & Technological Education*, 1-22. https://doi.org/10.1080/02635143.2023.220167

Talan, T. (2021). Augmented reality in STEM education: Bibliometric analysis. *International Journal of Technology in Education (IJTE)*, 4(4), 605-623. https://doi.org/10.46328/ijte.136

Tas, N., & Bolat, Y. İ. (2022). An Examination of the studies on STEM in education: A bibliometric mapping analysis. *International Journal of Technology in Education and Science*, *6*(3), 477-494. https://doi.org/10.46328/ijtes.401

Thomas, J., & Williams, C. (2010). The history of specialized STEM schools and the formation and role of the NCSSSMST. *Roeper Review*, *32*(1), 17–24. https://doi.org/10.1080/02783190903386561

Tofel-Grehl, C., & Callahan, C. M. (2017). STEM High schools teachers' belief regarding STEM student giftedness. *Gifted Child Quarterly*, *61*(1), 40–51. https://doi.org/10.1177/0016986216673712

Tomlinson, C. A. (2017). *How to Differentiate Instruction in Academically Diverse Classrooms* (3rd ed.). ASCD.

Ulger, B. B., & Çepni, S. (2020). Gifted education and STEM: A thematic review. *Journal of Turkish Science Education*, *17*(3), 443-466.

U.S. Department of Commerce. (2017). *STEM jobs: 2017 update*. Https://Www.Commerce.Gov/News/Reports/2017/03/Stem-Jobs-2017-Update.

Vanderbrook, C. M. (2006). Intellectually gifted females and their perspectives of lived experience in the AP and IB programs. *The Journal of Secondary Gifted Education*, *17*(3), 5–20.

VanTassel-Baska, J. (2003). Content-based curriculum for high-ability learners. In J. VanTassel-Baska & C. A. Little (Eds.), *Content-based curriculum for high-ability learners* (pp. 1–23). Prufrock Press.

Vossen, T. E., Henze, I., Rippe, R. C. A., Van Driel, J. H., & De Vries, M. J. (2021). Attitudes of secondary school STEM teachers towards supervising research and design activities. *Research in Science Education*, *51*, 891-911. https://doi.org/10.1007/s11165-019-9840-1

Wai, J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2010). Supplemental Material for Accomplishment in Science, Technology, Engineering, and Mathematics (STEM) and its relation to STEM Educational Dose: A 25-Year Longitudinal Study. *Journal of Educational Psychology*, *102*(4), 860–871. https://doi.org/10.1037/a0019454

Wicklein, R. C., & Schell, J. W. (1995). Case Studies of Multidisciplinary Approaches to Integrating Mathematics, Science and TechnologyEducation. In *Journal of Technology Education* (Vol. 6, Issue 2).

Wu, I. C., Pease, R., & Maker, C. J. (2019). Students' Perceptions of a Special Program for Developing Exceptional Talent in STEM. *Journal of Advanced Academics*, *30*(4), 474–499. https://doi.org/10.1177/1932202X19864690

Yoon, S. Y., & Mann, E. L. (2017). Yoon, S. Y., & Mann, E. L. (2017). Exploring the spatial ability of undergraduate students: association with gender, STEM majors, and gifted program membership. *Gifted Child Quarterly*, *61*(4), 313-327. https://doi.org/10.1177/0016986217722614

Journal of Turkish Science Education, 2024, *21*(1), 175-195.
DOI no: 10.36681/tused.2024.010

The Effect of the Pjb-HOTS learning model on cognitive learning, analytical thinking skills, creative thinking skills, and metacognitive skills of biology education students

Sintje Liline[1], Anensiana Tomhisa[2], Dominggus Rumahlatu[3], Kristin Sangur[4]

[1]*Pattimura University, Indonesia, ORCID ID: 0000-0003-4973-9490*
[2]*Pattimura University, Indonesia, ORCID ID: 0000-0002-0490-9129*
[3]*Pattimura University, Indonesia, ORCID ID: 0000-0002-4466-5528*
[4]*Pattimura University, Indonesia, sangur_kristin@yahoo.com, Corresponding author ORCID ID: 0000-0003-4576-6328*

ABSTRACT
In this industrial revolution era, university-level education emphasises higher-order thinking skills). This research aims to analyse the effect of implementing the PjB-HOTS learning model on cognitive learning, creative thinking skills, analytical thinking skills, and metacognitive skills of the students studying osmoregulation concepts in Animal Physiology courses. The sample consisted of 61 fifth-semester students divided into two classes. An open-ended test was used to measure students' cognitive learning levels, creative thinking skills, analytical thinking skills, creative thinking skills, and metacognitive skills. The research data were analysed using the Analysis of Covariance (ANCOVA). The results of this research show that the learning model had a significant effect on the cognitive learning gains ($0.000< \alpha= 0.05$), creative thinking skill ($0.001< \alpha= 0.05$), analytical thinking skill ($0.000< \alpha= 0.05$), and metacognitive skill ($0.000< \alpha= 0.05$). These results indicate that the combined syntax of PjBL and HOTS can foster students' higher-order thinking skills and improve their cognitive learning gains. We recommend the PjB-HOTS learning model be used for other biological concepts at the university-level.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 19.07.2021
Accepted: 17.11.2023

KEYWORDS:
PjB-HOTS learning, cognitive learning of biology, thinking skills.

To cite this article: Liline, S., Tomhisa, A., Rumahlatu, D., & Sangur, K. (2024). The Effect of the Pjb-HOTS learning model on cognitive learning, analytical thinking skills, creative thinking skills, and metacognitive skills of biology education students. *Journal of Turkish Science Education, 21*(1), 175- 195. DOI: 10.36681/tused.2024.010

Introduction

Education 4.0 is a part of Industrial Revolution (IR) 4.0 (Bonfield et al., 2020). It is a phenomenon that results from the necessity of the IR 4.0. For example, the curricula of primary schools, lower secondary schools and upper secondary schools are revised to prepare the pupils exiting the education system to compete in the IR 4.0 era. According to Venkatraman et al. (2022), the Education Framework 4.0 aims to support Industry 4.0 skills needs which include soft skills development and lifelong learning. Higher Order Thinking Skills (HOTS) are considered the most

suitable skills for the 4.0 education era. Hartono and Pahlevi (2020) explain that HOTS focuses on critical thinking and creative thinking to solve problems. HOTS-based learning can help learners improve their problem-solving skills. HOTS integrated with learning strategies can be used to improve the learning process by promoting learners' creativity at all levels of education (Zohar & Dori, 2008; Chinedu et al., 2015; Zubaidah et al., 2017; Heong et al., 2019; Istiyono et al., 2020).

So far, HOTS has always been evaluated at the end of learning activities. Researchers have developed appropriate instruments to measure HOTS in learning (Serevina et al., 2019; Erfianti et al., 2019). Syafryadin et al. (2021) have integrated the HOTS principle during the English learning process, while Pius et al. (2019) applied the HOTS principle during History learning. This means that implementing HOTS integrated with a learning model can also be done in Biology learning. The Project-Based Learning (PjBL) learning model is an innovative learning model that emphasizes the investigation process by the students and produces artifacts like objects or documents. Rumahlatu and Sangur (2019) reported that implementing the PjBL learning model had a more significant effect on fostering students' metacognitive skills through the construction of cognitive and manage their learning than the conventional learning model. Syawaludin et al. (2022), Kortam et al. (2018), Maiasputri et al. (2018), Surahman et al. (2018), and Berchiolli et al. (2018) recommend that the PjBL learning model be implemented to improve students' higher-order thinking skills and active participation in learning. The PjBL learning model can be integrated with HOTS into an innovative learning model called the Project Based-Higher Other Thinking Skills Learning Model (PjB-HOTS learning model. Each stage of the PjBL learning model, which includes planning, creating, and presenting, will be integrated into a single unit with HOTS components such as creative, critical, and analytical thinking skills.

