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Exploring students' pro-environmental knowledge and behaviour perceptions: a mixed methods investigation

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ABSTRACT

This study explored university students' pro-environmental knowledge and self-reported pro-environmental behaviours, and the influence of environmental education on their knowledge, beliefs and behaviour. This study also investigated the difference in forming pro-environmental behaviours across gender types and academic majors. The Theory of Planned Behaviour was used to frame the study and to understand if knowledge and beliefs translate into pro-environmental behaviours.

A mixed-method approach was taken to achieve the research objectives. The participants comprised of 226 undergraduate students from a leading university in Saudi Arabia. A questionnaire and interview protocol were used to collected data. Descriptive statistical analysis, t-tests, One-way ANOVA, post-hoc tests and thematic analysis were used to analyse the data sets. The results of the study showed that knowledge gained from formal environmental education does not translate to pro-environmental behaviours. This study highlights the need to promote pro-environmental behaviour in university settings by eliminating obstacles to pro-environmental actions.

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Introduction

Human actions largely influenced by social norms, beliefs, and values, has resulted in current environmental problems which greatly undermine long-term sustainability (Lange & Dewitte, 2019; Li et al., 2019; Carvalho et al., 2018; Thondhlana & Hlatshwayo, 2018). Humans that control this rapidly evolving world, for instance rapid industrialisation, overexploitation of natural resources and consumerism, as well as human error are having an adverse impact on the environment (Campbell, 2021). Some of the environmental problems include air and water pollution and the availability of water, global warming, improper waste disposal, depletion of natural resources, increase in human population, stratospheric ozone layer depletion, overconsumption, food wastage, logging and decline or disappearance of biological diversity (Schmidt & Matthies, 2018; Singh & Singh, 2017). Public health threats from the lack of valuable resources will be great unless nations are able to adapt. Averting household food waste and overconsumption of food as well as managing water resources are important for the promotion of global environmental sustainability and pro-environmental behaviours (Schmidt & Matthies, 2018; DeNicola et al. 2015).

The most prevalent environmental issues in Saudi Arabia are desertification, air quality deterioration, water pollution, littering, sewage pollution and food wastage (Almahasheer & Duarte, 2020; Baig et al., 2019). In a recent government report, Saudi Arabia ranked number one in the world for food waste (Ministry of Environment, Water, and Agriculture, 2018). According to the report, the country squanders 30 percent of the total food produced which is equivalent to US$13 billion in losses. Another recent study found that food waste posed a serious threat to sustainability as the citizens of Saudi Arabia discard about 78% of food purchased every week (Baig et al 2019). It is evident that food loss and waste are among the biggest sustainability challenges in Saudi Arabia.

Saudi Arabia which is heavily reliant on oil exports was until recently claimed to be a resource-cursed economy (Ali et al., 2020; Anser et al., 2020). In resource cursed economies, there is the tendency of people to avoid consumption of resources in a sustainable manner as they believe that everything is available and there is no motivation to conserve energy and protect natural resources and ecosystems. In Saudi Arabia, this problem is exacerbated by the fact that 35% of the Kingdom's electricity is still generated by the combustion of crude oil which is considered very expensive and results in the loss of approximately 900,000 barrels of oil per day (Zotin, 2018). Moreover, recycling and conservation efforts have typically failed to gain traction (Al Ghamdi & El-Hassan, 2019). Nevertheless, Saudi Arabia provides a good example of how to manage scarce water resources through adaptation and mitigation (DeNicola et al. 2015).

The Kingdom is trying to avoid or reverse the resource curse by reassessing its economic planning and moving away from a resource-dependent economy. The Vision-2030 resource conservation agenda, which focuses on protecting its precious natural resources, is also expected to raise awareness of sustainability practices (Al Surf & Mosafa, 2017). Environmental sustainability has been recently introduced as a topic in Saudi educational policy (Alsharif et al., 2020; Khan et al., 2020; Baig et al., 2019). One of the visions is to undergo social changes and such changes among teachers and students are seen as crucial for changing the mindset which remains under the sway of the resource curse effect (Anser et al., 2020). This implies that, in order to instil in the minds of students the notion that resources can be rapidly depleted by excessive use and must be used wisely, environmental education is essential for ensuring sustainability.

The urgency of the current environmental crisis requires the support of a higher education curriculum and pedagogy to better understand and address ecological problems and issues (Marouli, 2021). However, higher educational institutions and its leaders around the world are ill-equipped to address the global environmental crisis and environmental education has not been adequately implemented (Glavic, 2020). Most importantly, environmental education has not changed beliefs or generated more sustainable attitudes and behaviours among students around the world about various environmental issues (Komatsu et al., 2020). Thus, questions persist about the role of environmental education in creating environmental awareness and in promoting pro-environmental behaviours. The aim of this study was to investigate students' perceptions of their environmental knowledge, and the role of higher educational institutions in initiating environmental awareness and promoting pro-environmental behaviours of students. Specifically, the objectives were:

1) To assess students' self-reported knowledge on environmental topics, energy sources and pro-environmental behaviours.

2) To explore students' perceptions about their institution's environmental programmes/on-campus environmental activities and its role in promoting sustainable pro-environmental behaviours.

3) To determine the effect of gender and students' academic major on pro-environmental behaviour.

4) To identify the challenges facing students in taking part in these activities.

The research questions this study addresses are:

1) What are students' self-reported knowledge on environmental topics, energy sources and pro-environmental behaviours?

2) What are students' perceptions about their institutions' environmental programmes/on-campus environmental activities and its role in influencing sustainable pro-environmental behaviours?

3) Is there a significant difference in the pro-environmental behaviour of: (a) male and female students, and (b) students belonging to various academic majors?

4) What are the challenges facing students in taking part in environmental education and on-campus environmental activities (compulsory or voluntary activities)?

Literature Review

Role of Environmental Education

Global warming has reached 'worst case scenario' levels but the COVID-19 pandemic has shown that compulsory and voluntary restrictions on travel, on-campus learning and work can result in reductions in carbon emissions and air pollution (Botzen et al., 2021; Forster et al., 2020). Ironically, we cannot wish for a pandemic to emerge to save the earth and keep it green and healthy. An understanding of the nature of ecological problems is needed to address the environmental crisis (Rhead et al., 2015).

Environmental education is focused on knowledge, skills, and behaviour development and provides students with the opportunity to participate in real world issues, understand complex environmental issues facing the world, act more pro-environmentally and minimise the problems (Alsaati et al., 2020; Pizmony–Levy & Michel, 2018; King & Franzen, 2017; Monroe et al. 2017; Okur-Berberoglu, 2015). Environmental education programmes and activities are claimed to produce positive results in terms of environmental knowledge, beliefs, and in cultivating energy conservation behaviours (Janmaimool & Khajohnmanee, 2019; Ardoin et al. 2018; Akitsu et al., 2017; Ajaps & McLellan, 2015). Recent research shows that if formal environmental education is imparted to just 16% of students there could be a massive reduction in carbon dioxide (approximately 19 gigaton) by 2050 (Cordero et al., 2020). Environmental education is essential for achieving sustainable development (Hanifah et al., 2020). Addressing environmental problems require heightening people's awareness and knowledge of issues surrounding sustainability. Therefore, environmental education programmes have to be effective. They can be personally relevant and meaningful to the students if the teaching strategies are engaging and include experiential activities, and if they encourage discussions on debateable issues, address myths and fallacies, and include on campus activities (Monroe et al. 2017). These strategies include creating awareness of mitigation and adaptation behaviours (Schrot et al., 2020). While mitigation strategies involve taking steps to reduce risks, for example reducing greenhouse gases by using fuel efficient vehicles for transportation and using renewable energy sources such as solar energy, adaptation strategies help people to prepare for and adjust to the present and future problems caused by global climate change, such as drought, variations in ecosystems, and rise in sea levels (Reid, 2019; Monroe et al. 2017; Bofferding & Kloser, 2015).

Pro-environmental Beliefs and Behaviours

Environmental education is also said to raise students' concerns for ecological problems. Although people are concerned about the environment, concerns alone are not enough to ensure prompt and consistent actions to avert environmental harm (Inkpen & Bailey, 2020; Ajaps & McLellan, 2015). This suggests that other drivers are needed to translate concerns into actions. One of the key drivers is environmental education which is aimed at developing ecological awareness and for the promotion of pro-environmental behaviours (Cordero et al., 2020; Pizmony-Levy & Michel, 2018; Okur-Berberoglu, 2015). This supports the claims made by previous researchers that environmental education plays a determining role in increasing students' knowledge of environmental issues and in developing sustainability-conscious behaviours (Ntanos et al., 2018; Chankrajang & Muttarak, 2017; Meyer, 2015).

Pro-environmental behaviours, also referred to as sustainable behavior, is the responsible behaviour of an individual to engage in and minimise the negative environmental impact of human activities (Stern, 2011). Examples of these behaviours include the use of clean fuels (e.g., solar and wind energy) instead of fossil fuels, proper disposal of waste and recycling, conservation of power and water, etc. Cleveland et. al. (2012) identified six types of pro-environmental behaviours inherent in an individual: engaging in activism as an environment campaigner; avoiding purchase and use of environmentally harmful products; being a green consumer who is concerned about environmental degradation and uses eco-friendly or bio-degradable products; being a green passenger who prefers public transport or uses bicycles; being a recycler who uses recycling knowledge to buy recycled products; and as a utility saver who acts to minimise consumption of energy (oil, electricity), water etc.

The factors that influence one's pro-environmental behaviors are either external or internal. While the external factors involved in the process of behaviour change include learning in educational institutions and cultural influences, internal factors comprise of beliefs which include knowledge, attitudes and values (Ntanos et al., 2018). In other words, environmental beliefs are associated with environmental knowledge, values, and behaviour attitudes. Emotions and feelings such as moral obligation, responsibility and ecological conscience also influence environmental behaviours (Si at al., 2020; Xu et al., 2020; Yadav & Pathak, 2017). Cultural values and beliefs are also deemed to have a strong influence on environmental concerns and actions and are therefore vital for understanding how an individual reacts to ecological challenges (Komatsu et al., 2020). Shifts in pro-environmental behaviours can be achieved by changing cultural values and beliefs and that education can bring about desirable changes (Inkpen & Baily, 2000; Ntanos, et al., 2018).

While research demonstrates that environmental education provided through a formal education which can enhance learners' knowledge and develop pro-environmental behaviours, there are also claims that it may not contribute to students' engagement in direct impact of environmental behaviours, for example recycling and energy-saving behaviours (Hoffmann & Muttarak, 2019; Janmaimool & Khajohnmanee, 2019; Marouli & Duroy, 2019; Chankrajang & Muttarak, 2017). This suggests that knowledge alone cannot influence behavioural change.

Student Characteristics and Pro-Environmental Behaviours

Students' behaviours are not only influenced by environmental education but also by personal characteristics, namely demographic factors, and internal human factors (Runhaar, et al., 2019). Therefore, gender and academic majors (demographic factors) as well as perceived pro-environmental attitudes and intentions (internal human factors) were included in this study.

Many studies have revealed that socioeconomic characteristics are key for understanding the determinants of pro-environmental behaviours (Hansmann et al., 2020; Inkpen & Bailey, 2020; Vicente-Molina et al., 2018; Xiao & McCright, 2015). These socioeconomic factors included gender, age, educational level, or academic majors. There is evidence that women have better basic energy knowledge, slightly stronger intention and demonstrate relatively stronger environmental concern and behaviour than men (Hansmann et al., 2020; Akitsu et al., 2017; De Leeuw et al., 2015; Xiao & McCright, 2015; Rideout, 2014) although they are underrepresented in higher education and fields of study that are considered as male domains such as an engineering (Stoet & Geary, 2020). Women's knowledge, beliefs and perceptions are important as females and males play different roles in protecting the environment and so there are disparities in their pro-environmental behaviours, for instance females who study science majors are likelier to act pro-environmentally (Vicente-Molina et al., 2018). Research has also shown that although there exists a significant relationship between gender and environmental knowledge, gender differences in pro-environmental behaviour was not statistically significant (Nzengya & Rutere, 2021; Akitsu et al., 2017; De Leeuw et al., 2015; Gifford, 2014). This suggests that research on the relationship between gender and pro-environmental behaviours has yielded mixed results. As there is inconclusive evidence on whether gender differences exist, potential gender differences were examined in this study to explain if males and females have different worldviews on environmental issues.

Likewise, academic major or sub-disciplines is another socioeconomic characteristic which has an effect on pro-environmental behaviours. Hansmann et al., (2020) investigated the environmental behaviour of students at a Swiss University and found that positive environmental behaviours increased with higher education level of students. Furthermore, females and members of strongly environmentally oriented disciplines exhibited higher levels of pro-environmental behaviour. The results of the study validate Rideout (2014) who found that environmental behaviours varied with academic major.

Challenges Facing Students in Taking Part in Educational Programmes

The challenges facing students are partly because higher education does not fully support students and the very purpose of environmental education has often been compromised. Instructors are finding it difficult to provoke behaviour change in students (King & Franzen, 2017). They also lack knowledge of appropriate pedagogical approaches, for instance transformational teaching that includes active learning and collaboration, which is required to change the mindset of students and determination (Glavic, 2020; Wamsler, 2020). Research has therefore questioned the role of higher education in shaping environmental norms (Harring et al., 2020). Academics also argue that environmental education cannot promote a higher level of environmental awareness, especially awareness of renewable energy sources (Edsand & Broich, 2019). According to Janmaimool and Khajohnmane (2019) environmental knowledge provided in universities could foster environmental attitudes, but education itself cannot enhance students' pro-environmental behaviours. Educators and administrators in higher education not only lack strategic direction and supportive leadership, but also lack knowledge and awareness of environmental sustainability (Alsharif et al., 2020). There is no attempt made to respond to the needs and interests of students or to arouse their interest in the issues of environmental protection (Al Ghamdi & El-Hassan, 2019).

In the context of Saudi Arabia, higher education is unable to continue imparting rigorous environmental and sustainability education because of the lack of students' presence in on-campus activities (Abubakar et al., 2016; Alsaati et al., 2020). One study found that universities lacked adequate on-campus activities and that only 38% of the students took part in such events (Khan et al., 2020). Previous studies show that in Sweden and Taiwan where transformational teaching methods are being used, students join environmental sustainability projects voluntarily (Wamsler et al., 2018; Olsson, 2018). Moreover, the students who participated in the voluntary activities perceived that the sessions had a positive influence on environmental learning (Wamsler, 2020). Alsaati et al., (2020) evaluated students' level of consciousness and awareness for a sustainable environment in seven universities in Said Arabia and found that they lacked knowledge of sustainability and that their engagement in pro-environment related activities was low. While most students (66%) did not take part in compulsory and voluntary recycling activities in on-campus projects or elsewhere many (65%) reported that the universities did not have any recycling bins. These results corroborate the findings of another study conducted at a university in the Eastern Province of Saudi Arabia. The researchers found that there were no campus sustainability initiatives and that students lacked interest and did not have the inclination to take part in environmental activities (Abubakar et al., 2016). Al Ghamdi and El-Hassan (2019) examined students' attitudes, behaviours and factual knowledge of energy-related issues in Saudi Arabia and found that they lacked understanding of appropriate usage of energy. The researchers observed that the students were very poor in energy literacy and therefore are predisposed to develop a negative attitude towards environmental issues. Moreover, they were unwilling to take part in voluntarily activities.