Budsankom et al. (2015) invoke HOTS in three abilities are analytical thinking, critical thinking, and creative thinking. Rumahlatu et al. (2020) and Saputri & Corebima (2020) state that in addition to critical thinking skills and creative thinking skills, metacognitive skills can also improve students' comprehension of the learning material. Fosters of metacognitive abilities have a positive relationship with creative thinking which is shown through original ideas and idea formation (Puente-Diaz et al., 2021; Suratno et al., 2019). Metacognitive skills can also affect students' critical thinking skills through a research-based learning process that fosters these two abilities (Kozikoğlu, 2019; Gurcay & Ferah, 2018; Mataniari et al., 2020).

Educators should prepare an innovative learning model to improve students' higher-order thinking skills. Retnawati et al. (2018) state that educators should provide challenging opportunities for students to train their higher-order thinking skills. With the implementation of an appropriate learning model, it is expected that students, as the young Indonesian generation, are prepared and ready to face the challenges of the 4.0 Industrial Revolution.

Most of the lecturers in the Biology Education Department in Pattimura University have implemented innovative cooperative learning models, such as STAD, PBL, PjBL, NHT, GI and many other models. The lecturers have also implemented learning evaluations with HOTS-based questions. This shows that they apply the HOTS learning and evaluation model separately/partially. However, they have not integrated HOTS with the learning models to improve the students' higher-order thinking skills. Lecturers need to design HOTS-based learning models to effectively and efficiently foster students' higher-order thinking skills so that learning and evaluation processes become one unit. Previous researchers have successfully integrated HOTS with learning models (Heong et al., 2019; Launuru et al., 2021). This study aims to conduct this research to investigate the implementation of the PjB-HOTS learning model on the fosters of students' cognitive learning gains, analytical thinking skills, creative thinking skills, and metacognitive skills in the Biology education department at Pattimura University, Ambon. The conduct of this research can offer an innovative biology learning climate at the university level.

Methods

Table Representation

This research was of quasi-experimental design using a pretest-posttest nonequivalent group approach. The PjB-HOTS and PjBL learning models were used as the independent variables, while cognitive learning gains, creative thinking skills, analytical thinking skills, and metacognitive skills were used as the dependent variables. These two models were used in different classes to test the effect of the PjB-HOTS learning model on the dependent variable. Table 1 shows the quasi-experimental research design. The difference in learning from these two models can be seen in the Appendix.

Table 1

Research Design

Treatment Group	Pre-test	Post-test
PjB-HOTS learning model (X1)	Y1	Y2
PjBL learning model (X2)	Y1	Y2

Sample

The population of this research was the fifth-semester students taking the Animal Physiology course which consisted of three classes. The research samples involved two classes of students. Class A was taught using the PjB-HOTS learning model as the experimental class, and class B was taught using the PjBL learning model as the control class. The research samples were determined using the purposive sampling technique by considering several conditions: a heterogeneous class (gender and social background) and able to perform digital literacy.

Instruments

The instrument developed in this research was an open-ended test based on creative thinking skills, analytical thinking skills, and metacognitive skills. In addition, the instrument was also equipped with a scoring matrix for cognitive learning, creative thinking skills, analytical thinking skills, and metacognitive skills. Before being used, the instrument was initially tested for reliability and validity. Table 2 shows the validity analysis and the reliability analysis.

Table 2

Instrument Validity and Reliability

Question items	Question type	r_{xy}	Significant value	Interpretation	Cronbach's alpha Value	Interpretation
1	Smoothness	.187	= 0.05	Valid	.782	Good
2	Authenticity	.082		Valid		
3a	Flexibility	.080		Valid		
3b		.070		Valid		
4a	Develop	.285		Valid		
4b		.071		Valid		
5a	Rate	.370		Valid		
5b		.250		Valid		

5c	.066	Valid
5d	.056	Valid

Procedures

The learning activities in each class were carried out almost simultaneously and using different learning models (Table 4). The dependent variables (cognitive learning gains, creative thinking skill, analytical thinking skill, and metacognitive skill) were assessed using the same instrument. The research data were collected as follows. (1) The Pre-test was administered to both classes before the learning activities began. The pre-test results of the cognitive learning, creative thinking, analytical thinking, and metacognitive skills were used as covariates in the ANCOVA statistical analysis. (2) The experimental class was taught by using the PjB-HOTS learning model and the control class was taught using the PjBL learning model (Table 4). (3) Post-test was administered to measure students' cognitive learning gains, creative thinking skills, analytical thinking skills, and metacognitive skills.

Table 4

The Learning Syntax of the PJB-HOTS Learning Model

PjBL Stages for a control class	Explanation	HOTS Aspects	PjB-HOTS Integration for a experiment class	
Planning	1. Selecting a topic 2. Searching for information 3. Organising human resources in groups	• Creative Thinking • Analytical Thinking	Planning	1. Fostering students' analytical thinking about problems that can be used as the topics for osmoregulation investigation projects 2. Fostering students' analytical thinking to select relevant information to the concept of osmoregulation 3. Fostering students' creative thinking in dividing group tasks
Creating	4. Developing project stages 5. Implementing the project 6. Making a product (artefact) 7. Compiling project reports		Creating	4. Fostering students' creative thinking in arranging the stages of osmoregulation investigation projects 5. Fostering students' creative thinking in implementing the project 6. Fostering students' creative thinking in making a product 7. Fostering students' analytical thinking in compiling investigative data into project reports
Presenting	8. Presentation 9. Feedback		Presenting	8. Fostering students' creative thinking in doing presentations

Data Analysis

The research data were analysed using inferential statistics. The data were tested for normality and homogeneity using the One-Sample Kolmogorov-Smirnov Test and Leven's Test of Quality of Error Variances, respectively (Table 5). The Analysis of Covariance (ANCOVA) was used to analyse the effect of the implementation of the learning models on students' cognitive learning gains, creative thinking skills, analytical thinking skills, and metacognitive thinking skills. Furthermore, if

the analysis results indicated that the implementation of the learning model had an effect, the post hoc least significant difference (LSD) would be performed to determine the average statistical significance difference. The data analyses were performed using the SPSS 18.0 program.

Table 5

The Data of the Normality and Homogeneity Analyses of the Dependent Variable

Variable	Description	Description
Cognitive Learning Gains	Homogeneous	Normal
Creative Thinking	Homogeneous	Normal
Analytical Thinking	Homogeneous	Normal
Metacognitive Thinking	Homogeneous	Normal

Findings

Several osmoregulation projects carried out by students are described in Figures 1-3.