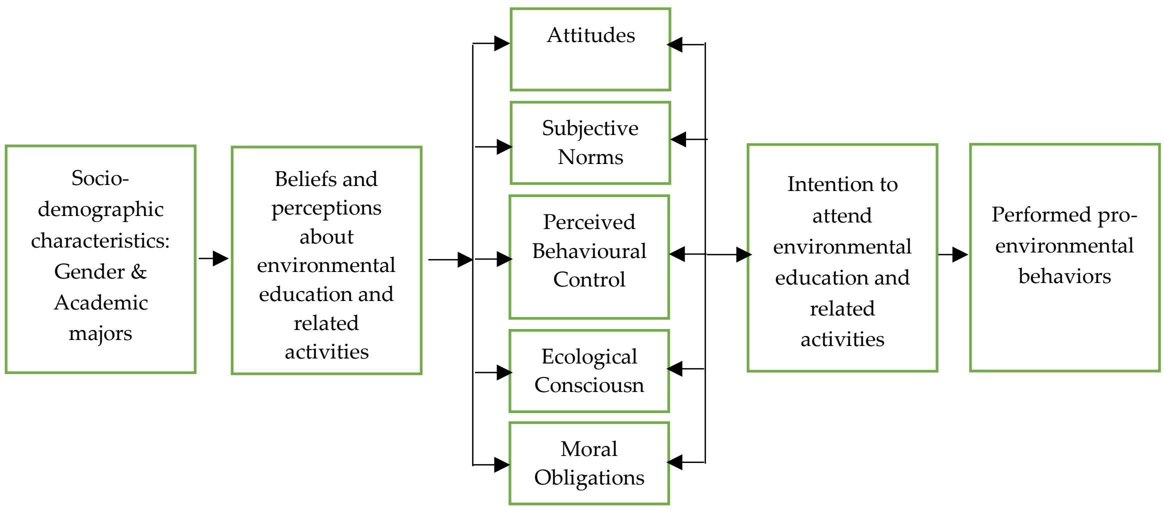
Alsharif et al., (2020) confirms the aforementioned findings by claiming that the universities had not adopted elements of the sustainability concept and that even the decision makers lacked knowledge and awareness of sustainable development. Moreover, instructors were tentative in calling students to action. These results indicate why students do not immerse themselves in compulsory and voluntary and suggests that both teachers and students lacked a sense of personal responsibility. A denial of personal responsibility is considered to be a major barrier for developing pro-environmental behaviours (Blankenberg & Alhusen, 2019). It appears that education policy makers are only focusing on providing information on the causes and consequences of climate change instead of educating, encouraging, and preparing students for contributing to the environmental cause (Diaz et al., 2020). Alsharif et al., (2020) argue that if universities are keen on organising on-campus activities then educators should play a key role in the transition towards sustainability by addressing energy and water consumption and waste management, and by adopting recycling initiatives (Alsharif et al., 2020).

Theoretical Framework

The Theory of Planned Behaviour (TPB) was used as it has been widely applied to understand change of behaviour in sustainability research (e.g., De Leeuw et al., 2015). It posits that an individual's behaviour can be predicted by understanding one's intention to engage in a particular behaviour (Ajzen, 1991). The four constructs associated with this theory include (a) subjective norms or perceived social pressure and expectations of others to engage in a behaviour, (b) attitudes toward an object or a phenomenon, (c) perceived behavioural control or perceived ability to change behaviour indirectly, and (d) intention or an individual's readiness to perform a behaviour (Ajzen, 2015;1991). Later Ajzen and other researchers have added ecological conscience and moral obligation as additional constructs (Si at al., 2020; Xu et al., 2020; Yadav & Pathak, 2017; Ajzen, 2015). While ecological consciousness reflects an individual's environmental commitment, moral obligation is the responsibility to perform a certain behaviour.

Figure 1

Theory of planned behaviour constructs



In the current study the socio-demographic characteristics were gender and academic majors. By using TBP, this study examined students' beliefs and perceptions about environmental education, to understand their attitudes, subjective and personal norms, perceived behavioural control, ecological consciousness, and moral obligations as well as their intentions to take part in prop-environmental activities. The objective was to know if environmental education and related activities had influenced their pro-environmental behaviours.

The rationale for drawing on the TPB was to identify gender-related and academic-major related differences in the pro-environmental behaviours of students. Although most studies that have adopted this framework have used a quantitative design to predict behaviours, a qualitative lens provides a better understanding of beliefs associated with behaviours (Ajzen, 1991). In the current study, the TPB was used to frame how students perceive the importance of environmental education, to assess their knowledge and attitudes, and to determine if these translate into pro-environmental behaviours.

Methods

This exploratory mixed methods study was conducted at a university in Saudi Arabia where environmental programmes, co-curricular and extracurricular activities were used as an extension to formal learning. An embedded mixed methods research design was used, and priority was not given to either quantitative or qualitative elements (Creswell & Plano Clark, 2017). The qualitative data provided additional knowledge related to the main objectives of the study and was critical to the present study (Plano Clark et al. 2013). Qualitative data was collected after gathering quantitative data to avoid bias and to ensure internal validity (Plano Clark et al. 2014). The rationale to start the research by collecting quantitative data followed by qualitative data was to help explain or elaborate on the quantitative results.

Sample

The university was purposefully selected purposefully which has a well-established track record in environmental programmes and on-campus activities. The recruitment of participants was managed through collaboration with the respective academic departments at the university. From a pool of approximately four thousand undergraduate students, a total of 301 students agreed to participate in the study. The final sample consisted of 226 students, including 103 males and 123 females, representing diverse academic sub-disciplines such as science, engineering, humanities education, and computer science. Notably, the majority of participants were affiliated with the science department, constituting 36% of the sample. The characteristics of the students are summarised in table 1.

The selection of participants for interviews involved a targeted approach. Twelve students who had completed the survey were purposively chosen for in-depth interviews, ensuring a balanced representation of both genders (Male=7 and Female=5). These interviewees provided valuable insights into the research questions and complemented the quantitative data gathered through the survey.

The research prioritised ethical considerations to safeguard the rights and well-being of the participants. Informed consent was obtained from each participant, clearly outlining the purpose, procedures, and potential risks involved in the study. Confidentiality measures were strictly maintained, ensuring that the collected data was anonymised and securely stored. Participants were assured of their right to withdraw from the study at any stage without consequences. The study also adhered to principles of fairness and equity in participant selection, ensuring diverse representation across genders and academic disciplines.

Table 1

Demographic characteristics

Demographic characteristics		Questionnaire	Interview
Gender	Male	103	7
	Female	123	5
	Total	*226*	*12*
Academic majors	Science	81	3
	Engineering	20	2
	Humanities	31	2
	Education	55	3
	Computer science	39	2
	Total	*226*	*12*

Research Instrument, Reliability, and Face Validity

Questionnaire

The research instrument was developed by adapting the Environmental Behaviour Questionnaire (Ntanos et al., 2018). It consists of three sections: (1) Socio-demographics (gender and academic sub-disciplines); (2) Dichotomous questions that assessed students' understanding of various environmental concepts, students' pro-environmental knowledge and environmental behaviours; and (3) Questions on students' attitudes towards environmental education and willingness to participate in ecological activities. The items in sections 3 were measured with a 5-point Likert scale. Cronbach's alpha was used to evaluate the internal reliability and the alpha coefficient was 0.72 suggesting that the items have relatively high internal consistency. The items in section 2 comprised of dichotomous questions about environmental behaviour and focused on simple actions that students could take to alleviate environment issues.

The self-administered questionnaire was created using Google Form and sent as an email and as a link along with participant information sheets, consent forms. Google Forms allowed sharing the forms via email, as a direct link, and through social media sites such as Twitter and WhatsApp. The respondents were asked to provide their email address in Google Form when completing the survey. Participation in the research was voluntary.

Descriptive statistics were used to analyse the survey data (sections 2 and 3). Then, gender differences in students' knowledge, beliefs, attitudes, and pro-environmental behaviours were examined using independent t-tests. A One-way ANOVA (Kruskal-Wallis H-test) using the Dunn's post-hoc test with Bonferroni correction were also performed to analyse cross-discipline differences.

Interviews

Semi-structured interviews were used to understand students' views on environmental education, the role of university in promoting pro-environmental behaviours, the reasoning on the self-reported pro-environmental behavior, as well as the challenges facing students in taking part in ecological activities. The interview protocol was developed based on literature, the TPB constructs and survey items. The interviews were conducted by making video calls using Blackboard. The calls were audio-recorded, with the consent of participants. The transcripts were translated from Arabic to English and thematically analysed using the procedures suggested by Braun and Clarke (2006). A peer researcher reviewed the interview transcripts, codes, and analyses.

Results

Quantitative Results

The data obtained from dichotomous scales were subjected to analysis through descriptive statistics, and the results are summarised in Table 2. The responses from a total of 226 students were considered for all items in the questionnaires. The outcomes of the Yes/No dichotomous questions were computed based on the responses gathered from all participants.

Table 2

Descriptive statistics: Students' self-reported knowledge and pro-environmental behaviours

Dichotomous questions	Yes	No	N*
Have you taken part in environmental education programmes?	40%	60%	90
Have you taken part in on-campus environmental activities?	33%	67%	75
Are you knowledgeable about Renewable Energy Sources?	66%	34%	149
Are you knowledgeable about non-Renewable Energy Sources?	67%	33%	151
Do you know what "Ecology" means?	46%	54%	104
Are you aware of global warming or climate change?	89%	11%	201
Do you know what the term "Energy Crisis" means?	77%	23%	174
Are Renewable Energy Sources used at your university?	76%	24%	172
Do use internet at home to access environmental information?	34%	66%	77
Do use computers or mobile devices to access environmental information?	36%	64%	81
Do use the library to acquire pro-environmental knowledge?	14%	86%	32
Do you turn off classroom lights during breaks?	47%	53%	106
Do you use public transportation for school to reduce pollution?	13%	87%	29
Do you walk to school to reduce pollution?	11%	89%	25
Do you use a bicycle to reduce pollution?	4%	96%	9
Do you use recycle bins in your university?	88%	12%	199
Do you use stationery supplies made from recycled materials?	55%	45%	124
Are you familiar with energy efficient devices and appliances?	78%	22%	176
Would you buy energy efficient devices and appliances?	72%	28%	163

Note: N*=*positive responses*

The descriptive data (Table 2) suggests that only 40% of the students attended environmental education programmes and a mere 33% took part in on-campus environmental activities. A vast majority of the students were aware of global warming or climate change (N=201), used recycle bins at their university (N=199), and understood what "Energy Crisis" meant (N=174). Most students reported being informed about various types of renewable (66%) and non-renewable energy sources (67%), with an additional majority indicating that renewable resources were being utilised at their university (72%). On the contrary, only 46% were familiar with the word "ecology".

With regard to pro-environmental behaviours, 47% of the students switched off classroom lights during breaks. However, many did not demonstrate pro-environmental behaviours. Only 13% used public transportation for school while a mere 11% walk to school to reduce pollution. The use of bicycles was very meagre (4%). Conversely, more than half (55%) used stationery supplies made from recycled materials. As regards reducing energy consumption, a vast majority of the students affirmed that were familiar with energy efficient devices and appliances (N=176) and they had purchased such products (N=163).

A very low percentage of the students (34%) responded positively that they used the Internet for gaining knowledge on environmental issues and 36% used computers or mobile devices to access environmental information. On the contrary, only 14% answered positively about using the school library for environmental information.

Table 3

Descriptive statistics – Gender differences in students' perceptions

	Beliefs about environmental education	Male		Female	
		M	SD	M	SD
1	Lecturers and professors often mention and discus environmental issues in class	3.40	1.35	3.43	1.24
2	Lecturers and professors discuss ways for students to protect the environment	3.13	1.45	3.49	1.40
3	Lecturers and professors mention and discus sustainable development in class	2.36	1.45	2.21	1.34
4	There are compulsory and voluntary activities on and outside campus	3.75	1.31	3.75	1.33
5	My environmental knowledge level has increased	3.01	1.45	3.81	1.16
6	The environmental education I receive is adequate	2.13	1.25	1.83	0.98
7	My participation in on-campus ecological activities has increased environmental awareness	4.09	1.01	4.19	0.79
8	I learnt that renewable energy sources can help solve ecological problems facing earth	4.03	1.04	4.11	0.90
9	My university's contribution is important for shaping environmental conscience	3.88	1.08	4.16	0.84

Descriptive data on gender differences in students' perceptions show (Table 3) that female students have positive dispositions towards environmental programmes and on-campus environmental activities and their university's role in shaping environmental consciousness. Similarly, most female students have better basic energy knowledge than males with regard to the benefits of renewable energy sources. The positive attitude of the female students is likely due to their participation in environmental programmes and compulsory and voluntary activities. However, students of both genders agreed that educators often discussed environmental issues (Male M=3.40; Female M=3.43) and about ways to protect the environment (Male M=3.13; Female M=3.49). Although both genders agreed that the environmental education, they were receiving was inadequate (Male M=1.13; Female M=1.83) and believed that their knowledge on environmental issues had increased (Male M=3.01; Female M=3.81).

Table 4

Descriptive statistics – Students' perceptions across academic majors

	Beliefs about environmental education	Science		Education		Engineering		Computer Science		Humanities	
		M	SD	M	SD	M	SD	M	SD	M	SD
1	Lecturers and professors often mention and discus environmental issues in class	2.98	1.35	3.89	1.15	3.45	1.43	3.54	1.19	3.55	1.03
2	Lecturers and professors discuss ways for students to protect the environment	2.84	1.50	3.96	1.15	3.20	1.58	3.44	1.27	3.39	1.41
3	Lecturers and professors mention and discus sustainable development in class	2.26	1.33	2.31	1.55	2.50	1.50	2.28	1.39	2.13	1.23
4	There are compulsory and voluntary activities on and outside campus	3.27	1.44	4.07	1.15	3.95	1.23	3.97	1.20	4.00	1.15
5	My environmental knowledge level has increased	2.99	1.51	4.07	1.10	3.10	1.48	3.33	1.22	3.90	0.79
6	The environmental education I receive is adequate	1.94	1.04	1.87	1.12	2.20	1.40	2.08	1.24	1.90	0.98
7	My participation in on-campus ecological activities has increased environmental awareness	3.95	1.13	4.29	0.74	3.90	1.07	4.23	0.58	4.42	0.50
8	I learnt that renewable energy sources can help solve ecological problems facing earth	3.81	1.18	4.25	0.80	3.75	1.25	4.23	0.58	4.42	0.50
9	My university's contribution is important	3.89	1.13	4.25	0.80	3.50	1.32	4.15	0.54	4.23	0.76

for shaping environmental consciousness										
Weighted mean scores	3.10	1.29	3.67	1.06	3.28	1.36	3.47	1.03	3.55	0.93

Descriptive data on differences in students' perceptions across academic majors show (Table 4) that students from all disciplines have positive dispositions towards their educators' role in imparting environmental education. However, they were not satisfied with the adequacy of the programmes and activities. However, students across all majors were satisfied with the university's role in raising environmental awareness. This is evident in the overall weighted mean for all the academic majors.

In order to compare the students' perceptions, independent samples t-test was conducted, and the results are presented in Table 5.

Table 5

Gender differences

Gender	N	Mean	t	Sig.(2-tailed)
Male	103	3.31	-1.118	0.265
Female	123	3.44		

The results indicate that there was no significant difference in pro-environmental behaviours of male and female students, t (202) = -1.118, p = .265. That is, the pro-environmental behaviours of female students (M = 3.44, SD = 1.11) was not significantly different from that of male students (M = 3.31, SD =1.27).

In order to analyse cross-discipline differences a series of One-way ANOVA tests were carried out. Responses from each of the five academic majors (science, engineering, humanities education and computer science) were compared statistically to assess whether, in fact, two or more of these sub-disciplines differed significantly from one another.

Table 6

Difference across academic majors

Source	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	12.079	4	3.011	4.041	0.003
Within Groups	165.170	221	0.747		
Total	177.250	225			

The results of the One-way ANOVA detected a significant difference in the perceptions and pro-environmental behaviours of students belonging to different academic majors (p<= 0.05). Therefore, the Bonferroni post hoc test, which is one of the multiple comparison tests, was used to see which group caused the difference.

Table 7

Post hoc mean comparison results

Groups	p-value
Science vs Education	0.00*
Science vs Engineering	0.003
Science vs Computer science	0.002
Science vs Humanities	0.002
Education vs Engineering	0.003
Education vs Computer science	0.000
Education vs Humanities	0.001
Engineering vs Computer science	0.003

Note: *p<0.01

Post hoc comparisons using the Bonferroni test indicated that there was no statistically significant difference ($p<.01$) between pro-environmental behaviours of students across disciplines.

Qualitative Findings

The interview data was carefully examined and coded for the possible presence of any of the TPB constructs. Thematic analysis using Microsoft Word yielded 9 themes. Important pro-environmental behaviour specific themes emerged for attitudes, subjective norms, perceived behavioural control and behavioural intentions as well as ecological consciousness and moral obligation. The themes provided critical insight into understanding students' perceptions of environmental education and the challenges they face in traditional learning environments.