Figure 1

One of the Osmoregulation Projects Was Carried Out By A Student Titled "Measurement Of Water Volume In Comet Fish By Using Water Variations". Through This Project, The Student Found Creative Ideas To Observe The Osmoregulation Ability Of Comet Fish In Water Variations That Are Different From Their Natural Habitat, Namely Freshwater. Analytical And Metacognitive Abilities Are Needed To Explain Why The Volume Of Boiled Water Decreases Faster Than Refilled Water And Pure Water

Measurement of Water Volume in Comet Fish by Using Water Variations

Date	Water Volume	Water Type			Observation Result		
		Pure Water	Water Gallon	Boiled Water	Pure Water	Water Gallon	Boiled Water
Monday, October 05, 2020	500 ml	500 ml	500 ml	500 ml			
Tuesday, October 06, 2020	500 ml	495 ml	492 ml	490 ml			
Wednesday, October 07, 2020	500 ml	490 ml	484 ml	480 ml			
Thursday, October 08, 2020	500 ml	485 ml	475 ml	470 ml			

Figure 2

The Next Osmoregulation Project Is "The Effect Of Water Salinity On Tilapia And Survival Ability" In This Project, The Student Found Creative Ideas To Observe The Differences In The Survival Abilities Of Tilapia In Seawater And Freshwater. Through This Project, the Student Will Analyse the Osmoregulation Ability Of Freshwater Fish That Live In Seawater, Also Find And Evaluate A Suitable Concept To Explain The Osmoregulation Ability (Metacognitive Ability)

The Effect of Water Salinity on Tilapia (*Oreochormis niloticus*) and Survival Ability

Time	Observation Result		Documentation
	Freshwater	Seawater	
0 minute	The fish stay alive and active	The fish stay alive and active	
15 Minute	The fish stay alive and active	The fish are still alive but the movement is starting to weak	
30 Menit	The fish stay alive and active	The fish are still alive but the movement is very weak	

Figure 3

a) The Students Is Carrying Out An Osmoregulation Project With The Title "Observation Of The Osmoregulation Of Earthworms (Lumbricus Terrestris)

b) Students Think Creatively To Arrange The Stages Of Observing The Osmoregulation Of Earthworms In Freshwater And Salt Solutions Based On Indicators Of Weight, Colour, Surface, And Fluids Released By The Worm's Body. Meanwhile, Analytical And Metacognitive Skills Are Needed To Compile A Final Report That Explains The Concept Of Osmoregulation Of Earthworms In Two Different Habitats

(a)

Observation Results

Indicator	Freshwater				Salt Solution			
	Beginning	10 Minute	20 Minute	30 Minute	Beginning	10 Minute	20 Minute	30 Minute
Weigh of body	5.1 gr	5.15 gr	5.15 gr	5.15 gr	4.3 gr	3.9 gr	3.2 gr	2.8 gr
Colour of body	Pinky	Shiny red	Shiny red	Shiny red	Pinky	Pale red	Pale red	Pale white
Surface of body	Slick	More slick	More slick	More slick	Slick	Less sticky	Sticky	More sticky
Fluids released of body	Nothing	Nothing	Nothing	Nothing	Nothing	White liquid	Nothing	Nothing

(b)

The results of the ANCOVA analysis on the effect of the learning models on the students' cognitive learning gains of osmoregulation concepts are presented in Table 6.

Table 6

The Results of ANCOVA analysis

Variable	Learning Model
Cognitive Learning Gains	*
Creative Thinking Skill	*
Analytical Thinking Skill	*
Metacognitive skill	*

Note: (*) has a significant effect on α= 0.05 (The results of statistical analysis can be seen in the Appendix)

The results of the ANCOVA analysis show that the learning model had a significance value of 0.00 0 <α=0.05. This indicates that the implementation of the learning models significantly affected the student's cognitive learning gains, creative thinking skills, analytical thinking skills, and metacognitive skills in learning osmoregulation concepts. The implemented learning models were the PjB-HOTS and the PjBL learning models. Moreover, to find out which learning model had a more significant effect on the improvement of students, a post hoc LSD test was performed (Table 7).

Table 7

The Results of LSD Analysis

Learning models	Cognitive Learning Gains	Creative Thinking Skill	Analytical Thinking Skill	Metacognitive skill
PjB _HOTS	81.1081[a]	25.5405[a]	26.0000[a]	69.7027[a]
PjBL	74.3750[b]	24.0833[b]	24.0833[b]	63.4028[b]

The results of the LSD analysis show that there is a difference in LSD notation between the PjB-HOTS learning class and the PjBL learning class. Using the PjB-HOTS learning model, the class taught had a higher average score than the class taught using the PjBL class.

Discussion

Cognitive Learning Gains

This research's cognitive learning gains are related to the students' ability to understand osmoregulation concepts using their thinking ability. Inferential analysis using the ANCOVA showed that the implementation of the learning models affected students' cognitive learning gains (p=.000 <α=0.05) (Table 6). Moreover, the Post Hoc LSD test results showed that implementing the PjB-HOTS learning model in the experimental class had more significant effects in improving students' cognitive learning gains than implementing the PjBL learning model in the control class (Table 7). The difference in the improvement of the students' cognitive learning gains between the experimental and control classes are affected by the learning activities in the learning model, which can develop the student's cognitive structure.

The learning activities in the PjBL learning model and the PjB-HOTS learning model focus on finding information, formulating problems, and completing projects through investigations. However, there are several differences between the two learning models. In the PjB-HOTS learning model, the lecturers direct and train the students' critical thinking, analytical thinking, and creative thinking skills in the learning activities. For example, the students are asked to analyse problems and information related to osmoregulation and then determine the topic of investigation and critically arrange the

stages of the investigation. Through these learning stages, students' cognitive structures can be formed. Wang and Ruhe (2007) explain that one of the cognitive processes is making decisions on one or several choices from a certain set of alternatives.

The next learning stage of the PjB-HOTS learning model that can shape students' cognitive structure better than the control class is critical and creative in implementing projects and discussions with group members to make products and investigation reports. The integration of the PjB-HOTS learning model has a unified PjBL stage that is integrated with HOTS. Students are trained to plan projects using analytical and critical thinking skills, implement projects by fostering creative and analytical thinking skills, and prepare final products, reports, and presentations by fostering critical and creative thinking skills. When the students have already trained their critical thinking and discussed arranging the stages of the project, they already comprehend the osmoregulation concepts. Therefore, they can better prepare reports and make products than the students in the control class Lin et al. (2013) explain that the good cognitive abilities of students can be used to discuss other problems. Vukic et al. (2020) explain that good cognitive formation can build a strong understanding of the basis for understanding the principles for a more comprehensive understanding.

Freeman and Dale (2013) added two phenomena for cognitive formation, namely through single and multiple processes. Implementing projects based on the development of higher-order thinking skills is an important stage in forming students' cognitive processes in studying osmoregulation concepts. This can be explained through the concept of multiple cognitive formations. The multiple cognitive systems are formed through students' cognitive development, perception, direct practice, discussion involvement, and focus of attention on the given task, and is induced by skills and stimuli (seeing, feeling, hearing, and kinaesthetic), as well as student interactions with other students (Barsalou, 2017; Dale & Duran, 2011; Frixione & Lieto, 2014).

After participating in the series of learning stages, a HOTS-based final test is given at the end of the lesson. According to Ansori (2020) and Suprapto et al. (2020), cognitive abilities can be related to HOTS if the test items are based on interesting and contextual stimuli, the test items measure students' reasoning skills (knowledge transfer, processing and application of information, finding the relationship of various information, using the information to solve problems, and examining ideas and information critically). In order to answer these HOTS-based test items, students should already accustomed to developing HOTS in the learning activities using the PjB-HOTS learning model. Students who learn to use the PjBL learning model are also given a HOTS-based test. However, students who are taught using the PjB-HOTS and PjBL learning models have different abilities in answering HOTS-based test.

Creative Thinking Skill

HOTS is very important to train the students to foster their creative thinking skills in the learning process and to answer HOTS-based test items. The results of the ANCOVA inferential analysis showed that the implementation of learning models affected students' creative thinking ($p=.001 < \alpha=0.05$) (Table 8). Moreover, the results of the LSD test showed that the PjB-HOTS learning model implemented in the experimental class had a more significant effect on the improvement of students' creative thinking skills than the implementation of the PjBL learning model in the control class (Table 9). These results indicate that students taught using the PjB-HOTS learning model could foster their creative thinking skills to learn osmoregulation concepts better than those taught using the PjBL model. Both the PjBL learning model and the PjB-HOTS learning model emphasize investigation activities and producing scientific products. However, the PjB-HOTS learning model fosters students' creative thinking skills in each PjBL learning stage. As a result, the students can provide alternative ideas from the information they obtain from the internet. Creative thinking skill is the ability to generate images, new ideas, alternative hypotheses, and evaluation capabilities (Kampylis, Berki & Saariluoma, 2009). In addition, Hidayati, Fitriani, Saputri & Ferazona

(2023) and Mufida, Sigit & Ristanto (2020) state that investigation activities can encourage students to find new and unique ideas.

The indicators of creative thinking shown in the learning process are that students can express their project ideas well, identify and solve problems through project activities. Ersoy and Baser (2014); Hasan, Lukitasari, Utami & Anizar (2019) explain that the improvement of creative thinking can last in a long process through investigation activities, both information investigation and experiment investigation. Eragamreddy (2013) adds that creative thinking is based on the awareness to increase their thinking to do information searching to their comprehension of a concept.

Meanwhile, Yudiarti and Lantu (2017) explained that creative thinking skills are formed through simultaneous convergent and divergent thinking so that students can create innovative products. This can happen because, during the PjB-HOTS learning activities, the students are accustomed to divergent thinking to find ideas for solving animal osmoregulation investigation projects. The problem-solving activity is continued to produce scientific products in the form of scientific reports that can be used as material for scientific presentations in the lecturing activities. In this case, Ichsan, Sigit, Miarsyah, Ali & Suwandi (2020) and Chasanah, Kaniawati & Hermani (2017) argue that classes that foster HOT skills during the learning activities have high problem-solving skills. Students who learn the concept of osmoregulation using the PjBL learning model also carry out problem solving activities at each stage of PjBL, but the problem-solving activities carried out by students in the PjB-HOTS class have been trained with creative and analytical thinking skills.

Analytical Thinking Skill

Analytical thinking skill is one of the skills described in the higher-order thinking skills (HOTS). In Bloom's taxonomy, analytical thinking skill is in the C4 domain. The results of the ANCOVA inferential analysis showed that the implementation of learning models affected the students' analytical thinking skills ($p=.000<\alpha=0.05$) (Table 10). Moreover, the Post Hoc LSD test results showed that implementing the PjB-HOTS learning model in the experimental class had more significant effects in improving students' analytical thinking skills than implementing the PjBL learning model in the control class (Table 11). These results indicate that the students taught using the PjB-HOTS learning model could foster their analytical thinking skills in studying the concepts of osmoregulation better than the students taught by using the PjBL learning model. In the learning stages of the PjB-HOTS learning model, students are trained to think analytically about using the information found, analyzing the data from the investigation results into tables or graphs, and thinking analytically to structure the implementation of projects correctly. Participating in the learning activities of the PJB-HOTS learning model, the students can link the concepts of osmoregulation and understand and synthesize the concepts of osmoregulation. According to Ramos, Dolipas & Villamor (2013); Irwanto (2017); Irwanto, Roheti, Widjajanti & Suyanto (2017), analytical skill is an understanding of the relationship between the whole concepts and the sub-components of the concept; connecting the causes and effects, distinguishing and categorizing, and interpreting information from charts, graphs, or diagrams.

PjBL learning also provides a learning environment for conducting investigations and analyzing the investigations into tables and graphs. However, the PjB-HOTS learning model is more than that because the lecturer fosters students' analytical thinking skills in every PjBL learning activity. This is one of the differences between PjBL learning and PjB-HOTS learning models. According to Yusuf and Widyaningsih (2019); Warmadewi, Agustini & Wedhanti (2019); Supriyatin, Rahayu, Ristanto & Ichsan (2019), such learning strategies train students to use their higher-order thinking skills, to analyze and to evaluate contextual problems, and to use a variety of questions. In addition, they also state that supportive learning environments can foster thinking skills for reasoning, evaluation, problem-solving, decision making, and problem analysis.

At the implementation of the PjB-HOTS learning model, lecturers also foster students' thinking skills with questions to stimulate students' analytical thinking skills to analyze and evaluate problems related to the concepts of osmoregulation. Similarly, in their research, Abidinsyah, Ramdiah & Royani (2019) state that the most commonly used cognitive abilities to improve students' HOTS skills are applying, analyzing, decision making, and implementing.

Metacognitive Skill

Metacognitive skill is one part of the higher-order thinking skills (HOTS) which assesses one's awareness of their learning process, using learning strategies, evaluating the learning process, and the learning results. The results of the ANCOVA Inferential analysis showed that the implementation of the learning model affected students' metacognitive skills ($p=.000<\alpha= 0.05$) (Table 12). Moreover, the post hoc LSD test results indicate that implementing the PjB-HOTS learning model in the experimental class had a more significant improvement in students' metacognitive skills than implementing the PjBL learning model in the control class (Table 13).

Project-based research leads students to pose research problems related to osmoregulation independently. In implementing the PjBL learning model, the lecturer guides students to do the projects according to the learning stages. During the project learning stage, the students' learning values are independence in seeking information, planning, making decisions, implementing projects and making conclusions, and curiosity.

Meanwhile, at implementing the PjB-HOTS learning model, the lecturer guides the students based on the HOTS-based PjBL learning stage. Each learning stage is integrated with critical thinking, creative thinking, and analytical thinking skills. During the learning activities, the lecturer familiarizes the students to think critically, analytically and creatively; even during independent learning, the students are critical in asking questions and creative in making products. The learning process begins with online learning using zoom meetings. At that time, students did project planning with lecturers. Lecturers familiarize students with practicing critical, analytical, and creative thinking skills by setting problems according to the osmoregulation concept, seeking information, and making project implementation stages. After that, students experience independent learning to carry out projects and make products. However, students and lecturers continue to ask questions using the WhatsApp application to control the students' independent learning process. The same result was also conveyed by Samsudin, Jamali, Zain & Ebrahim (2020) that the integration of STEM with PjBL fosters students to carry out projects using their independence to design techniques, produce research procedures, and divide work into groups to make simple pulleys. Rahardjanto, Husamah & Fauzi (2019) apply Hybrid-PjBL learning and report that although learning is done online, Hybrid-PjBL learning is able to stimulate critical thinking, creativity, and self-regulation skills through project implementation.