The students were asked how environmental education had shaped their environmental conscience or awareness and attitudes and motivated them, the students reported that the university was a harbinger of change but claimed that substantial changes are required to better influence pro-environmental behaviours.

Attitude

The themes associated with this TPB construct were positive mindset, negative dispositions, environmental concerns, and environmental responsibility. Students shared overwhelmingly positive attitudes about the activities. Their attitudes prompted participation in on-campus and voluntary activities, and it was evident that they wanted to gain new experiences.

> The environmental awareness programmes facilitate better understanding of environmental protection. It provided new resources and it was an opportunity that I did not want to miss out on. (Male Student 2)
>
> It was fun and enjoyable. I mean the recycling activities. (Male Student 5)
>
> It gave use the platform to discuss important issues like recycling and sustainable consumption practices, for example recycle plastic, soda cans and paper, bringing our own coffee mugs instead of using plastic cups, using less paper, and using lights with sensors. (Female Student 8)
>
> Our university plays a moderate role in raising awareness of environmental challenges and in shaping our attitudes and behaviours. It helps build knowledge necessary to address complex environmental issues. (Female Student 10)
>
> I am able to make changes to my lifestyle so I can help the environment. (Female Student 11)
>
> I have become passionate, and I do something because of what I learned. (Female Student 12)

All the participants agreed that there should be improvements in the EE content. There was a general endorsement of activities but that more could be done to motivate students:

> I learnt that natural resources are depleting fast. But I am not really impressed about the programmes. (Male Student 2)

> Teachers must organise more activities even during the pandemic and encourage students to participate in campaigns. At the least they should call out to those who have been vaccinated (COVID-19) and motivate us to take part in these events. (Female Student 12)

The above response show that some students were keen on learning more about environmental sustainability, but also want to see action by their educators and institution. When asked how well or in what way the voluntary and compulsory activities had helped in making pro-environmental decisions, few students expressed that they had developed a sense of environmental responsibility.

> I feel personally responsible for the behaviours of some at the university and people in the neighbourhood. Some of my suggestions fell on deaf ears. More and more people are using cars, and no one wants to walk. Many do not use dustbins. (Female Student 8)

> I am worried about my family and the people; I mean their well-being. I started thinking about the environment, when I heard that fuel was being burnt to obtain energy, I was shocked and so I feel this should be changed. (Female Student 10)

> People, including some of my friends, are more focused on buying new products and no one wants to recycle stuff. I feel that environmental education in schools and universities can change this mindset. (Male Student 7)

The argument was that if everybody would be responsible, one would not question or discuss the actions as such actions would be considered as the norm. There were interesting responses from two students who believed that environmental issues never affect their lives:

> Climate change does not affect my life, because I take care of myself and my family and keep the environment clean. Eating meat not effect environment. No one in my family has contracted the virus, or other diseases. (Male Student 3)

> I don't fully understand global warming. But I feel that people and the media are overreacting. (Male Student 4)

The above responses show that some students are still under the influence of the resource curse effect and that education alone can bring about change.

Overall, the respondents identified a range of educational and social experiences that had influenced them to believe and act pro-environmentally. Some had changed their attitudes and behaviours and developed sustainable practices.

Subjective Norms

The theme associated with this TPB construct was social pressure. When asked where they got their inspiration from, respondents indicated that the learning occurred in real-life situations, outside of formal education. According to them subjective norms had influence their actions.

> I learnt a lot about environmental sustainability in online videos posted by my lecturer. My lecture and peers influenced me and helped me understand the effect of waste on the environment. (Male Student 2)

> The programmes and activities that I have taken part in had little influence on my knowledge about the environment. I gained this through my interactions with overseas friends via social media and from my family. (Male Student)

Social relationships seemed to have dictated subjective norms. They were influenced by social pressure from lecturers, friends, family, and peers. This finding demonstrates that subjective norm in TPB was a significant factor which encouraged the students to participate in an activities and develop pro-environmental behaviours.

Perceived Behavioural Control

The students perceived that they had noticed changes in the way they behaved since taking part in the environment programmes. The theme associated with this TPB construct was self-awareness.

> I chose to participate in on-campus and voluntary activities although I had to attend online science lectures because I wanted to learn how to reuse materials and plant trees. (Male Student 1)
>
> I always use reusable eco bags for shopping instead of disposable plastic bags. (Female Student 8)
>
> Although the activities clashed with my studies I chose to involve in recycling and waste segregation as I wanted to demonstrate it to other students. (Male Student 7)
>
> The programmes taught me to act in a simple way every day. When I go for a walk on the beach, I have made it a habit of asking people to throw trash and waste in bins. (Female Student 12)

The aforementioned excerpts show that perceived behavioural control allowed them to introduce recycling and waste segregation approaches to others and learn how to reuse materials.

> After taking part in activities, I have recycled almost anything I can and started encouraging friends and family to save energy and water. I always tell my younger brothers and sister to switch off the electric fan when not in use or close the faucet immediately after use. (Male Student 1)
>
> Previously, when I watched tsunamis and flash floods devastating different parts of the world on TV, I could do nothing. Although I am just a human and cannot fight nature, I now do small things like not wasting food, or keeping the surroundings clean or taking part in recycling or buying recycled products. (Female Student 10)

This shows that environmental education had influenced students' attitudes and affected them emotionally. It had also helped them transfer this learning to real life. It shows that the students' perceptions of their abilities to implement changes. Overall, the students' perceived behavioural control had increased, for example conserving water and energy to create a greener and healthier planet. They realised that even small actions could make a big difference.

Behavioural Intention

The activities had a big impact on the students as suggested by two themes 'ecological conscience' and 'moral obligation'. Environmental education had not only shaped students' attitudes but also their behavioural intention. For instance, their concerns had positive and significant effect on their intention to use energy sparingly, buy energy efficient appliances and devices etc. Students' concern for the environment had an impact on their behavioural intention to purchase green products.

> Once I complete my degree, I intend to buy a hybrid electric car. (Male Student 2)
>
> I have always been a green consumer. (Female Student 9)

Environmental conscientiousness and moral obligation had exerted greater influence on students' intention to buy green products.

> I always buy appliances that are energy efficient, for example air conditioner with an inverter or electric fans that work on solar energy. (Male Student 2)
>
> My friends had installed automatic sensor faucets at home to save water. I persuaded my dad to do the same. (Female Student 10)

The students viewed that conserving water and energy would lead to reduction in water and electricity bills. This results further shows that attitude, subjective norm, and perceived behavioural control had a substantial effect on behavioural intention.

It is also evident from the responses that simply learning about environmental issues or taking part in activities might not lead to changes in students' pro-environmental behaviours. It is social pressure, empathy for citizens' well-being or moral obligation, personal responsibility, self-awareness or ecological consciousness and the belief that they can influence the situation that made them to act pro-environmentally. They appeared to do so by focusing beyond themselves and showing concern.

Challenges

One of the challenges facing students was that the lecturers did not have professional development or training to provoke behaviour change. Another challenge was lack of time, which prevented some students from volunteering for the activities. The third challenge was commitment or reluctance to take part in the activities.

> Instructors support teaching climate change more in theory than in practice as it is outside their subject area. In other words, they had insufficient knowledge of environmental education, an understanding of contemporary and dynamic environmental issues and lacked training. (Female Student 10)
>
> Some instructors say that they lack adequate knowledge and so they avoid topics related to environment. (Male Student 2)
>
> The programmes are good, but not many students take part in it. They say that they do not find time as it clashes with classes. (Male Student 7)
>
> The online videos and activities are informative and can change one's attitudes. However, not all students are committed. Some lecturers are also not committed and do not encourage us to take part in activities such a recycling. (Female Student 9)

This study found various challenges to implementation of environmental education in higher education in Saudi Arabia.

Discussion and Conclusion

Key Findings

The main aim of this study was to investigate the role of environment education in influencing students' pro-environmental behaviours at a university in Saudi Arabia. A mixed- methods research design was adopted, and the quantitative and qualitative data were subjected to triangulation and findings relating to the research questions are discussed below.

The findings suggest that environmental education is being welcomed by students in higher educational institutions in Saudi Arabia. However, further integration of the principles of environmental education may be meaningful. The quantitative findings showed that most students did not attend environmental education programmes. This was not what was expected. The students were also not very well informed and did not demonstrate thorough understanding of environmental concepts. The current study also found that although the students were aware of climate change, they did not use public transportation or walk or use bicycles. This suggests that they do not have greater concern for environmental problems. Further research is required to examine how and why different factors play a role in turning intention into behaviour in these kinds of situations. However, both quantitative and qualitative data suggest that only a few students were environmentally responsible and practiced environmentally friendly habits. These results paralleled those obtained in previous studies from Saudi Arabia (Alsharif et al., 2020; Abubakar et al., 2016; Alsaati et al., 2020).

Although it is possible that the students had joined these programmes and activities with a greater disposition towards environmental issues, and their knowledge on environmental issues had increased, the students were not happy with the programmes. The reason behind this problem is lack of encouragement from lecturers. A with previous studies, this study found from the interviews that lecturers lacked commitment and failed to trigger behaviour change (Glavic, 2020; Wamsler, 2020; King & Franzen, 2017). This shows that environmental education and awareness of ecological problems does not necessarily translate into environmentally responsible behaviour (Harring et al., 2020; Janmaimool & Khajohnmane, 2019). However, the problem can be addressed by implementing faculty training sessions on the significance of such initiatives and integrating environmental topics into the curriculum. Additionally, establishing open communication channels, recognising and rewarding lecturer involvement, and advocating for institutional policies supporting educators' engagement in extracurricular environmental activities can contribute to fostering a more encouraging academic environment.

The results obtained from the *t*-test and One-way ANOVA show that there were no significant differences in the beliefs of males and females as well as student belonging to five academic sub-discipline. However, post hoc tests revealed that there were no significant differences in the knowledge and pro-environmental behaviours of students across disciplines. One of the interesting findings was that female students had better basic energy knowledge than males with regard to environmental concepts. This finding is congruent with previous studies (for example Hansmann et al., 2020; Akitsu et al., 2017; De Leeuw et al., 2015; Xiao & McCright, 2015; Rideout, 2014).

Qualitative results suggest that attitude, subjective norm, and perceived behavioural control were important constructs that helped understand students' intention to attend environmental education. The students' attitudes included positive mindset, negative dispositions, environmental concerns, and environmental responsibility. The students' normative beliefs or increased "social pressure" to attend on-campus activities indicates a strong positive subjective norm. The students' perceived behavioural control also played a key role in influencing pro-environmental behaviours. They were environmentally conscious and committed and perceived that they had the ability to recycle and manage waste. The students' moral obligation to patronise green products and reduce the environmental impact of energy and water usage played a significant role in understanding their intention to engage in pro-environmental behaviours. This is congruent with previous research such as Si at al. (2020), Xu et al. (2020) and, Yadav and Pathak (2017).

Limitations

This study has limitations. The evidence is limited to students from only one university and therefore may not be generalisable. However, the results provide a rich and detailed picture of students' perceptions, experiences and expectations of environment education and its role in promoting pro-environmental behaviours. Future studies should consider larger samples from multiple universities in order to have a better basis for comparison. Another limitation is self-report bias which may have occurred when students responded to survey items and rated their level of knowledge.

Originality and Value

This study offers quantitative and qualitative findings that affirm the significance of environmental education for higher education students. Although previous research has used TBP and examined students' environmental knowledge and pro-environmental behaviours, very few studies have used qualitative or mixed methods research design.

Implications

The results of this study are crucial to university administrators, educators and policy makers, to help them detect inappropriate practices. This study is of particular relevance for educators and policymakers who can use the findings to design effective programmes and on-campus activities aimed at promoting environmental consciousness and enhancing environmental protection. This study could also sensitise the policymakers to make a conscious effort to infuse principles of environmental education in teacher preparation programmes so that its usage would be part of a holistic approach that promotes students' pro-environmental behaviours.

Recommendations

Programmes and on-campus activities should be designed in such a way that it can contribute to developing and encouraging critical thinking, problem-solving, awareness, motivation, and sensitivity amongst students to promote action toward environmental improvement.

Policymakers should give more emphasis to environmental education in primary , intermediate
and secondary schools and offer professional development opportunities for teachers so that they can deliver environmental education curriculum effectively.

Workshops and seminars should be organised to encourage educators to stay up to date on environmental issues.

Educators should give more emphasis to on-campus and outdoor programmes and activities. Since students are learning from home, due to the pandemic, videos should be used to educate them. The students could be encouraged to post their pro-environmental habits or practices on YouTube and the university website.

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Exploration of science concepts in Indonesian indigenous culture: actualization of the Indonesian curriculum

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ABSTRACT
Ojhung is one of the indigenous Indonesian cultures from Sumenep Regency which contains relevant science concepts to be applied in science learning. Therefore, this research aimed to identify and explore the concepts of science contained in the Ojhung tradition while evaluating their relevance to the *Merdeka* or national curriculum. This research uses a qualitative design with a grounded theory based on scientific concepts in the Ojhung tradition and can be applied in science learning. The concepts of science that have been successfully explored and identified are Newton's Third Law, Sound Waves, Sense of Hearing, Pressure, Flexibility, Body Muscles, Moments of Inertia, and Skin Wounds. All concepts that have been explored can actualise learning outcomes in the Merdeka Curriculum. This research implies applying science concepts to Ojhung to improve public scientific literacy and science learning in schools.

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Introduction

Culture and tradition are familiar words to hear because they have many meanings for people who still maintain and preserve the culture and traditions found in each region (Mackie, 2018; Smith et al., 2020; Suarta et al., 2022). Indonesia is a country that has quite a variety of ethnic groups, each of which has its own characteristics that we can find in each region, especially the culture characteristic of each region in Indonesia (Fatmawati, 2021). One area in Indonesia with many indigenous cultures is the Sumenep Regency (Humaidy & Ariwidodo, 2020; Ridwan, 2018) located at the eastern end of Madura Island and which has a variety of indigenous cultures that vary within the region (Qodariyah & Wahed, 2019). The people of Sumenep generally tend to uphold cultural values, making this area rich in art and culture that is still maintained and preserved by the local community. One aspect of the indigenous cultures still being preserved is *Ojhung* (Raditya, 2022).

Ojhung is the art of fighting by hitting and fending off opponents using rattan (*Lapalo*) and led by a referee (Pradana et al., 2019). Initially, the *Ojhung* tradition was carried out as a ritual or traditional ceremony to conjure up rain. However, over the course of time, the *Ojhung* tradition is staged in entertainment events and community games, for example, at village celebrations, earth almsgiving, and *nadzar* [a solem promise] events. In its development, this tradition underwent several changes in roles, *bhabhutoh* [referee], staging arenas, and staging equipment (Abbas, 2017). *Ojhung* is a rain-summoning tradition with a spell called *Bato' Peter*. The phrase *bato' peter* consists of the word *bato',* which means 'cough' and the word *peter,* which means 'lightning' (Maknuna et al., 2013).

However, believing in a myth sometimes negatively impacts mental health (Nie & Olson, 2016) and can form a negative mindset (Kishore et al., 2011). The *Ojhung* tradition has the potential to act as a source of scientific concepts that can be explored to explain societal myths and superstitions. This can certainly improve the science literacy skills of the community and school learners if applied in learning because it integrates knowledge with daily life. In previous research by Said-Ador (2017), the learning process which refers to the context of pupil life including cultural heritage (local wisdom) can act as a conduit for understanding chemistry or physics topics, developing aspects of attitudes and skills, and conducting scientific investigations based on natural laboratories that can improve cognitive, affective and psychomotor learning outcomes. Exploring science concepts in *Ojhung's* local wisdom has the potential to change the mindset of society and pupils through science learning.

In Indonesia, science is included as one of the subjects in the '*Merdeka*' (=Independent for all levels) Curriculum, especially at the secondary levels (Phases D, E, and F). Science learning in this curriculum emphasises the aspects of meaningful and everyday life and their learning outcomes (Wiyarsi et al., 2023). The science concepts contained in *Ojhung* certainly have the potential to actualise the *Merdeka* Curriculum in science learning because they are related to pupils' daily lives. Combining indigenous science with scientific knowledge in learning can improve student learning outcomes (Khusniati et al., 2023; Sumarni et al., 2016). This integrated approach enriches the curriculum by providing diverse perspectives and real-world applications. Consequently, students gain a deeper understanding and appreciation of scientific concepts, leading to enhanced academic performance (Abah et al., 2015; Chinn, 2015; Zidny et al., 2020).