Moreover, Saido, Siraj, Bin-Nordin & Al-Amedy (2015); Ichsan, Rahmayanti, Purwanto, Sigit, Singh & Babu (2020); Husamah, Fatmawati & Setyawan (2018); explain that higher-order thinking skills (HOTS) can be fostered if the students are engaged with problems, uncertainty and questions. In addition, an innovative learning model can foster students' higher-order thinking skills (HOTS) to give explanations, make the decision, understand facts, change from not knowing to know, and from unable to able. Those statements indicate that implementing the PjB-HOTS learning model can foster students' metacognitive skills better than the PjBL learning model. Students who are taught using the PjB-HOTS learning model have a different learning experience from the PjBL learning model. Although both of these learning models focus on project implementation. However, the PjB-HOTS learning model has several stages that are integrated with the HOTS component so that it improves students' metacognitive abilities better than the PjBL learning model in the control class.

The PjBL learning model is also an innovative learning model, but in this RI 4.0 era, PjBL should be developed or modified in other stages. Hsu, Van-Dyke & Smith (2014) argue that project-based learning integrated with graph-oriented computers is more effective in improving scientific understanding, scientific argumentation skills, and a dynamic learning environment. Meanwhile, the

integration of STEM in PjBL learning is very beneficial for forming thinking structures such as clarifying problems, establishing ideas, and making products; improving cooperation and communication in groups; increasing creativity and imaginativeness; caring about actual issues in society; and fostering digital literacy technology capabilities (Lin, Wu, Hsu & Williams, 2021; Baran, Baran, Karakoyun & Maskan, 2021).

Metacognitive skill is a higher-order thinking skill that combines the students' soft skills and cognitive skills. The students' soft skills include planning, monitoring, and evaluating their learning processes. Furthermore, cognitive skills are used to process thoughts to understand, analyze, synthesize new information, and learn. Therefore, it is essential to train metacognitive skills in learning. According to Rahmat and Chanunan (2018); Antonio and Prudente (2021), metacognitive skills include the ability to control one's resources to regulate their cognition through student-centred learning, and a strategy that fosters the student to investigate and make scientific conclusions.

Conclusion and Implications

The implementation of the PjB-HOTS learning model affected students' cognitive learning gains in studying the concepts of osmoregulation. Moreover, it can also be used to foster students' higher-order thinking skills including creative thinking skills, analytical thinking skills, and metacognitive thinking skills.

References

Abidinsyah, A., Ramdiah, S., & Royani, M. (2019). The implementation of local wisdom-based learning and HOTS-based assessment: Teacher survey in Banjarmasin. *Jurnal Pendidikan Biologi Indonesia*, *5*(3), 407–414.

Ansori, A. Z. (2020). Analysis of biology daily assessment according to cognitive process dimension and higher order thinking skills question. *Journal of Biology Education*, *9*(1), 30–35.

Antonio, R. P., & Prudente, M. S. (2021). Metacognitive argument-driven inquiry in teaching antimicrobial resistance: Effects on students' conceptual understanding and argumentation skills. *Journal of Turkish Science Education*, *18*(2), 192–217.

Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The influence of Project-Based STEM (PjbL-STEM) applications on the development of 21st century skills. *Journal of Turkish Science Education*, *18*(4), 798–815.

Barsalou, L. (2017). *Understanding contemplative practices from the perspective of dual-process theories*. In Mindfulness in Social Psychology. Psychology Press.

Berchiolli, B., Movahedzadeh, F., & Cherif, A. (2018). Assessing student success in a project-based learning biology course at a community college. *The American Biology Teacher*, *80*(1), 6–10.

Bonfield, C. A., Salter, M., Longmuir, A., Benson, M., & Adachi, C. (2020). Transformation or evolution?: Education 4.0, teaching and learning in the digital age. *Higher education pedagogies*, *5*(1), 223-246.

Budsankom, P., Sawangboon, T., Damrongpanit, S., Chuensirimongkol, J. (2015). Factors affecting higher order thinking skills of students: A meta-analytic structural equation modeling study. *Educational Research and Reviews*, *10*(19), 2639–2652.

Chasanah, L., Kaniawati, I., & Hernani, H. (2017). How to assess creative thinking skill in making products of liquid pressure?. *Journal of Physics: Conference Series*, *895*(1), 012164.

Chinedu, C. C., Olabiyi, O. S., & Kamin, Y. (2015). Strategies for improving higher order thinking skills in teaching and learning of design and technology education. *Journal of Technical Education and Training*, *7*(2), 35–43.

Dale, R., & Duran, N. D. (2011). The cognitive dynamics of negated sentence verification. *Cognitive Science*, *35*(5), 983–999.

Eragamreddy, N. (2013). Teaching creative thinking skills. *International Journal of English Language & Translation Studies*, *1*(2), 124–145.

Erfianti, L., Istiyono, E., & Kuswanto, H. (2019). Developing lup instrument test to measure higher order thinking skills (HOTS) Bloomian for senior high school students. *International Journal of Educational Research Review*, *4*(3), 320–329.

Ersoy, E., & Baser, N. (2014). The effects of problem-based learning method in higher education on creative thinking. *Procedia-Social and Behavioral Sciences*, *116*, 3494–3498.

Freeman, J. B., & Dale, R. (2013). Assessing bimodality to detect the presence of a dual cognitive process. *Behavior Research Methods*, *45*(1), 83–97.

Frixione, M., & Lieto, A. (2014). Concepts, perception and the dual process theories of mind. *The Baltic International Yearbook of Cognition, Logic and Communication*, *9*(5), 1–20.

Gurcay, D., & Ferah, H. O. (2018). High school students' critical thinking related to their metacognitive self-regulation and physics self-efficacy beliefs. *Journal of Education and training Studies*, *6*(4), 125–130.

Harahap, A., & Astrid, A. (2021). Boosting Classroom Interaction Based on Higher Order Thinking Skills (HOTS) in English Learning for Beginners. *International Journal of Language Education*, *5*(1), 477-489.

Hartono, R., & Pahlevi, T. (2020). Development of assessment instruments based on hots at surabaya vocational high school. *JISAE: Journal of Indonesian Student Assessment and Evaluation*, *6*(2), 210–218.

Hasan, R., Lukitasari, M., Utami, S., & Anizar, A. (2019). The activeness, critical, and creative thinking skills of students in the Lesson Study-based inquiry and cooperative learning. *Jurnal Pendidikan Biologi Indonesia*, *5*(1), 77–84.

Heong, Y. M., Ping, K. H., Yunos, J. J. M., Othman, W. W., Kiong, T. T. T., Mohamad, M. M., & Ching, K. K. B. (2019). Effectiveness of integration of learning strategies and higher-order thinking skills for generating ideas among technical students. *Journal of Technical Education and Training*, *11*(3), 32–42.

Hidayati, N., Fitriani, A., Saputri, W., & Ferazona, S. (2023). Exploring University Students' Creative Thinking Through Digital Mind Maps. *Journal of Turkish Science Education, 20(1), 119-135*.