This research identified and explored the concepts of science contained in the *Ojhung* tradition while analysing their relevance to the *Merdeka* Curriculum. The following research questions guided this study:

1) How is the *Ojhung* tradition described practically?
2) How are science concepts reconstructed from the *Ojhung* tradition?
3) What is the relevance of these concepts in *Ojhung* to the *Merdeka* Curriculum in science learning?

The concepts of science contained in the tradition will increase the science literacy of the community and reduce belief in myths and superstitions. This research can also help actualise the *Merdeka* Curriculum because it has relevant content and context. It provides rich contexts for science learning and links it with more comprehensive worldviews required for advancing sustainability (E.-J. A. Kim et al., 2017; E.-J. A. Kim & Dionne, 2014).

Literature Review

Exploration Study of Science Concepts in Local Wisdom

Exploratory research on science concepts has been widely researched, for example, the exploration of science concepts and science process skills on Balinese local wisdom (Suarmika et al., 2020), exploration of physics concepts in traditional *Kolecer* (Sholahuddin & Admoko, 2021), exploration of chemical concepts in Sasak and Javanese local wisdom (Sutrisno et al., 2020;

Wahyudiati & Qurniati, 2023), and the concept of utilising forest resources in *Ngata Toro* local wisdom (Yuliana et al., 2017). The traditional concepts are categorised under the headings of Ethnoscience, Ethnophysics, Ethnochemistry, or Ethnobiology, which can be applied to learning (Silvini et al., 2020; Suprapto et al., 2021).

Exploratory research tests the reliability of research instruments and their suitability for subsequent research (Lee & Shim, 2007). The main objective of exploratory research is to generate inductively derived generalisations regarding the group, process, activity or situation under study (Stebbins, 2001). Subsequently, the researcher weaves these generalisations into the basic theory explaining the study's object. The ultimate goal of exploratory research is to formulate new hypotheses for follow-up research, or at least to provide a basis for determining and formulating more specific research problems (Kothari & Garg, 2019). The end result of exploratory research is a hypothesis or the beginning of a new theory (Casula et al., 2021). Since a problem has not been formulated and a hypothesis does not yet exist, the number of samples taken in exploratory research is not very important (Kusewitt Jr., 1985); however, it is important that they are representative.

Ojhung Tradition

The *Ojhung* tradition is the art of fighting, hitting and fending off opponents using rattan and guided by a referee (Pradana et al., 2019). This tradition was born and developed in Sumenep Regency, especially in Bunbarat Village. This tradition contains a magical element because it is a traditional ceremony or ritual to conjure up rain (Abbas, 2017). The *Ojhung* tradition is carried out in a series of earth alms traditions and is believed by the community to protect them from all forms of calamities that can threaten the village.

Currently, there is very little research on the *Ojhung* tradition. This is evidenced by the search for the keyword "*Ojhung*" on the Scopus web which yields 0 document results. Nonetheless, some local references, as examples of research by Pradana et al. (2019), reveal that this tradition can be used as sports tourism because it is attractive and contains sportsmanship. Other research by Supiani (2016) describes the actualisation of the values implicit in the *Ojhung* tradition in primary school pupils. Therefore, this exploratory research becomes a necessary creativity and has still not been carried out by previous studies.

Merdeka Curriculum

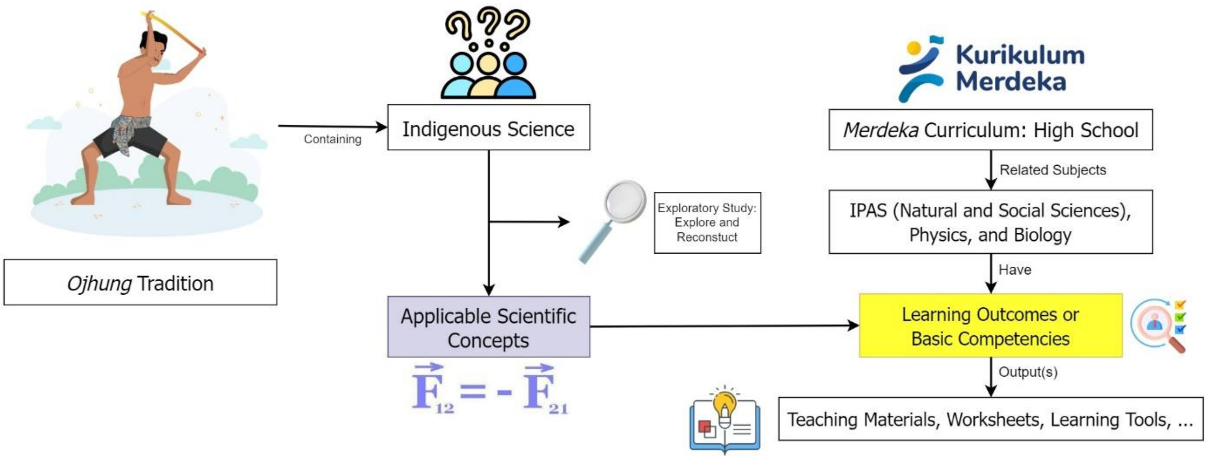
In responding to the changes that continue to occur and increasing the quality of Indonesian human resources in a better direction than the education sector, the Indonesian government has enacted a new policy known as independent learning in the *Merdeka* Curriculum (De Vega & Nur, 2022; Maipita et al., 2021; Purwanti, 2021). The concept of a *Merdeka* learning curriculum emphasises the provision of freedom in the field of education. In this case, the teacher is a facilitator for pupils in providing learning because the learning process is supposedly student-centred (Abdigapbarova & Zhiyenbayeva, 2022). The essence of independent learning in the *Merdeka* Curriculum is the freedom to think individually and in groups to produce critical, creative, collaborative, innovative and participatory among learners (Jainah et al., 2022). The learning outcomes emphasised in this curriculum are related to everyday life (Solikhah, 2022), so the science concepts contained in the *Ojhung* tradition can have a role in actualising learning in the *Merdeka* Curriculum. Previous research also recommended adopting indigenous knowledge in science education (Zidny et al., 2020).

Research Framework

Definitely, the *Ojhung* tradition harbours numerous scientific concepts that often remain unrecognised, leading to their categorisation as indigenous science. This concept elucidates the intertwining of scientific knowledge with cultural norms and values, which serve as the bedrock for societal structures and progress. Typically conveyed orally and steeped in experiential wisdom and symbolism, indigenous science encounters limitations in dissemination through contemporary models due to the fundamental differences in epistemology, communication methods, and the reliance on context-specific knowledge that is often difficult to translate into the written or digital formats favored by modern scientific discourse (Sumarni et al., 2016). This socially constructed reservoir of living knowledge can serve as an alternative educational resource if it undergoes codification, reinterpretation and elevation to the status of scientific knowledge (Sumarni et al., 2022). Exploratory research offers a pathway to unravel and reconstruct indigenous science into formalised knowledge applicable to educational curricula. Through this investigative process, researchers can uncover science concepts ripe for integration into educational frameworks.

All education units in Indonesia are currently transitioning from the 2013 Curriculum (K-13) to the *Merdeka* Curriculum based on the ministry decree number 008/H/KR/2022. One of the differences between these two curriculum types is the intended competencies. In K-13, basic competencies are expressed as points and sorted to achieve core competencies evaluated annually. Meanwhile, in the *Merdeka* Curriculum, learning outcomes are compiled in each phase and expressed in paragraph form, providing a more holistic and narrative-driven approach to student progress. This method allows for a more comprehensive understanding of student development, capturing the nuances of learning that go beyond standardised metrics and offering educators a richer, more detailed framework to assess and support student growth over time (Munandar et al., 2021). In relation to the *Ojhung* tradition, the most relevant subjects are IPAS (natural and social sciences), Physics and Biology. The real actualisation of the concepts of science contained in the *Ojhung* tradition can be applied as teaching materials or worksheets for learners. So far, traditions in Indonesia that have been reconstructed from the original science and implemented in teaching materials, such as *Karapan Sapi* tradition-based worksheets (Fauzi et al., 2022), *Hombo Batu*-themed with mobile learning (Saputra & Kuswanto, 2018), augmented reality of the *Ketapel* local wisdom (Rahmasari & Kuswanto, 2023). In addition, some of the learning outcomes in the *Merdeka* Curriculum are more directed to material related to everyday life so that the concepts of science in *Ojhung* will make it easier for teachers and pupils in learning. The research framework is witnessed in Figure 1.

Figure 1
Research framework



Method

General Background

This research uses qualitative design (Safdar et al., 2021), with data analysis techniques in the form of descriptive qualitative without testing a hypothesis. Qualitative research focuses on data collection, analysis and writing (Yin, 2011). The type of qualitative research is grounded theory (Kandasamy et al., 2017; Redman-MacLaren & Mills, 2015), which is a qualitative research method that uses a systematic set of procedures to develop an inductive theory for a phenomenon. This method starts from a statement that is still vague and eventually produces a theory collected from various data. The resulting theory is based on scientific concepts in the *Ojhung* tradition and can be applied in science learning.

Data Collection

Data collection techniques in this study involved indirect observation (Anguera et al., 2018) and document studies (Sommerhoff et al., 2018). Indirect observations come from observations of documentation and videos of the implementation of *Ojhung*'s local wisdom obtained from Youtube and other digital platforms. The indicators of scientific concepts to be explored such as the concept of physics (mechanics, dynamics and thermodynamics), the concept of biology (touch systems, the concept of enzymes and anatomy of the human body), and the concept of biochemistry (chemical compounds residing in the body). Literature studies of this study use journal sources, empirical research that has been carried out, and books. The documentation study was carried out to synthesise relevant indicators of science learning in accordance with the *Merdeka* Curriculum. Focus Group Discussions (FGDs) involving two science education experts and one professional science teacher aimed to discuss, validate, confirm and reconstruct science concepts on the *Ojhung* tradition and its linkages to the *Merdeka* curriculum. The FGD was conducted for about 60 minutes using the Indonesian language.

Data Analysis

The data analysis technique used in this study is a qualitative descriptive analysis. Activities in qualitative data analysis are referred to the Miles and Huberman model (Miles et al., 2014), which includes four stages (Suliyanah et al., 2021), namely: collection of data from various reliable sources to obtain the necessary information that supports the ability of research objectives; data reduction is carried out to sort out important things that focus on the needs of the author in order to facilitate the collection of the desired data in accordance with the objectives of the study; data presentation generally in the form of short descriptions, charts, relationships between subjects, and so on; and conclusion and verification.

Trustworthiness

In qualitative research, the term trustworthiness is used in place of terms including internal and external validity, dependability and objectivity (Kosasih et al., 2022; Suprapto & Ku, 2022). Trustworthiness consists of credibility, dependability, confirmability and transferability (Peterson, 2019). The credibility and dependability of the data were reflected in the data collection instruments referring to the relevant literature. The credibility of the data is achieved by triangulating the data to reduce research bias through documentation, literature studies, and FGD. Documentation studies are carried out through relevant documents as well as the results of documentation of researchers who have seen the *Ojhung* tradition before. Meanwhile, the FGD also helped the researcher confirm and develop the exploratory results based on suggestions with experts and practitioners. In terms of dependability, researchers have recorded the entire process of data and research results. Confirmability in this study was carried out by collecting data by all team members, then a critical discussion with experts and practitioners was carried out with various perceptions so that the data could be more trusted. Finally, the transferability of this research has been set up by researchers in a complete, in-depth, detailed manner involving experts as well as analysing the relationship in aspects of science learning in the *Merdeka* Curriculum so that users can apply the results of exploring science concepts in learning.

Result and Discussion

Practical Overview of the Ojhung Tradition

It was observed that the *Ojhung* game generally started at 3:00 p.m. after *ashar* prayers. In this game, people aged 17 to 50 are allowed to compete in the *Ojhung* tradition. Usually, the players choose their dueling opponents behind the arena. If an agreement occurs, they must register with the organizers of the *Ojhung* event.

Ojhung game arenas are generally found in rinks measuring 10 x 10 m. The equipment used in the *Ojhung* game tradition, as well as functioning as a weapon, is a rattan stick used as a punching tool called *a lapalo* or *kol-pokol*. Rattan wood is flexible and sturdy The rattan has a length of 1 metre, which is the characteristic of. In addition, players use head protection (*bhungkus* or *bhuko*) and left arm pads (*bulen* or *tangkes*). The game is arranged by a referee who, by the local people, is called *bhubhuto*. In its implementation, the performance was accompanied by the *Okol* orchestra, whose musical equipment consisted of traditional East Javanese musical instruments in the form of *ghambang* and *dhuk-dhuk*.

Ojhung's performance art is the same as other fighting arts involving two fighters with a referee. The main goal of the *Ojhung* players is to try to hit the opponent's back. The referee will declare one of the winners after successfully injuring the opponent's back or knocking down the opponent's *lapalo.* If the attack hits the head, the area of the outer arm and the lower part of the body, then the attack is not considered successful. In specific matches, the referee has the right to stop matches that he thinks are one-sided.

The player who gets the most points during the three rounds becomes the winner. Players can also be disqualified directly during the game if they attack by going more than three steps, or if the rattan slips from the grip and hits more than once in a round. There are five referees: four people are player supervisors, and one person is the determinant of the game (main judges). Family, sportsmanship, and togetherness are the main values that have always been upheld in the *Ojhung* game.

Results of Exploration of Science Concepts in Ojhung

After exploration and FGD, several scientific concepts in the *Ojhung* tradition have been identified: Newton's Third Law, sound waves, sense of hearing, pressure, flexibility and body muscles, and kinetic energy. The results of the exploration can be comprised in Table 1.

Table 1

Results of Exploration of Science Concepts in Ojhung

Science Concepts	Explanation	References in the Literature	Figure
Newton's Third Law	One player gives the whip a boost to attack another player, and then the player gives the force to resist the attack from the first player, as seen in Figure 2.	The force of two bodies on each other is always equal in magnitude and in the opposite direction (Göbel et al., 2021)	Figure 2 *A player attacks an opponent in Ojhung*  *Source: Youtube Wirawiri Promotion*
Sound Waves and Sense of Hearing	The accompaniment sound of traditional musical instruments, such as the *okol* orchestra, as seen in Figure 3, whose musical equipment consists of *ghambang* and *dhuk-dhuk* made from a wooden plate that vibrates from being hit. If those instrumentals are played, it causes sound interference that is pleasant to hear.	Previously, the concept of sound waves in gamelan has been studied for sound waves, fast propagation of sounds, resonance and vibration and the sense of hearing (Wardani, 2021).	Figure 3 *Okol orchestra*  *Source: Youtube Aural Archipelagio*
Pressure	Pressure will be applied when the first player hits the second player using a *lapalo* (Figure 4). If the force of the blow given to the rattan by the first player is greater, then the pressure generated also increases.	The concept of pressure is the same as the distribution of force over the area of a surface. Thus, if the force exerted on an object is greater, the pressure generated will be even greater (Serway & Jewett, 2014).	Figure 4 *A player presses his opponent*  *Source: Direktorat Warisan dan Diplomasi Budaya*
Flexibility	*Ojhung*'s tradition of using *lapalo* as a weapon to whip opponents because of its flexibility and strength. The *lapalo* flexibility and strength in hitting the opponent are affected by the cross-sectional area of the *lapalo* itself. Additionally, this flexibility also has a relationship with the elasticity properties of the materials used (Figure 5).	The content of cellulose and lignin is closely related to the strength of rattan. Therefore, the high concentration of cellulose content increases the rattan Modulus of Rupture (Gu & Zhang, 2020).	Figure 5 *The rattan flexibility used by players*  *Source: Youtube Wirawiri Promotion*

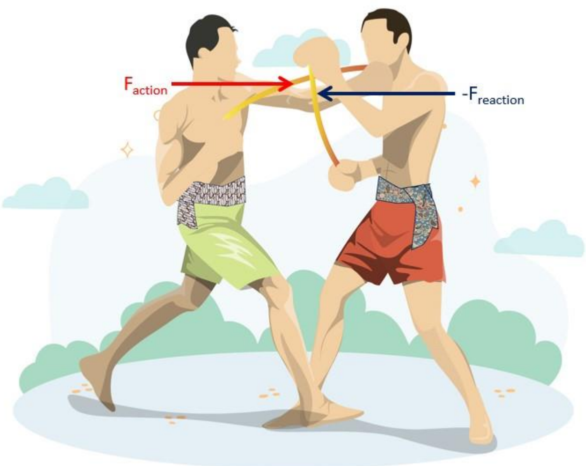
Science Concepts	Explanation	References in the Literature	Figure
Body Muscles and Inertia Moment	In the game, players must prepare their stances before attacking and dismissing the opponent's attack (Figure 6). Stances strengthen mass in a standing position, and due to their greater mass, the torso and pelvis have stronger moments of inertia during rotation.	When the pelvis and torso have more mass, these body parts, while the rotation has a greater moment of inertia (Choppin et al., 2021).	Figure 6 *Ojhung players do the stance*  *Source: Youtube Wirawiri Promotion*
Kinetic Energy	In *Ojhung*, players must whip the opponent using *lapalo,* which requires energy because it is affected by the speed of the player's lash (Figure 7), causing injury if it hits the skin.	When work is done on an object by applying a net force, the object speeds up and gains kinetic energy (Halliday et al., 2014).	Figure 7 *Ojhung players get whipped*  *Source: Youtube Wirawiri Promotion*

Newton's Third Law, Pressure, Flexibility and Elasticity in Lapalo

Newton's third Law states that for every action, there is always an equal and opposite reaction. The forces of two bodies on each other are always equal in magnitude and the opposite direction (Göbel et al., 2021; Landell-mills, 2021; Zuza et al., 2018). For example, during the match, the first player gave *Lapalo* a boost to attack the second player. While the second player provides a force to withstand the attack of the first player. This is one example of the application of Newton's Third Law to the game *Ojhung*. If the force vector is depicted in the *Ojhung* activity, as shown in Figure 8.

Figure 8

Vector illustration of Newton's 3rd Law



The vector direction from the first player towards the left is a given action force, in the form of a push against the second player's whip. Then, the second player generates a reaction force that an arrow toward the opposite action force by the first player depicts. To indicate that the reaction force is always opposite to the action force, the reaction force is always written using a negative or minus sign. The equations applicable to Newton's third law in general and as an integration of reaction action forces in the *Ojhung* game are written in Eq. 1 (Aquino et al., 2018).

$$F_{action} = -F_{reaction} \qquad \ldots (1)$$

The equipment used in the game that simultaneously serves as a weapon and a punching tool is a rattan stick. The tool by the local people is called *lapalo* or *kol-pokol*. The concept of applied pressure is the spread of force on the area of an object's surface (Elandt et al., 2019; Halliday et al., 2014). If the force exerted on the rattan by the first player is greater, the pressure also generated increases. The force and the pressure are directly proportional. So, when the first player hits the second with a high force, he will feel pain. It is also influenced by the cross-sectional area of the object used to exert pressure, in this case, it is rattan. The size of the rattan affects the pressure generated. The greater the cross-sectional area, the smaller the pressure. Conversely, if the cross-sectional area is smaller, the pressure is greater. The equation of this concept is written in Eq. 2.

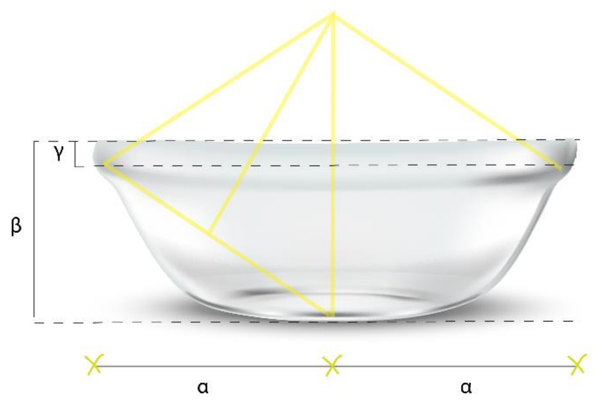
$$P = \frac{F}{A} \qquad \ldots (2)$$

P is pressure, F is the force, and A is the cross-sectional area. Thus, from this equation, it can be seen that the relationship between pressure and cross-sectional area is inversely proportional, while the relationship between force and pressure is directly proportional (Serway & Jewett, 2014).

In general, rattan rods are composed of cellulose (39–58%), lignin (18–27%), and starch (8–15%) (Zuraida et al., 2017). Rattan's strength is closely correlated with its cellulose and lignin levels. The high proportion of cellulose increases rattan's Modulus of Rupture (MOR). The high lignin content makes the strong connection between rattan strands possible. Rattan is flexible anatomically because it contains protoxylem. Rattan and bamboo bend more easily if they have more parenchymal cells and larger cavities of the metaxylem and phloem (Dwianto et al., 2020).

Figure 9

Rattan cross-sectional geometry



The rattan's flexibility and strength in hitting the opponent are influenced by the rattan's cross-sectional area, as seen in Figure 9. The cross-sectional area is equal to the sum of the cross-sectional areas of the rectangle and the area of the circle's segments. The sector area of a circle less the area of a triangle, can also be used to represent the segment area of a circle. As a result, Eq. 3 may be used to compute the cross-sectional area (S) in mm², where α is half the rattan's width (mm); β is the rattan's overall thickness (mm); and γ is the thickness of the rattan piece's rectangular cross-section (mm) (Gu & Zhang, 2020).

$$S = \alpha(\beta + \gamma) + \frac{\pi\left(90 - arc\,\frac{\alpha}{\beta - \gamma}\right)[\alpha^2 + (\beta - \gamma)^2]}{360\cos^2 arc\,\frac{\alpha}{\beta - \gamma}} - \frac{\alpha\sqrt{\alpha^2 + (\beta - \gamma)^2}}{2\cos arc\,\frac{\alpha}{\beta - \gamma}} \quad \ldots (3)$$

Meanwhile, elasticity is a material property that enables changes in both size and shape when subjected to an external force, but the material returns to its original size and shape once the external force is removed, provided that the applied force is smaller than the elastic limit (Halliday et al., 2014). *Lapalo* players exert an external force by whipping it at other players. Research indicates that rattan used as *lapalo* has a good modulus of elasticity, with a range of 130.2 to 2830.7 N/mm² (Olorunnisola et al., 2005). This concept of elasticity can be further explained by teachers, for example, by demonstrating the use of rattan to teach elasticity in materials. This will help pupils understand the practical applications of elasticity and flexibility in everyday life.

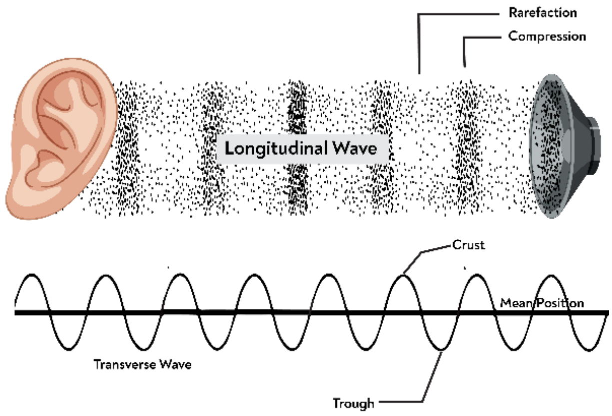
Sound Waves and Sense of Hearing in Okol

During *Ojhung* activities, the host enlivens the show as a game commentator. East Javanese accompaniment music also adorns the *Ojhung* playing arena, including the *gamelan*. *Gamelan* is a traditional Javanese musical instrument made of metal or bronze, with a set of instruments played together (Astuti & Wulandari, 2023). The sound waves produced by the gamelan come from vibrating strings (*siter, rebab*), vibrating air columns (*gender*), and vibrating wooden plates (*ghambang*) (Prasetya, 2012). If those instrumentals are played, it causes sound interference that is pleasant to hear. Previously, the concept of sound waves in *gamelan* has been studied for sound waves, fast propagation of sounds, resonance as well as vibration and sense of hearing (Wardani, 2021).

To become a sound itself, it must meet three aspects: vibrating source (sound generator), conducting media, and receiving media (eardrum). These three aspects must be fulfilled so that sounds/sounds can be created. A sound can be produced from vibrations of objects that can produce sounds, ranging from falling objects and musical instruments to vibrations from human vocal cords (Sterling et al., 2018). The vibration will change the pressure on the medium (compression and rarefaction), as illustrated in Figure 10.

Figure 10

Illustration of vibrations from the sound system to the receiving media



In this cycle of pressure changes, it will create a pattern called a sound wave. So, a sound wave is a series (cycle) of pressure changes moving through the medium. The medium can be in the form of a liquid, a solid substance, or in the form of a gas. Sound waves can propagate in water or air (Nassi et al., 2020).

Sound waves consist of air molecules that vibrate and then propagate in all directions. The molecules will be crowded in some places, so they can produce regions that can produce high pressure, but in other places, stretch, they can produce regions with low pressure. High-pressure and low-pressure waves alternately pass through the air and disperse from the source of the sound. This wave conducts sound to the human ear, the sound wave is a longitudinal wave (Karaoglu, 2020; Vincze & Vincze-Tiszay, 2021; Volfson et al., 2022; Zohuri, 2019). In general, the formulation of the theory of the rapid propagation of sound waves is written in Eq. 4.

$$v = \frac{s}{t} \qquad \ldots (4)$$

In Eq. 4, v is the velocity of the sound wave, s is the distance, and t is time. Then, the resonance of the sound will also appear due to vibration from the sound systems. Sound resonance is the event of vibrating an object due to vibrations produced by the sound source. Sound resonance can only occur if an object has a natural frequency equal to the natural frequency of the vibrating sound source (Caicedo-Lopez et al., 2020; Nunes et al., 2021). In addition to objects, the medium around the sound source can also resonate as long as it has the same natural frequency as the natural frequency of the sound source.

Gamelan can produce sound because it obtains mechanical energy from the outside. The tweeter can direct the energy outward. After getting energy from the outside, there is a process of displacement and change of energy in gamelan. The mechanical energy from the blow given by the whistleblower will be stored for a moment in the gamelan and immediately converted into vibration energy that produces sound. There are many types of gamelans. The difference between *gamelan pelog* and *sendro* is in the fundamental frequency of each note and interval. *Gamelan slendro* has a tone range high enough to give the impression of a happy, carefree, light, and crowded atmosphere (Purnomo et al., 2022). In addition, the *gamelan pelog* has a high tone range to give a gallant, grandiose, sacred and sacral effect (Cahyadi & Mutiarasari, 2021). In *ojhung*, the gamelan instruments used include a *gamelan pelog* that aims to give the impression of a fierce fight. Pitch intervals are measured using cent measures based on logarithmic calculations since the perception of the human auditory system to tonal frequencies is logarithmic (Klapuri, 2003). Cent measures are a logarithmic unit of measure used for musical intervals, specifically to compare the size of pitches or the difference between two frequencies. In the context of tuning and music theory, one cent is 1/100th of a semitone, making it a useful standard for precise tuning adjustments and the analysis of musical intervals. The measuring value of cent units is formulated through the following comparative calculation in Eq. 5.

$$int = \log \frac{f_{n+1}}{f_n} x \frac{1200}{log 2} \qquad \ldots (5)$$

Note:

f_{n+1} = fundamental frequency of (n + 1) tones

f_n = fundamental frequency of n-th tone of comparison

The Number $\frac{1200}{log2}$ is the multiplier factor for converting measurement results into cents. The number 1200 cents is equivalent to *log 2*, that is, the logarithm of the frequency comparison of one octave (Prasetya, 2012).

Sound waves enter the outer ear and pass through the ear canal, a small opening that connects to the eardrum. Incoming sound waves cause the eardrum to vibrate, and these vibrations are then sent to the three tiny bones (*maleus*, *inkus* and *stapes)* in the middle ear (Singh et al., 2022; Thresa et al., 2019). The cochlea, a fluid-filled snail-shaped structure in the inner ear, receives sound waves amplified or enhanced by the bone in the middle ear. Between the cochlea's beginning and end, an elastic barrier divides it into upper and lower portions. The main auditory structure is located on the ground floor, which is why this partition is known as the basilar membrane.

A running wave develops along the basilar membrane as soon as the vibration causes the fluid inside the cochlea to tremble. On the basilar membrane, the sensory cells, known as hair cells, ride the waves. The wide end of the cochlea, which resembles a snail, has hair cells that can pick up high-pitched noises like a baby crying. Near the centre, people heard low-pitched noises, such as a big dog barking. As the hair cells move up and down, microscopic hair-like projections (known as stereocilia) perched above the hair cells crash into the structures above them and bend. Bending causes the pore-like channel, which is at the end of the stereocilia, to open. When that happens, chemicals enter the cell, creating an electrical signal. The auditory nerve carries these electrical signals to the brain, converting them into sounds we recognize and understand (T. Kim & Park, 2020; Sonmez & Varol, 2020; Warwick, 2020).

Muscles and Moment of Inertia in Stance Movements

In the *Ojhung* game, the players must prepare their stances before attacking and dismissing the opponent's attack, as seen in Figure 11. Stances can strengthen standing positions when attacking or punching opponents (Triaiditya et al., 2018). The attacker lowers his centre of gravity while extending his stance, lunging toward his opponent and sticking his punch arm forward, executing a punch in the opponent's exposed and unattended abdomen. Participants must relax to maintain their stance and balance (Venkatraman & Nasiriavanaki, 2019).

Figure 11

Players who use stance on Ojhung

A double increase in punch speed will takes twice as much energy to make it happen in the first place. Punching is studied as a kinetic link principle in which the movement of the joint occurs sequentially. The kinetic link principle is the idea that body parts work together in a chain during movement. It means starting with movement in the center of the body and then moving outward to create smooth and efficient motion, helping to perform better and avoid injuries. The next distal joint's peak speed exceeds the previous proximal joint. Due to their greater mass, the torso and pelvis have stronger moments of inertia during rotation (Hellström, 2009). The larger muscles linked to this joint contract during movement and peak in angular velocity before the following segment. After attaining their maximum contraction, these muscles relax and transmit it to the following distal section. The muscles involved in a fist punch to understand the role of the main individual muscles in a blow. It was found that the gastrocnemius is the first muscle activated during a blow due to moving the body forward with *plantarflexion* [the movement of pointing our toes downward, away from our shin]. Rectus femoris and biceps femoris are activated subsequently to extend the knee and hip. This is followed by the trapezius, deltoid, and biceps brachii muscles to flex the elbow immediately, followed by an elbow extension performed by the brachial triceps and a radial *carpi flexor* in the forearm to execute the blow (Leung et al., 2015). Like *Ojhung*, players must provide high speed to provide a powerful lash so that the kinetic energy is also high.

Kinetic Energy Causing Skin Wound

Simply, kinetic energy is the energy of an object that is affected by its motion, meaning that objects that move must have and be able to impart energy. When a player whips a *lapalo* at an opponent, it means that the moving *lapalo* has kinetic energy because it has two components: mass and acceleration, which are the basis of the kinetic energy equation (Serway & Jewett, 2014).

$$K = \frac{1}{2} \times m \times v^2 \quad \dots (6)$$

The greater the kinetic energy delivered to the opponent, the greater the frictional force between the lapalo and the skin. Friction can occur when a player hits the *Lapalo* with a rough surface against the skin with a smooth surface. The more uneven the surface of the object, the greater the friction force and vice versa (Taylor, 2022). The size of the friction force is what causes the skin to become inflamed or bruised when hit by a *Lapalo*. In other words, players lashed out from the opponent's *Lapalo* will certainly get deformations on their skin in the form of injuries. The skin is our body's first line of defence against the external environment and acts as the primary and essential physical interface. After the *Ojhung* player's body is injured, the wound will undergo a healing process that goes through four processes: haemostatic, inflammatory, proliferative, and remodelling (Yang et al., 2022).

The Relevance of Science Concepts in *Ojhung* with the *Merdeka* Curriculum

The relevance of the concept of science in *Ojhung* to a *Merdeka* curriculum can be seen in Table 2 as quoted from the Decree of the Board of Education Standards, Curriculum, and Assessment, Ministry of Education, Culture, Research, and Technology Number 008/H/KR/2022 concerning Learning Outcomes in Early Childhood Education, Primary and Secondary Education Levels in the *Merdeka* Curriculum (Kementerian Pendidikan Kebudayaan Riset dan Teknologi, 2022). This relevance was also formulated based on the results of FGDs with experts and practitioners.