Husamah, H., Fatmawati, D., & Setyawan, D. (2018). OIDDE learning model: Improving higher order thinking skills of biology teacher candidates. *International Journal of Instruction*, *11*(2), 249–264.

Hsu, P. S., Van Dyke, M., Chen, Y., & Smith, T. J. (2015). The effect of a graph-oriented computer-assisted project-based learning environment on argumentation skills. *Journal of Computer Assisted Learning*, *31*(1), 32–58.

Ichsan, I. Z., Rahmayanti, H., Purwanto, A., Sigit, D. V, Singh, C. K. S., & Babu, R. U. M. (2020). HOTS-AEP-COVID-19: Students knowledge and digital worksheet of ILMIZI environmental learning model. *International Journal of Advanced Science and Technology*, *29*(6), 5231–5241.

Ichsan, I. Z., Sigit, D. V, Miarsyah, M., Ali, A., & Suwandi, T. (2020). Implementation Supplementary Book of Green Consumerism: Improving Students HOTS in Environmental Learning. *European Journal of Educational Research*, *9*(1), 227–237.

Irwanto. (2017). The characteristic of analytical thinking and science process skills (ATSPS) test for senior high school students. *Proceeding The 2nd International Seminar on Chemical Education*, 382–392.

Irwanto, Roheti, E., Widjajanti, E., & Suyanto. (2017). Students' science process skill and analytical thinking ability in chemistry learning. *AIP Conference Proceedings*, 1–10.

Istiyono, E., Widihastuti, Supahar, & Hamdi, S. (2020). Measuring creative thinking skills of senior high school male and female students in physics (CTSP) using the IRT-based PhysTCreTS. *Journal of Turkish Science Education*, *17*(4), 578–590.

Kampylis, P., Berki, E., & Saariluoma, P. (2009). In-service and prospective teachers' conceptions of creativity. *Thinking Skills and Creativity*, *4*(1), 15–29.

Kline, P. (2000). *The Handbook of psychological testing*. Routledge.

Kortam, N., Basheer, A., Hofstein, A., & Hugerat, M. (2018). How Project-Based Learning promotes 7th grade students' motivation and attitudes towards studying biology. *Action Research and Innovation in Science Education*, *1*(2), 9–17.

Kozikoglu, I. (2019). Investigating critical thinking in prospective teachers: Metacognitive skills, problem solving skills and academic self-efficacy. *Journal of Social Studies Education Research*, *10*(2), 111–130.

Launuru, A., Rumahlatu, D., & Matdoan, M. N. (2021). PjBL-HOTS learning model: Its application and effect on cognitive learning outcomes, critical thinking, and social attitudes. *BIOEDUPAT: Pattimura Journal of Biology and Learning*, *1*(1), 1–10.

Lin, P. C., Hou, H. T., Wang, S. M., & Chang, K. E. (2013). Analyzing knowledge dimensions and cognitive process of a project-based online discussion instructional activity using Facebook in an adult and continuing education course. *Computers & Education*, *60*(1), 110–121.

Lin, K. Y., Wu, Y. T., Hsu, Y. T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of STEM Education*, *8*(1), 1–15.

Maiasputri, N., Ahda, Y., & Sumarmin, R. (2018). The Validity of the development of project-based oriented learning modules on evolution and biotechnology materials for high school. *International Journal of Progressive Sciences and Technologies*, *6*(2), 433–438.

Mataniari, R., Willison, J., Hasibuan, M. E., Sulistiyo, U., & Fatria, D. E. W. I. (2020). Portraying students' critical thinking skills through Research Skill Development (RSD) framework: A case of a biology course in an Indonesian University. *Journal of Turkish Science Education*, *17*(2), 302–314.

Mufida, S. N., Sigit, D. V, & Ristanto, R. H. (2020). Integrated project-based e-learning with science, technology, engineering, arts, and mathematics (PjBeL-STEAM): Its effect on science process skills. *Biosfer: Jurnal Pendidikan Biologi*, *13*(2), 183–200.

Pius, R. L. G., Awang, M. M., Ahmad, A. R., & Dahalan, S. C. (2019, October). The Teachers' Readiness in Integrating Higher Order Thinking Skills (Hots) In Teaching and Learning History Subject. *In The 2nd International Conference on Sustainable Development and Multi-Ethnic Society* (pp. 34-40). Redwhite Pres.

Puente-Díaz, R., Cavazos-Arroyo, J., & Vargas-Barrera, F. (2021). Metacognitive feelings as a source of information in the evaluation and selection of creative ideas. *Thinking Skills and Creativity*, *39*, 100767.

Rahardjanto, A., Husamah, & Fauzi, A. (2019). Hybrid-PjBL: Learning outcomes, creative thinking skills, and learning motivation of preservice teacher. *International Journal of Instruction*, *12*(2), 179–192.

Rahmat, I., & Chanunan, S. (2018). Open inquiry in facilitating metacognitive skills on high school biology learning: an inquiry on low and high academic ability. *International Journal of Instruction*, *11*(4), 593–60.

Ramos, J. L. S., Dolipas, B. B., & Villamor, B. B. (2013). Higher order thinking skills and academic performance in physics of college students: A regression analysis. *International Journal of Innovative Interdisciplinary Research*, *4*, 48–60.

Retnawati, H., Djidu, H., Kartianom, A., & Anazifa, R. D. (2018). Teachers' knowledge about higher-order thinking skills and its learning strategy. *Problems of Education in the 21st Century*, *76*(2), 215–231.

Rumahlatu, D., & Sangur, K. (2019). The influence of project-based learning strategies on the metacognitive skills, concept understanding and retention of senior high school students. *Journal of Education and Learning*, *13*(1), 104–110.

Rumahlatu, D., Sangur, K., & Liline, S. (2020). The effect of complex instruction team product (CITP) learning model on increase student's skills. *International Journal of Instruction*, *13*(1), 587–606.

Saido, G. M., Siraj, S., Bin-Nordin, A., & Al-Amedy, O. S. (2015). Higher order thinking skills among secondary school students in science learning. *The Malaysian Online Journal of Educational Science*,

3(3), 13–20.

Samsudin, M. A., Jamali, S. M., Zain, A. N. M., & Ale Ebrahim, N. (2020). The effect of STEM Project Based Learning on self-efficacy among High-School physics students. *Journal of Turkish Science Education*, *17* (1), 94–108.

Saputri, W., & Corebima, A. (2020). The correlation between metacognitive skills and cognitive learning results of biology pre-service teachers on different learnings. *Journal of Turkish Science Education*, *17*(4), 487–503.

Serevina, V., Sari, Y. P., & Maynastiti, D. (2019). Developing high order thinking skills (HOTS) assessment instrument for fluid static at senior high school. *Journal of Physics: Conference Series*, *1185*(1), 012034.

Suprapto, E., Saryanto, Sumiharsono, R., & Ramadhan, S. (2020). The analysis of instrument quality to measure the students' higher order thinking skill in physics learning. *Journal of Turkish Science Education*, *17*(4), 520–527.

Supriyatin, Rahayu, S., Ristanto, R. H., & Ichsan, I. Z. (2019). Improving HOTS in biology learning: A supplement book of plant growth and development. *Universal Journal of Educational Research*, *7*(12), 2642–2646.