Table 2

The relevance of the science concepts in Ojhung to the Merdeka curriculum

Subject	Learning Outcomes According to the *Merdeka* Curriculum	Science Concept in *Ojhung*
IPAS (Natural and Social Sciences)	Learners can identify the organisational system of living beings and outline the relationship between organ systems and their functions and abnormalities or disorders that appear in certain organ systems (digestive, circulatory, respiratory, and reproductive systems).	Sense of Hearing in *Okol*, Muscles in Stance Movements, Skin Wound after Being Lashed by Lapalo
	Learners can describe and measure a variety of motions and forces, understand the relationship between the concepts of effort and energy, measure the amount of temperature caused by the heat energy given, as well as can distinguish between insulators and heat conductors.	Newton's Third Law and Pressure in *Lapalo*, Kinetic Energy, Heat

Subject	Learning Outcomes According to the *Merdeka* Curriculum	Science Concept in *Ojhung*
	Learners understand motion, force and pressure, including simple machines. They understand vibrations and waves, reflection and refraction of light, and simple optical tools often used in everyday life.	Newton's Third Law and Pressure in *Lapalo,* Sound waves in *Okol,* light
Physics	Learnerss can apply the concepts and principles of vectors, kinematics and dynamics of motion, fluids, symptoms of sound waves and light waves in solving problems, as well as applying the principles and concepts of heat and thermodynamics with their various changes in heat machines.	Newton's Third Law, Pressure, and Flexibility and Elasticity in *Lapalo*; Moment of Inertia in Stance Movements, Sound Waves in *Okol,* and Kinetic Energy
Biology	Learners can describe the relationship between organ structures in organ systems and their functions and abnormalities or disorders that arise in those organ systems; understand the function of enzymes.	Sense of Hearing

Conclusion and Implications

The *Ojhung* tradition presents scientific concepts including Newton's Third Law, sound waves, sense of hearing, pressure, flexibility, body muscles, moments of inertia, and skin wounds. Newton's Third Law on *Ojhung* is when the player gives the whip a boost to attack the other player, then gives the force to resist the attack from the first player. Sound waves and the sense of hearing are invoked by the accompaniment sound of traditional musical instruments, such as the *okol* orchestra, whose musical equipment consists of *ghambang* and *dhuk-dhuk*, is successfully heard by people around it. This is because it utilises the principle of sound waves that propagate in air. The concept of pressure is invoked by a *lapalo* stroke influenced by force and cross-sectional area. Flexibility relates to the *lapalo* strength in hitting the opponent being affected by the cross-sectional area of the *lapalo* itself. The concept of body muscles and moments of inertia is when players perform stance movements that can strengthen muscles and moments of inertia to attack opponents. The concept of skin wounds and their healing occurs when the affected skin is lashed *lapalo*. All concepts that have been explored can actualise learning outcomes in the *Merdeka* Curriculum.

The limitation of this study is that it relies on indirect observation. Subsequent research should use field data through observation and interviews of *Ojhung* players directly, providing a more holistic and contextual insight into Ojhung culture. This research implies applying science concepts to *Ojhung* to improve people's science literacy. The results of this study can also actualise the *Merdeka* Curriculum because the concept of science in *Ojhung* is relevant to learning outcomes that emphasise everyday life. As a recommendation of this study, future researchers can develop learning instruments, such as teaching modules, teaching materials, worksheets and learning media, which internalize science concepts in the *Ojhung* tradition, improving pupils' understanding of local traditions and motivate them towards preserving this culture. Indigenous knowledge has contributed greatly to the development of modern science and technology, providing insights and practices that have been integrated into various fields. Moreover, indigenous knowledge can function as a learning stimulant to motivate and help learners construct a knowledge framework by offering unique perspectives and methodologies. This culturally rich knowledge base encourages critical thinking, creativity, and a deeper understanding of the natural world, fostering a more inclusive and holistic approach to education. By incorporating indigenous knowledge into the learning process, educators can create a more engaging and relevant curriculum that resonates with diverse student backgrounds and experiences.

Ethical Considerations

Two research committees have reviewed the study and approved it. Researchers have obtained approval from the owner of a YouTube channel, who uploaded a video of *the Ojhung* tradition for exploratory research. The photo of player *Ojhung* in this article is also kept anonymous to maintain his privacy. The participants involved in the FGD had declared their willingness to voluntarily participate in this study. By having their spoken consent declaration, the authors were able to get their voluntary informed consent. The procedures were carried out in accordance with applicable guidelines and regulations.

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The examination of preschool children's environmental attitudes and awareness

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

ABSTRACT
This study aims to examine the impact on environmental attitudes and awareness of kindergarten pupils of an intensive education programme based on basic science process skills including the 'reduce, reuse and recycle (3Rs)' paradigm for preschool children. A quasi-experimental pattern with non-equivalent pretest-posttest and with a control group was used. The study was carried out with kindergarten pupils a district located in the Aegean region. The study was conducted with a total of 38 children in four classes, two of them in the experimental group and the remaining two in the control group due to the pandemic conditions. The "Environmental Awareness and Attitude Scale for Preschool Children" was utilised in the study. According to the results obtained in the study, there is a significant difference between the mean scores of the pretest and posttest of the experimental group. In addition, it was found that the mean of posttest scores of the experimental group was significantly higher than the mean of posttest scores of the control group.

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Introduction

The causes and consequences of environmental problems which cause alarm danger bells to ring and which pose great risks to human beings have become discussion topics all over the world. Stakeholders such as schools and universities should be involved in remediation of environmental disasters (Wiyatmi, Suryaman, Sari and Dewi, 2023). The raising of generations who sensitively handle ecological problems and are sensitive towards the environment may bring about a more liveable world. This can be achieved with a strong, efficient and systematic education.

All the efforts and activities that people make to live a healthy life, to better know and protect the environment in which they live are imparted by environmental education or education for the environment (Koçak, n.d.). Observation of environmental conditions and local cultures contributes to a better understanding of science concepts, environmental protection and increased environmental awareness (Khusniati, Heriyanti, Aryani, Fariz and Harjunowibowo, 2023). Environmental science is the field of science that investigates the interactions of living things with their environment and each other (Uşak, 2015). Environmental education is based on protecting and improving nature, natural resources and the entire environment (Koçak, n.d.). In addition to taking measures to protect the environment, it is a necessity to educate people to become environmentally conscious and knowledgeable about environmental subjects (Balkan Kıyıcı, 2009). The effect of environmental education given in the early periods may last for a lifetime (Onur, Çağlar and Salman, 2016). The necessity of providing environmental education in the preschool period is emphasised by various researchers (Essa and Young, 2003; Ahi and Alisinanoğlu, 2016; Vadala, Bixler and James, 2007; Buldur and Ömeroğlu, 2021).

Sabo (2010) stated that environmental education given in early childhood has prospective gains and affects individuals' attitudes towards the environment in adulthood. The environmental education given to children at an early age:

- allows children to have positive experiences about nature (Erol, 2016);
- supports aesthetic development areas by strengthening the development of children in all aspects (Erol, 2016);
- contributes to the development of awareness, sensitivity (Erol, 2016) and attitude of children (Erten, 2004; Erol, 2016) about the environment;
- enables children to become environmentally responsible and respectful citizens (Erol, 2016).
- supports the moral development of children along with cognitive, affective, psychomotor, social and self-care development areas (Erten, 2004);
- develops children's problem solving, critical thinking and decision-making skills (Louv, 2012).

The general purpose of environmental education is to provide individuals with the necessary knowledge and skills to protect and improve the environment by shaping their understanding and beliefs about the environment (Moseley, Desjean-Perrotta and Utley, 2010). In the Belgrade charter (1975), the purpose of environmental education is stated as follows: "The aim of environmental education is to constitute a world population, which is aware of environmental and environmental problems, and is worried about the environment, and that has the knowledge, skills, attitude, commitment, and motivation to work individually and collectively toward solutions of existing problems and the prevention of new ones." (UNESCO, 1975, p 3).

It has been stated that children need learning experiences that they can experience on their own, which will improve their sensory development with science activities appropriate for their age and development (Tasdemir and Yildiz, 2024). With environmental education, children's ability to perceive and understand their environment, as well as their sensory development, will be enhanced. It has been stated that that the attitudes and beliefs of children who receive education at an early age are necessary for them to lead a better life (Sabo, 2010). It is clear that the teacher has an important role in early environmental education. It is recommended that environmental education be integrated into multiple disciplines, that building environmental consciousness in individuals be prioritised, and that teachers should develop environmental awareness as well (Yüzüak and Erten, 2022). According to Ormancı and Çepni (2019), teachers play a crucial role in providing efficient science education during preschool. This is also the case for environmental education.

Attitude towards the environment is defined as the sum of negative thoughts such as fear, anger, and anxiety caused by environmental problems and positive thoughts such as value judgments and environmentally friendly actions such as readiness to solve environmental problems (Erten, 2004). Environmental knowledge and attitudes towards the environment begin to take shape at the preschool age (Taşkın and Şahin, 2008). Erol and Ogelman (2021) stated that the positive attitudes and behaviours acquired about the environment in the preschool age are also maintained in the later stages and that these attitudes guide the behaviour of people. Similarly, Robertson (2008) stated that environmentally sensitive people who are aware of their environment from an early age and display protective behaviours towards the environment maintain these attitudes and behaviours in the future periods of their lives. DeVille et al. (2021) stated that the total time spent in nature provides connectedness to nature and, as a result, leads to better environmental attitudes and behaviours. Better environmental behaviours is important in preventing environmental problems. Sabo (2010) stated that most of the children have an innate love and interest towards nature. This is a phenomenon that helps to deal with environmental problems. The most effective way to deal with environmental problems is to raise awareness of their causes and consequences and to create a positive attitude towards the environment (Gürbüz, Kışoğlu and Erkol, 2007).

Environmental pollution has occurred as a result of the negative behaviours of people towards the environment for many years, and as a result of this situation, the concept of environmental awareness has begun to be promoted (Gülay and Önder, 2011). Başal (2015) has expressed environmental awareness as avoiding behaviours that will harm nature, realising that human beings are a part of nature. Dindar (2021), defines ecological awareness as being aware of the impact of human behaviour on the environment. Individuals with ecological awareness avoid harmful behaviour. However, there may be various reasons why environmental awareness is not reflected in attitudes and behaviours (Cappellaro, 2011). The transformation into positive attitudes and behaviour of environmental awareness is possible with systematic environmental education given at an early stage. Teaching materials should focus on the problems that learners face in everyday life (Lutfauziah, Al Muhdhar and Rohman, 2023). The issue of environmental pollution has now become a problem that children face very often in their lives.

Decisions such as creating new behaviour patterns towards the environment for society and raising environmental awareness involve a learning process that should be realised at all levels of education and continue throughout life. (Thor and Karlsudd, 2020). While transferring information about the environment, it is also aimed to transform them into attitudes and behaviours (Geçmiş and Salı, 2014). Raising individuals with environmental awareness along with environmental protection behaviours is among the main objectives of environmental education (Erol, 2016; Erol and Ogelman, 2019).

Başal (2015) stated that scientific thinking skills of the children will be supported as a result of learning by doing and experiencing about environmental subjects and having direct experiences with the environment. Buhan (2006) stated that observing and classification skills, which are among the basic science process skills, are gained by children in an entertaining way through environmental subjects. The environmental education activities in the pre-school period should accordingly be planned and conducted in a way that will attract children's attention, develop their communication skills, enable them to learn by doing and experiencing and gain them basic science process skills.

Literature Review

There are studies examining the effects of different educational interventions on environmental attitudes and awareness in the literature. Masykuroh, Yetti, Nurani, and Rahmawati (2024) examined the effects of the Sasami Program on environmental literacy, environmental awareness and attitude in early childhood education in their study. In the study, it was concluded that the implementation of the Sasami Programme, which includes ecological literacy such as sorting garbage, "reduction, reuse, recycling" (3Rs), gardening, animal love, teaches environmental literacy, environmental knowledge, environmental awareness and attitude value. Christidi and Christopoulou (2022) aimed to raise the environmental awareness of kindergarten pupils who were involved in educational robotics and STEAM education activities. The research revealed that young children developed and acquired knowledge of programming and algorithmic thinking in a playful way through the use of the educational robot and managed to develop their cognitive, environmental awareness and communication skills. Küpeli (2023) investigated the effect of the quality of preschool outdoor education environments on the environmental attitudes and awareness of 60–66-month-old children and their levels of affinity to nature (biophilia). It was concluded that the quality of outdoor educational environments has a significant effect on children's environmental awareness and attitudes and their affinity to nature. Tan and Güler (2024) investigated how practical recycling activities in preschool (60-72 months) affected children's recycling and environmental awareness. As a result of the research, it was observed that children's environmental awareness changed positively and they especially paid attention to the integrity of nature with living beings. Vukadin (2022) investigated to what extent theme-based outdoor activities can improve the environmental awareness of kindergarten pupils. According to the results, theme-based outdoor activities proved to be an effective approach to developing environmental awareness. There are also studies in the literature that handle the environment from different perspectives. Kang, Ko, and Park (2012) achieved positive results in the sub-dimensions of environmental life attitude, resource recycling, attitude towards environmental protection, and awareness in the experimental group in which they applied the nature-friendly environmental education programme. Kabadayi and Altınsoy (2018) concluded that there was a significant increase in the environmental pollution awareness post-test scores of the group to which science and nature activities were applied. Ruiz-Mallen, Barraza, Bodenhorn and Reyes-García (2009) concluded in their study that the environmental protection awareness of the children in the group in which they applied the environmental education program designed for forestry increased. It is seen in these studies in the literature that positive results are obtained in groups where different educational interventions are applied.

As can be seen from the literature review, no any study has been found that handle basic science process skills and environmental issues together in early childhood. Ormancı and Çepni (2019) stated that it is important to conduct new studies in areas that have not been studied regarding science education in the preschool period. Handling environmental education within the scope of science in the preschool period based on scientific process skills is a novelty in this context. It is also thought that the materials used and the activities applied will add innovation to the literature. The activities prepared based on basic science process skills, including reduction, reuse, recycling (3Rs) and environmental issues towards cognitive development set this study apart from other studies. All of these reveal the significance of the study. The research was carried out to examine the effect of an intensive education program on the environmental attitudes and awareness of preschool children. In line with this purpose, the research sought answers to the following questions:

1. Is there a significant difference between the environmental attitudes and awareness pretest-posttest scores of the children in the experimental and control groups?
2. Is there a significant difference between the environmental attitudes and awareness post-test scores of the children in the experimental and control groups?

Methods

The research is quantitative quasi-experimental with non-equivalent pretest-posttest and with a control group. In this model, children are not randomly assigned to groups. Since the classes were prepared in advance by the school administration, and so it was randomly decided which groups would be experimental and control groups (Özmen and Karamustafaoğlu, 2019). The prepared education programme will be briefly expressed as an intensive education programme. The intensive education program prepared by the researcher for preschool children based on basic science process skills, including the "reduction, reuse, recycling" (3Rs) environmental paradigm was applied to the experimental group. The data of the study were collected in the spring semester of the 2020-2021 academic year. "The Environmental Awareness and Attitude Scale for Preschool Children" developed by Büyüktaşkapu Soydan & Öztürk Samur (2017) was used in the study. The scale consists of two sub-dimensions: "Environmental Awareness" (12) and "Environmental Attitude" (14). The dependent variable is the "Environmental Attitudes and Awareness" of preschool children, and the independent variable whose effect is examined is the "Intensive Education Programme (IEP)" developed by the researchers. The schematic design of the research is shown in Table 1.