Surahman, E., Wedi, A., Soepriyanto, Y., & Setyosari, P. (2018). Design of peer collaborative authentic assessment model based on group project based learning to train higher order thinking skills of students. *International Conference on Education*, 75–78.

Suratno, Komaria, N., Yushardi, Dafik, & Wicaksono, I. (2019). The effect of using synectics model on creative thinking and metacognition skills of Junior High School students. *International Journal of Instruction*, *12*(3), 133–150.

Syawaludin, A., Prasetyo, Z. K., Jabar, C. S. A., & Retnawati, H. (2022). The Effect of Project-Based Learning Model and Online Learning Settings on Analytical Skills of Discovery Learning, Interactive Demonstrations, and Inquiry Lessons. *Journal of Turkish Science Education*, *19(2), 608-621.*

Venkatraman, S., Benli, F., Wei, Y., & Wahr, F. (2022). Smart Classroom Teaching Strategy to Enhance Higher Order Thinking Skills (HOTS)—An Agile Approach for Education 4.0. *Future Internet*, *14*(9), 255.

Vukić, Đ., Martinčić-Ipšić, S., & Meštrović, A. (2020). Structural analysis of factual, conceptual, procedural, and metacognitive knowledge in a multidimensional knowledge network. *Complexity*, *2020*, 1–17.

Wang, Y., & Ruhe, G. (2007). The cognitive process of decision making. *International Journal of Cognitive Informatics and Natural Intelligence (IJCINI)*, *1*(2), 73–85.

Warmadewi, P. S., Agustini, D. A. E., & Wedhanti, N. K. (2019). Analysis of learning higher order thinking skill (HOTS) toward English subject. *Jurnal Penelitian Dan Pengembangan Sains Dan Humaniora*, *3*(2), 134–140.

Yudiarti, D., & Lantu, D. C. (2017). Implementation creative thinking for undergraduate student: a case study of first year student in business school. *Advanced Science Letters*, *23*(8), 7254–7257.

Yusuf, I., & Widyaningsih, S. W. (2019). HOTS profile of physics education students in STEM-based classes using PhET media. *Journal of Physics: Conference Series*, *1157*(3), 032021.

Zohar, A., & Dori, Y. J. (2008). Higher order thinking skills and low achieving students: Are they mutually exclusive? *The Journal of The Learning Sciences*, *12*(2), 145–181.

Zubaidah, S., Fuad, N. M., Mahanal, S., & Suarsini, E. (2017). Improving creative thinking skills of students through differentiated science inquiry integrated with mind map. *Journal of Turkish Science Education*, *14*(4), 77–91.

Appendix 1

LESSON PLAN EXPERIMENT CLASS (PjB-HOTS LEARNING)

Study programme	**Biology Education**
Course code	**PBN-503**
Course/Semester	**Animal Physiology / V**
Meeting time	**150 minutes**
Meeting	**9th**
Programme Learning Outcome (PLO)	1. Students will be able to understand and apply the fundamental concepts and principles of biology, including cell and molecular biology, physiology, genetics, structure and development, biosystematics, evolution, and ecology in their roles as professional educators. 2. Student capable of conducting scientific research and acquiring knowledge in the field of Biology, utilizing the research findings to perform a critical evaluation of their own learning process, while proposing alternative measures for continual enhancement.
Course Learning Outcome (CLO)	To be able to identify the mechanisms of osmoregulation and excretion in aquatic and terrestrial animals, together with the organs involved.
Learning Materials	1. The mechanisms of osmoregulation and excretion in aquatic animals and the corresponding organs are discussed in this section. 2. Mechanisms of osmoregulation and excretion, as well as the associated organs, in tertiary animals are discussed in this paper.
Learning Model	PjB-HOTS Learning
Learning Strategy	Active student/Student centre learning
Learning Methods	Experiments, Projects, and Varied discussions

Learning Activities

PjB-HOTS Learning Integration		Week	Lecturer Activity	Student Activity
Planning	✓ Fostering students' analytical thinking about problems that can be used as the topics for osmoregulation investigation projects ✓ Fostering students' analytical thinking to select relevant information to the concept of osmoregulation ✓ Fostering students' creative thinking in dividing group tasks	I (using Zoom Cloud Meeting)	✓ Direct students to analyse the phenomenon of osmoregulation in animals living in marine, freshwater, brackish, and terrestrial environments ✓ Direct students to find information and then analyse the information into an investigation topic.	✓ Students analyse the phenomenon of osmoregulation in animals living in marine, freshwater, brackish, and terrestrial environments ✓ Students search for information then analyse the information into an investigation topic.
Creating	✓ Fostering students' creative thinking in arranging the stages of osmoregulation investigation projects ✓ Fostering students' creative thinking in implementing the project ✓ Fostering students' creative thinking in	II (using Zoom Cloud Meeting) III (Using Zoom Cloud Meeting to independently	✓ Direct students to analyse scientific articles to find the stages of project implementation ✓ Directing students to be critical in reading scientific articles to develop project stages ✓ Directing students to be	✓ Students Analyse scientific articles to find the stages of project implementation ✓ Students are critical in reading scientific articles to develop project stages ✓ Students are creative in

	making a product ✓ Fostering students' analytical thinking in compiling investigative data into project reports	research and coordinate with the course instructor)	creative to carry out project activities ✓ Directing students to be critical in carrying out projects ✓ Directing students to creatively create products in the form of scientific writing in the form of articles, posters, etc. ✓ Directing students to conduct data analysis according to the correct data analysis technique ✓ Directing students to analyse relevant literature to develop project reports ✓ Directing students to be creative in compiling reports according to the rules in scientific reports	carrying out project activities ✓ Critical students in carrying out the project ✓ Creative students make products in the form of scientific writing in the form of articles, posters, etc. ✓ Students perform data analysis according to the correct data analysis technique ✓ Students analyse relevant literature to develop project reports ✓ Students are creative in preparing reports according to the rules in scientific reports
Presenting	✓ Fostering students' creative thinking in doing presentations	IV (using *Zoom Cloud Meeting*)	✓ Directing students to be critical when listening to other groups making presentations ✓ Directing students to be creative in asking questions to groups that are presenting	✓ Students are critical when listening to other groups making presentations ✓ Students are creative in asking questions to the group that is presenting

Instrument

Non-Test: Scientific product assessment instruments

Tests: cognitive, analytical thinking, creative thinking, and metacognitive

Reference

- Campbell at, 2000, Biology. Printed by PT Gelora Aksara Pratama. Jakarta (In Indonesian)
- Isnaeni, W. 2006. Animal Physiology. Yogyakarta: Kanisius (In Indonesian)
- Scientific articles

Appendix 2

LESSON PLAN CONTROL CLASS (PjBL)

Study programme	**Biology Education**
Course code	**PBN-503**
Course/Semester	**Animal Physiology / V**
Meeting time	**150 minutes**
Meeting	**9th**
Programme Learning Outcome (PLO)	1. Students will be able to understand and apply the fundamental concepts and principles of biology, including cell and molecular biology, physiology, genetics, structure and development, biosystematics, evolution, and ecology in their roles as professional educators. 2. Student capable of conducting scientific research and acquiring knowledge in the field of Biology, utilizing the research findings to perform a critical evaluation of their own learning process, while proposing alternative measures for continual enhancement.
Course Learning Outcome (CLO)	To be able to identify the mechanisms of osmoregulation and excretion in aquatic and terrestrial animals, together with the organs involved.
Learning Materials	1. The mechanisms of osmoregulation and excretion in aquatic animals and the corresponding organs are discussed in this section. 2. Mechanisms of osmoregulation and excretion, as well as the associated organs, in tertiary animals are discussed in this paper.
Learning Model	PjBL
Learning Strategy	Active student/Student centre learning
Learning Methods	Experiments, Projects, and Varied discussions

Learning Activities

PjBL	Week	Lecturer Activity	Student Activity
Planning	I (using Zoom Cloud Meeting)	✓ Direct students to determine project topics on osmoregulation in animals living in marine, freshwater, brackish, and terrestrial environments. ✓ Direct students to find and collect information about osmoregulation that supports the implementation of the project	✓ Students determine the topic of osmoregulation in animals living in marine, freshwater, brackish, and terrestrial environments. ✓ Students search for and collect information on osmoregulation
Creating	II (using Zoom Cloud Meeting) III (Using Zoom Cloud Meeting to independently research and coordinate with the course instructor)	✓ Direct students to formulate the stages of project implementation ✓ Directing students to carry out project activities ✓ Directing students to make products in the form of scientific writing in the form of articles, posters, etc. ✓ Directing students to conduct data analysis according to the correct data analysis technique	✓ Students formulate the stages of project implementation ✓ Students carry out project activities ✓ Students create products in the form of scientific writing in the form of articles, posters, etc. ✓ Students analyse data according to the correct data analysis technique

		✓ Directing students to compile reports according to the rules in scientific reports	✓ Students compile reports according to the rules in scientific reports
Presenting	IV (using *Zoom Cloud Meeting*)	✓ Directing students to listen to other groups making presentations ✓ Directing students to ask questions to the presenting group.	✓ Students listen to other groups presenting ✓ Students ask questions to the group that is presenting

Instrument

Non-Test: Scientific product assessment instruments

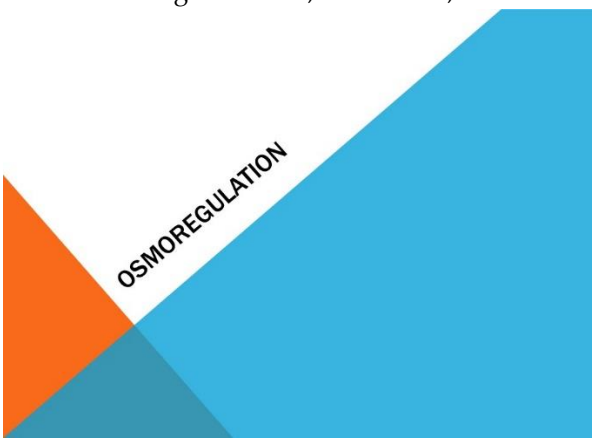
Tests: cognitive, analytical thinking, creative thinking, and metacognitive

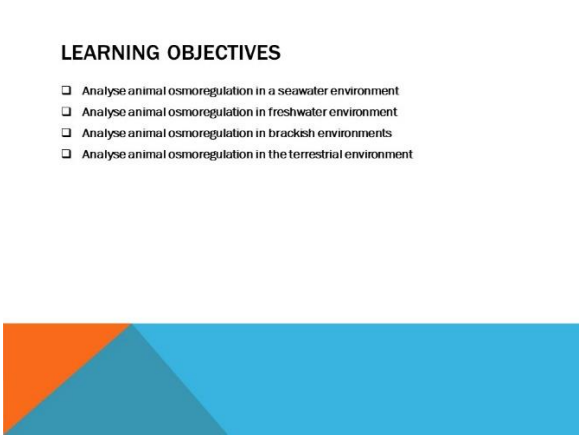
Reference

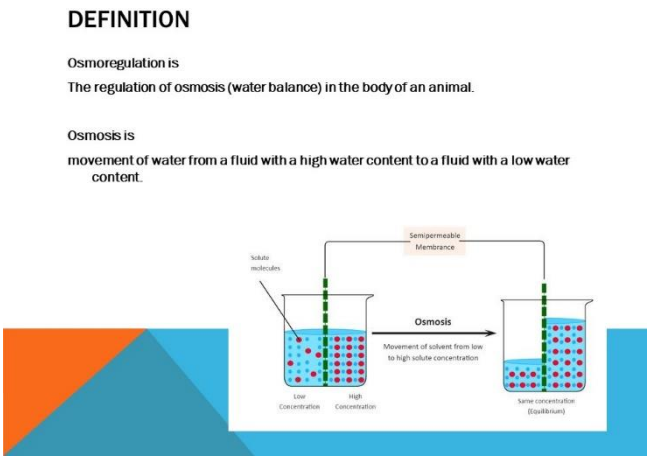
- Campbell at, 2000, Biology. Printed by PT Gelora Aksara Pratama. Jakarta (In Indonesian)
- Isnaeni, W. 2006. Animal Physiology. Yogyakarta: Kanisius (In Indonesian)
- Scientific articles

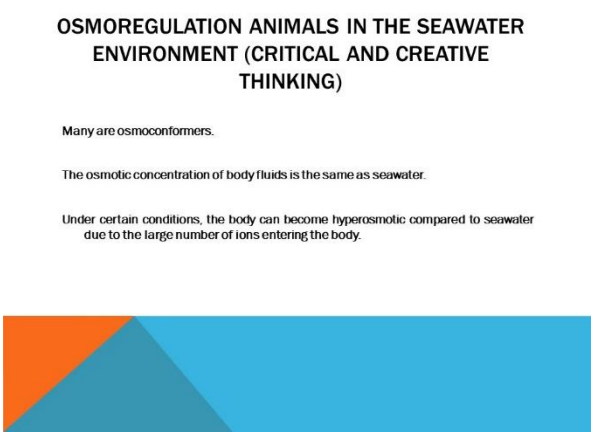
Appendix 3

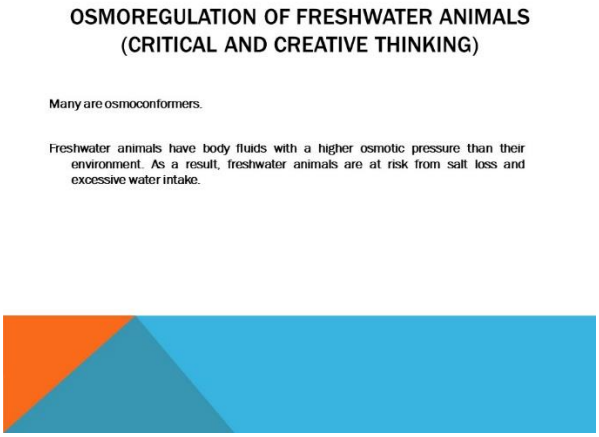
The following are learning materials to direct students to analyse the phenomenon of osmoregulation in animals living in marine, freshwater, brackish water and terrestrial environments.











OSMOREGULATION ANIMAL LAND
(CRITICAL AND CREATIVE THINKING)

Water discharge occurs very easythrough evaporation

Notes:
the learning material presented is the same between the control and experimental classes, the difference is that the experimental class adds fosterment of critical, analytical, and creative thinking skills in learning process.