Table 1

Quasi-Experimental Pattern Non-Equivalent Pretest-Posttest and with a Control Group

Study of Groups	Pretest	Process	Posttest
Experimental	Environmental Awareness and Attitude Scale for Preschool Children	The Intensive Education Programme Including Activities Based on Basic Science Process Skills Covering Reduction, Reuse and Recycle (3Rs) Environmental Issues	Environmental Awareness and Attitude Scale for Preschool Children
Control	Environmental Awareness and Attitude Scale for Preschool Children	2013 the Pre-School Education Programme of Ministry of National Education (MEB)	Environmental Awareness and Attitude Scale for Preschool Children

Data Collection Tool

The scale developed by Büyüktaşkapu Soydan & Öztürk Samur (2017) consists of two sub-dimension, environmental awareness (12) and environmental attitudes (14), and a total of 26 items with pictures. In order to measure the validity of the scale, factor analysis was performed and the correlation coefficients between the subscales was determined. The correlation coefficients between the factors of the Environmental Awareness subscale were $r = 0.80$, 0.78 and 0.83 and for the Environmental Attitudes subscale were $r = 0.70$, 0.79 and 0.72 respectively. While the three factors in the environmental attitude sub-dimension explain 44.02% of the total variance, the three factors in the environmental awareness sub-dimension explain 40.94% of the total variance. Cronbach's alpha reliability coefficient for the environmental attitude sub-dimension and the Cronbach's alpha reliability coefficient for the Environmental awareness sub-dimension were found to be .73 and .66, respectively. The Cronbach alpha reliability coefficient for the entire scale was found to be .67 (Büyüktaşkapu Soydan & Öztürk Samur, 2017). In this study, the Cronbach's alpha reliability coefficient for the environmental awareness sub-dimension and the Cronbach's alpha reliability coefficient for the environmental attitude sub-dimension were found to be .68 and .80, respectively. The Cronbach alpha reliability coefficient for the entire scale was found to be .60.

Participants

The study group consists of preschool children and their teachers attending kindergarten education in a province in the Aegean region. Due to the pandemic conditions, the research was carried out with a total of 38 students in four classes, two of which were in the experimental group and the remaining two classes in the control group. There are 19 children in each of the experimental and control groups. Information about the gender of the children in the experimental and control groups is given in Table 2.

Table 2

Information on the Gender of Experimental and Control Children

Gender	n	%
Female	12	13
Male	7	6
Total	19	19

Intensive Educational Programme

The intensive education programme used in the study aimed to raise awareness and develop positive attitudes in children about the environment, as well as to develop their basic science process skills. There are activities prepared based on basic science process skills, including the 'reduction, reuse, recycling (3Rs)' paradigm and environmental issues. The activities require children to use basic science process skills, including observing, measuring, inferring, predicting, classifying, data recording and communicating, and to interact with various materials. During the activities in the program are used waste paper, pulp, fruit kernels, liquid soap container, empty container, spoon, tongue stick, used solid soap pieces, branch-wood pieces, waste materials, grater, funnel, etc. materials. Cognitive development gains and indicators of the intensive education program were adapted according to the literature research (Büyüktaşkapu, 2010) and 2013 preschool education programme. There are a total of 27 activity plans in the intensive educational programme. Activities include issues such as environmental pollution, energy efficiency, love of nature, preventing unnecessary consumption of resources, efficient use of resources, environmental awareness, thrift, waste and climate change. There are a total of 27 activity plans integrating with activity such as drama, art, music, mathematics, Turkish literacy preparation, science and play.

The activities were vetted by five experts working in pre-school education, science education and the environment, and were revised in accordance with the feedback from the experts.

Educational Activities Applied to the Control Group

Control group teachers implemented the activities prepared according to the acquisitions in the Ministry of National Education Preschool Education Programme updated and implemented in 2013. This is a developmental programme prepared for children aged 36-72 months. When planning learning processes, achievement and indicators appropriate to children's developmental levels are taken into account (MEB, 2013). The preschool education programme is flexible and is suitable for adaptation and individualisation according to the changing characteristics of the child, family and physical environment (MEB, 2013). The programme gives freedom to the teacher (MEB, 2013) which is why the activities implemented in kindergartens vary. The activities to be implemented in the control groups were examined weekly by the researcher. On the days when the activities were to be carried out, the researcher and the classroom teachers came together and reviewed the day's activities together prior to implementation. When the activities implemented in the control group during the implementation period (Nine weeks) were examined, it was seen that environmental activities were treated within the scope of special days and weeks (Energy Thrift Week, Forest Week, World Water Day). In addition, there are activities that are also handled within the scope of preschool values education (an activity for environmental cleaning, an activity for thrift and wasting, an activity for nature love). An activity related to recycling was also implemented.

Experimental Procedure

Three of the 27 activity plans included in the intensive education programme were randomly selected and applied by skipping a day for a week in a different classroom where the experimental and control group students were not included. The school administration, classroom teachers, and parents were informed about the research. Parent consent forms were obtained from families for the research. The activities were applied to the experimental group three days a week for nine weeks (Monday, Wednesday, Friday). Information about the intensive training programme is given in Table 3. On other days when the intensive education programme was not implemented, the activities of the Ministry of National Education Preschool Education Programme (2013) were implemented by their own classroom teachers. During this process, the activities of the official curriculum were continued in the control group, and no experimental procedures were applied. Before starting the program implementation, the "Environmental Awareness and Attitude Scale for Preschool Children" was applied as a pretest to the children in the experimental and control groups. After the applications were completed, the "Environmental Awareness and Attitude Scale for Preschool Children" was applied as a posttest to the experimental and control groups.

Table 3

Distribution of Reduction, Reuse and Recycling and Basic Science Process Skills in Activities

Activity	Distribution of Basic Science Process Skills in Activities	3Rs (Reduce, Reuse and Recycle) Environmental Issues in Activities	Duration of the Activity (The duration of an activity is 50 minutes)	Activities weeks
1. Activity	Classifying, Predicting, Data Recording and Communicating	Recycle	Two activity hours	First week
2. Activity	Classifying, Inferring, Predicting, Measuring, Data Recording and Communicating	Recycle	Two activity hours	First week
3. Activity	Inferring, Data Recording and Communicating, Classifying, Predicting	Reduce	Two activity hours	First week
4.Activity	Inferring, Classifying, Predicting, Data Recording and Communicating	Reuse	Two activity hours	Second week
5. Activity	Classifying, Predicting, Data Recording and Communicating	Recycle	Two activity hours	Second week
6. Activity	Inferring, Predicting	Reuse	Two activity hours	Second week
7. Activity	Inferring, Classifying, Predicting	Reuse	Two activity hours	Third week
8. Activity	Observing, Classifying, Predicting, Measuring, Data Recording and Communicating	Reuse	Two activity hours	Third week
9. Activity	Observing, Classifying, Measuring, Data Recording and Communicating	Reuse	Two activity hours	Third week
10. Activity	Observing, Predicting, Inferring, Classifying, Data Recording and Communicating	Recycle	Two activity hours	Fourth week
11. Activity	Predicting, Inferring, Classifying, Measuring, Data Recording and Communicating	Reduce	Two activity hours	Fourth week
12. Activity	Observing, Predicting, Inferring, Classifying, Data Recording and Communicating	Reuse	Two activity hours	Fourth week
13. Activity	Inferring, Predicting, Data Recording and Communicating	Recycle	Two activity hours	Fifth week
14. Activity	Inferring, Predicting	Recycle	Two activity hours	Fifth week
15. Activity	Inferring, Classifying, Measuring, Data Recording and Communicating	Reduce	Two activity hours	Fifth week
16. Activity	Inferring, Predicting, Data Recording and Communicating	Reuse	Two activity hours	Sixth week

17. Activity	Predicting, Inferring, Classifying, Measuring, Data Recording and Communicating	Recycle, Reuse	Two activity hours	Sixth week
18. Activity	Observing, Predicting, Inferring, Classifying, Data Recording and Communicating	Reduce	Two activity hours	Sixth week
19. Activity	Inferring, Observing, Predicting, Classifying, Data Recording and Communicating	Reduce	Two activity hours	Seventh week
20. Activity	Inferring, Observing, Classifying, Predicting	Reuse	Two activity hours	Seventh week
21. Activity	Observing, Inferring, Predicting, Data Recording and Communicating	Reduce	Two activity hours	Seventh week
22. Activity	Inferring, Data Recording and Communicating, Predicting	Reuse	Two activity hours	Eighth week
23. Activity	Observing, Inferring, Data Recording and Communicating, Predicting	Reduce	Two activity hours	Eighth week
24. Activity	Inferring, Classifying, Measuring	Reduce, Reuse	Two activity hours	Eighth week
25. Activity	Inferring, Data Recording and Communicating, Predicting	Reduce	Two activity hours	Ninth week
26. Activity	Observing, Inferring, Data Recording and Communicating, Classifying, Predicting, Measuring	Recycle	Two activity hours	Ninth week
27. Activity	Observing, Inferring, Data Recording and Communicating, Classifying, Predicting	Recycle	Two activity hours	Ninth week

Data Analysis

In the study, skewness and kurtosis coefficients were examined for the normality condition. The fact that the skewness and kurtosis coefficients are between + 2 and - 2 indicates that the data are normally distributed (George & Mallery, 2010). According to skewness/kurtosis values, it was seen that the scores obtained from the sub-dimensions of the scale and the whole scale showed a normal distribution. Therefore, parametric tests were used for statistical computations. In the study were used the *t-test* for independent samples, the *t-test* for the dependent sample, and covariance statistical analysis methods.

Findings

The Skewness and Kurtosis coefficients for the experimental group were -0.479 and 0.406, respectively. In the control group, these coefficients were found to be 0.377 and -0.412, respectively. When the data were normally distributed, dependent sample t-test was used from statistical analysis. According to the t-test results, it was determined that the difference between the pre-test scores of the scale of the experimental and control groups was not significant $t(36) = -1.711$, $p>0.05$.

Findings Regarding the First Research Question of the Study

Is there a significant difference between the environmental attitudes and awareness pretest-posttest scores of the children in the experimental and control groups?

Experimental Group

The post-test Skewness and Kurtosis coefficients of the experimental group were found at -0.743 and 0.193, respectively. The dependent sample t-test, which is one of the statistical analyses, was used in the study. According to the dependent sample t test, it was found that the scale pretest mean score of the experimental group was 1.44, the posttest mean score was 1.70, and the t value was -5.725. Therefore, the difference between the environmental awareness and attitude pretest and posttest mean scores of the experimental group was found to be significant in favour of the posttest ($p<0.05$).
The results of the dependent sample t-test related to the differentiation of the experimental group environmental attitude sub-dimension pre-posttest score mean were computed. Accordingly, the environmental attitude sub-dimension pretest mean score of the experimental group was 1.60, the posttest mean score was 1.71, and the t value was -1,714. Although the posttest mean scores of the experimental group are higher than the pretest mean scores of the experimental group, the difference between the pretest and posttest scores of the environmental attitude sub-dimension of the experimental group are not statistically significant ($p>0.05$). During the application, the experimental group children stated that they choose other answers due to the disease, although they found appropriate answers in some questions related to the environmental attitude sub-dimension questions. (for example; when asked whether they would pick up the rubbish they saw on the ground and throw it in the rubbish bin, the children stated that they could not touch the rubbish because there was an epidemic).

The results of the dependent sample t-test related to the differentiation of the experimental group environmental awareness sub-dimension pre-posttest mean scores were computed. Accordingly, the environmental awareness sub-dimension pretest mean score of the experimental group was 1.23, the posttest mean score was 1.70, and the t value was -8.688. The difference between the environmental awareness sub-dimension pre-posttest mean scores of the experimental group was found to be significant in favour of the posttest ($p<0.05$).

Control Group

The post-test Skewness and Kurtosis values for the control group were found 0.42 and -1.522, respectively. Since the data were distributed normally, the dependent sample t-test, which is one of the parametric tests for the differentiation of the pre-posttest mean scores of the control group, was used. According to the dependent sample t test, it was found that the scale pretest mean score of the control group was 1.53, the posttest mean score was 1.49, and the t value was 0.883. According to the dependent sample t test results, no significant difference between the pre-posttest mean scores of the control group arose ($p > 0.05$).

The results of the dependent sample t-test related to the differentiation of the control group environmental attitude sub-dimension pre-posttest score means were computed. Accordingly, the pretest mean score of the environmental attitude sub-dimension of the control group was 1.68, the posttest mean score was 1.64, and the t value was -.392. The difference between the environmental attitude sub-dimension pre-posttest mean scores of the control group was not significant ($p > 0.05$).
The results of the dependent sample t-test related to the differentiation of the control group environmental awareness sub-dimension pre-posttest score means were computed. Accordingly, the control group environmental awareness sub-dimension pretest mean score was 1.33, posttest mean score was 1.28, and t value was .444. The difference between the environmental awareness sub-dimension pre-posttest mean scores of the control group was not significant ($p > 0.05$).

Findings Regarding the Second Research Question of the Study

Is there a significant difference between the environmental attitudes and awareness post-test scores of the children in the experimental and control groups?

Since the covariance analysis assumptions were met and the data were normally distributed, it was decided to perform covariance analysis. Analysis of covariance was performed to determine whether there was a significant difference between the post-test scores of the experimental and control groups. For the covariance analysis were considered as a control variable (covariate) the preschool environmental awareness and attitude pretest scores.

When the posttest mean scores corrected according to the covariate are examined, there is a significant difference between the posttest scores of the experimental and control groups (F=1.35) = 18.066, p = 0.000). According to the Eta square values, it is seen that being in the experimental group explains 34.0% of the variability of the post-test scores, independent of the pre-test scores ($\eta 2$ = 0.340). When the effect of environmental attitude sub-dimension pre-test scores are controlled, there is no a significant difference between the environmental attitude sub-dimension post-test scores of the experimental group and the control group (F=1.35) = 0.541, p = 0.467). When the effect of environmental awareness sub-dimension pre-test scores are controlled, there is a significant difference between the environmental awareness sub-dimension post-test scores of the experimental group and the control group (F=1.35) = 19.510, p = 0.000). When the Eta square values are examined, it is seen that being in the experimental group explains 35.8% of the variability of the post-test scores, independently of the pre-test scores ($\eta 2$ = 0.358).

Discussion, Conclusion and Recommendations

The purpose of the research was to examine the effect of the intensive education programme on preschool children's environmental attitudes and awareness. In the study, it was determined that the difference between the environmental attitude and awareness pre-test score averages of the experimental and control group children was not significant. Therefore, at the beginning of the study, it could be stated that the children in the experimental and control groups were on a par in terms of environmental awareness and attitude.

The difference between the pre-test and post-test mean scores obtained from the scale for the experimental group was found to be significant in favour of the posttest. In addition, there was a significant difference between the pre-test and post-test mean scores for the environmental awareness sub-dimension of the experimental group in favour of the post-test. Although the post-test mean scores for the environmental attitude sub-dimension were higher than the pre-test mean scores, there was no statistical significant difference between the mean scores. In the control group, it was found that the difference between the pretest and posttest mean scores obtained from the entire scale was not significant. Also, environmental attitude and environmental awareness sub -dimensions were not found to differ significantly between pre -test and post -test mean scores. According to these results, it might be said that the experimental group activities were effective more than activities applied to the control group in developing children's attitude and awareness levels. Although the children in the experimental group knew the appropriate answers to some questions related to the environmental attitude sub-dimension, they stated that their mothers would not allow them due to the disease (Some of the children stated that their mothers told them not to touch the rubbish they saw on the ground due to the covid 19 epidemic). This may be the reason why there is no significant difference in environmental attitude sub-dimension scores. In other words, the fact that the application coincided with the epidemic period may have caused no significant difference in environmental attitude sub - dimension scores. In his study of Samur (2018) on the TEMA preschool programme, the difference between the score’s environmental awareness and attitude scale for preschool children of the experimental group children was found to be meaningful in favour of the posttest. In addition, for the experimental group, while the difference between the pre-test and post-test scores in the environmental awareness sub-dimension was significant, the difference between the pre-test and post -test scores in the sub -dimension of the environmental attitude was not significant. In the study conducted by Buldur & Ömeroğlu (2021), a significant difference was found between the environmental awareness and environmental attitude pre-test and post-test scores for the experimental group in favour of the post-test. In the control group, there was no significant difference between the pretest and posttest scores of both environmental attitude and environmental awareness sub-dimension. In another study conducted with preschool children (Okyay, Sayın, Güneş Demir & Özdemir, 2022), a significant difference was found between the pre-test and post-test scores in both environmental attitude and environmental awareness sub-dimensions in the application group. Although environmental attitude post-test scores increased, there are also studies in the literature in which there is no statistically significant increase (Samur, 2018; Yılmaz, Yılmaz Bolat & Gölcük, 2020). These results are similar to the study. In the literature, there are studies in which similar results to the results of this study were obtained in the sub-dimension of environmental awareness (Tanriverdi, 2012; Akbayrak & Kuru Turaşlı, 2017; Samur, 2018; Buldur & Ömeroğlu, 2021; Okyay et al., 2022; Kurt Gökçeli, 2022; Maciel, Fuentes-Guevara, da Silva Gonçalves, Mendes, de Souza & Corrêa, 2022), as well as there are also studies in which different results were obtained from this study in the sub-dimension of environmental attitude (Schneller, Johnson & Bogner, 2015; Koçak Tümer, 2015; Uslucan, 2016; Erol & Ogelman, 2021; Buldur & Ömeroğlu, 2021).

When the environmental attitude and awareness post-test mean scores of the experimental and control group children were examined, it was found that the environmental attitude and awareness post-test mean scores of the experimental group children were significant. When the post-test mean scores of the environmental awareness sub-dimension of the children in the experimental group and the control group were compared, it was seen that there was a significant difference in favour of the experimental group. In terms of environmental attitude sub-dimension post-test mean scores, the difference between the post-test mean scores of the experimental and control groups was not found to be significant. It is believed that the activities applied to the experimental group improve children's attitudes and awareness towards the environment. There are studies in the literature in which a significant difference in environmental attitude and awareness post-test scores in favour of the experimental group was obtained through the implementation of various environmental education programmes (Erol & Ogelman, 2016; Buldur & Ömeroğlu, 2021; Okyay et al., 2022). Dahl (2020) concluded that the mean scores of the children participating in the garden education programme in the environmental awareness and attitude sub-dimensions were significantly higher than the scores of the children in the control group. The results are similar to this study in that the applied educational programme led to a significant increase in the environmental awareness and attitude scores of the experimental group. Biber, Cankorur, Güler and Demir (2023) aimed to examine the environmental awareness and attitudes towards the environment of 5–6-year-old children attending nature-centred private kindergartens and public kindergartens. According to the results of the research, a significant difference was found in environmental attitudes and environmental awareness of children in nature-centred kindergartens compared to children in public kindergartens. The finding of a significant difference in environmental awareness and attitude scores in the group where the educational intervention was carried out is parallel to the results of this study. The fact that the children of the experimental group experienced environmental awareness, environmental attitude, environmental pollution, sustainability, recycling, reduction, reuse (3Rs) and environmental issues in the activities may have contributed to a significant increase in the scores. Maciel et al. (2022) carried out environmental education practices with preschool children. The study aimed to develop an environmental education project in a public school of early childhood education, through the construction of a mobile mandala garden as a pedagogical tool. The construction of a mobile mandala garden for the cultivation of vegetables was used as a pedagogical tool for the development of environmental education practices (pedagogical activities) around the vegetable garden. In the study has been stated that educational practices improve to children's environmental awareness. Data, Mahat, Hashim, and Saleh (2020) concluded that environmental education, conducted with recyclable materials provides children with knowledge about the environment and recycle issues. Being knowledgeable on these issues will hopefully contribute to the development of environmental attitudes and awareness. Environmental education carried out with children contributes to the development of their environmental awareness and attitudes.

Environmental education interventions carried out for a specific purpose can make significant contributions to preschool children. Yang, Wu, Tong, and Sun, (2022) performed a study on narrative-based environmental video education. It was found that the environmental awareness of the experimental group children that conducted narrative-based environmental education was more developed than the control group children, and this case was reflected in their environmental attitudes. Liu, Teng and Han (2020) found in their study that environmental knowledge has a positive effect on environmental attitudes and behaviours. Acquiring environmental knowledge and having experiences with the help of educational programmes and different educational environments provides for achieving the desired results. The fact that children have different experiences regarding the environment through intensive education programme activities can be stated as making positive contributions to their environmental knowledge, environmental awareness and attitudes.

Different studies on the subject can be repeated in different regions and using a decent sized sample. The study is limited to data obtained from the "Environmental Awareness and Attitude Scale for Preschool Children". Environmental attitudes and awareness of early childhood children can be examined according to different variables such as gender, age and parental education level. The study carried out under Covid 19 pandemic conditions can be repeated under normal conditions. Longitudinal studies can be conducted towards preschool children's environmental awareness and attitudes.

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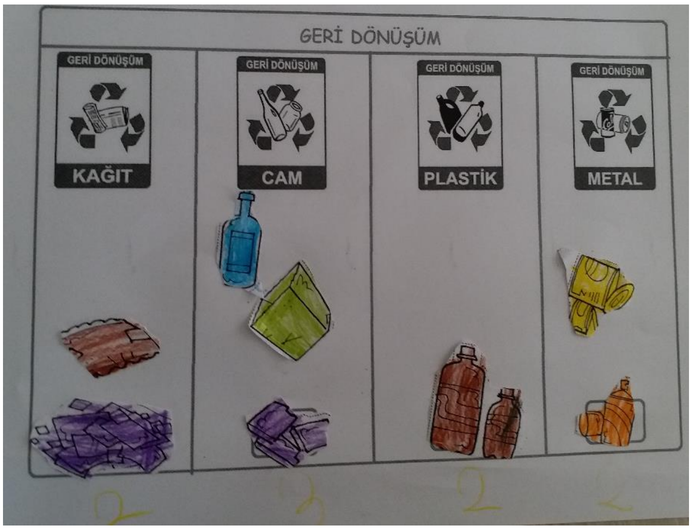
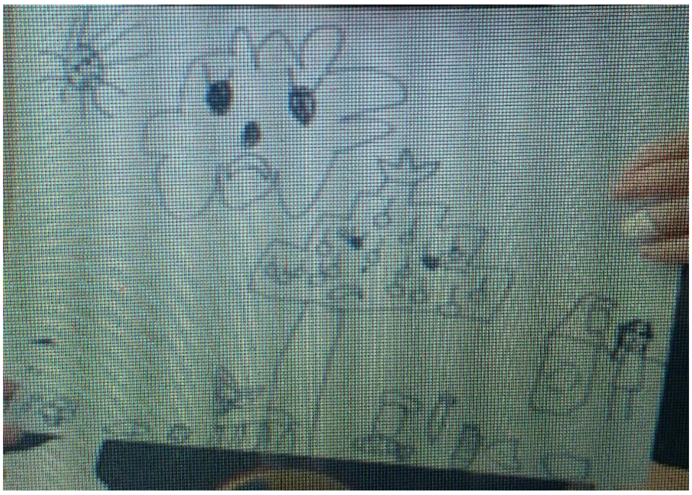
Appendix

Some worksheets related to the activities carried out

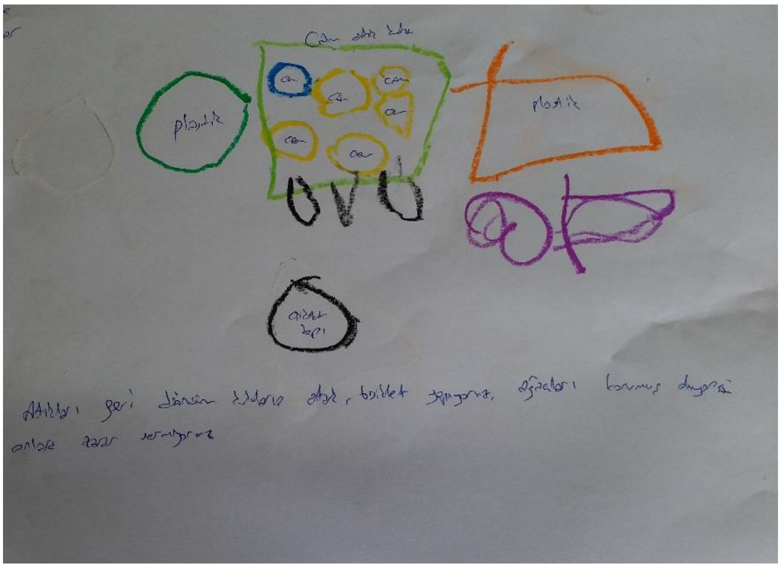


Grouping paper, glass, plastic and metal wastes (Classification)



A picture explaining recycling (data saving)
Child: "Since the waste is thrown on the ground rather than in the recycling bin, the environment is polluted and the trees, clouds and sun are unhappy."

Sock Puppet: The product made regarding reuse by recycling used clothes (inferring

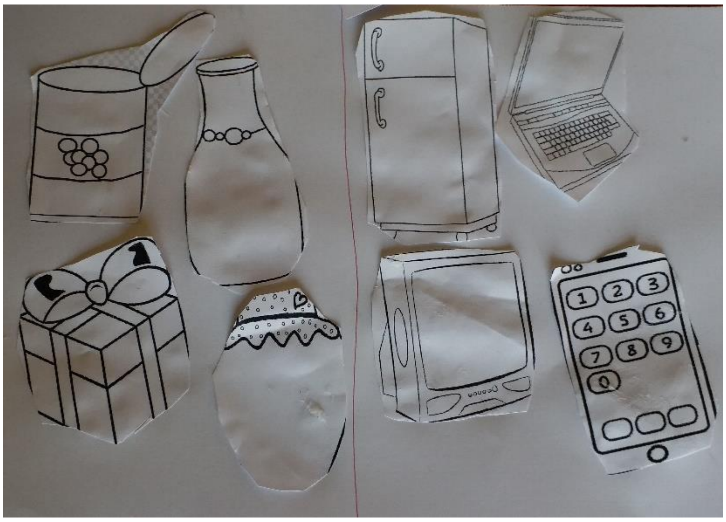


A picture of what can happen by recycling waste (predicting)

Child: "We make bicycles by recycling waste. We protect trees."

Waste collection game: Weight measurement of paper, glass, plastic and metal waste (measuring)

Table showing the weight measurement of waste collected in the waste collection game (measuring)



Distinguishing between things that can and cannot be reused / by repairing (observing)

A picture regarding plastic bag, causing nature pollution (observing)

Child: "I made a live paper bag with a smiley face. A paper bag circulating in natüre."

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The effect of changes in teaching methods on pupils' academic performance in biology

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ABSTRACT
Biology teachers received professional development to effect instructional changes that ensure student cognitive engagement and knowledge acquisition at higher cognitive levels. We asked the following questions: 1) What are the initial needs of teachers to promote active learner engagement and knowledge acquisition at higher cognitive levels? 2) What changes in teaching practice does each form of support trigger? 3) Do supportive and reflection-based professional development succeed in improving pupil academic achievement? Teachers received support in the form of interactive lectures and ready-made examples in the form of a written lesson plan to develop teaching practices that promote cognitive engagement and knowledge acquisition at higher cognitive levels. Throughout the professional development programme, they reflected on the success of their teaching practices derived from the lectures and implemented according to the prepared plans based on feedback. The analysis of video recordings of lessons enabled the collection of feedback, while learning communities facilitated critical discussions. Changes in teaching were monitored and identified through (self-)evaluation of recorded lessons using the Teaching Observation Form (TOF). The impact of the training on students' academic performance was determined using knowledge tests administered before and after the teacher training. Although teachers made positive changes in their teaching, these did not lead to an improvement in students' academic performance.

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Introduction

The intent of this paper is to support the critical discourse on professional development and perspectives on the complex construct of professional development (Mooney Simmie et al., 2024), where what matters is not only whether certain changes are elicited in teachers, but also whether these changes have a significant impact on pupil learning (Desimone, 2023). In today's world of uncertainty, "teachers need to engage in development processes throughout their lifetime, to be accountable for their practices, and to use and draw from research, counter-intuitive knowledge, and evidence as valuable contributions to their thinking, to their practices and to their professional development" (Mooney Simmie, 2023, p. 917).

It is not easy to give a clear answer to the question of what constitutes effective professional development. Several pieces of research (e.g. Desimone, 2009; Darling-Hammond et al., 2017; Dunst et al., 2015) have highlighted a number of characteristics of effective teacher professional development: focusing on learners' understanding of subject matter and how they learn that content, facilitating active engagement, encouraging collaboration with other teachers, aligning with established curricula and school policies, and delivering learning sessions of appropriate duration to allow for practice and feedback. Recently, such "lists" of characteristics of effective professional development have been criticised. Research on the effectiveness of professional development that includes the aforementioned characteristics provides conflicting results, suggesting that the education field does not have a coherent, cohesive vision of what makes professional development programmes effective (Desimone, 2023). Furthermore, Asterhan & Lefstein (2024) note that the consensus on the key features of effective professional development is not based on solid evidence from large-scale, replicated and rigorously controlled research studies. Hill et al. (2022) criticise the empirical research on which the consensus on a core set of characteristics is based. Yang et al. (2020) were unable to confirm the effectiveness of the established characteristics of effective professional development on pupil learning in their study. Asterhan & Lefstein (2024) caution against the ambition to identify general characteristics of effective professional development at all. They believe that it is unrealistic to expect a universal answer to the question of which approach to professional development is effective. It is necessary to focus on understanding the conditions under which change occurs in the classroom (Hayes et al., 2024). The effectiveness of professional development programmes and their implementation depends on a variety of environmental factors, such as teachers' working conditions, instructional materials and other resources, school leadership, and informal processes of teacher learning (Asterhan & Lefstein, 2024). Some successful professional development programmes include peer support and the sharing of experiences (Hill & Papay, 2022). Teachers need to be supported in examining their existing pedagogical beliefs and how they manifest these in the classroom culture (Hayes et al., 2024). Desimone (2023) argues that professional development programmes should focus on helping teachers become experts who can make decisions about what each of their pupils needs. It is important to provide teachers with ongoing mentoring and collegial support to encourage the development of specific professional skills and knowledge and to maintain habits of mind (Graham et al., 2020).

Literature Review

Active learning as a feature of high-quality teaching (Baumert et al., 2010; Förtsch et al., 2016) positively affects learner performance (Dogani, 2023; Neumann et al., 2012;) and is necessary to acquire knowledge at higher cognitive levels. According to Bloom's taxonomy, higher cognitive levels include the processes of understanding, applying, analysing, evaluating and creating according to revised Bloom's taxonomy (Anderson & Krathwohl, 2001). Cognitive activation implies the planned involvement of learners in the teaching and assessment processes, enabling them to master the process of independent learning and self-assessment. It is reflected in the interaction between teachers and pupils by asking questions that promote higher-level cognitive processes. Teachers' questions and feedback positively affect learners' performance (Kyriakides et al., 2013) and contribute to an in-depth understanding of the content by activating their prior knowledge and promoting discussion about the content being learned (Förtsch et al., 2016; Praetorius et al., 2014). In addition to the questions the teacher asks, the questions posed by learners are also important, as is their free expression of ideas and hypotheses and the oral or written expression of understanding of the content being learned. Encouraging learners to engage in the above activities develops the skills of analysis, assessment, and creation, which are higher-level cognitive skills (Aisyah et al., 2018) and include various forms of thinking such as critical, logical, and creative (Mainali, 2012). Metacognitive higher-level thinking processes, which are simultaneously part of the cognitive system (Ristić Dedić, 2019), control the above-mentioned cognitive activities. The described interaction encourages learners to monitor their work and progress and to use metacognitive knowledge and skills, which ultimately helps to practice and master the process of self-assessment. This process is inseparable from the learning process.

More cognitive processes in teaching can be stimulated by active learning methods such as flipped classroom and inquiry-based learning. The flipped classroom is an active learning approach implemented to improve the quality of learning in school (Ozdamli & Asiksoy, 2016). It includes homework in the sense of acquiring the information needed to solve tasks at higher cognitive levels in the classroom (Bergmann & Sams, 2012). At home, learners acquire knowledge at the level of reproduction using materials selected and designed by the teacher, which is then expanded to higher cognitive levels in the classroom. According to Candaş & Altun (2023) and Kurnianto et al. (2019) the flipped classroom improves critical thinking skills and learning outcomes in science and positively impacts motivation for critical thinking.

Inquiry-based learning is a very appropriate strategy for teaching science (Constantinou et al., 2018; Ladachart et al., 2022) and thus biology. It takes place in phases that correspond to the scientific methodology. In the conceptualisation phase, preceded by the orientation phase, pupils pose research questions and hypotheses, then test the hypotheses and draw conclusions (Pedaste et al., 2015). It requires high cognitive engagement and indicates metacognitive skill development (Nunaki et al., 2019). Using these strategies, learners acquire biological factual, conceptual, and procedural knowledge at higher cognitive levels determined by the outcomes of the prescribed subject curriculum.

Rationale, Objectives, Research Questions and Research Design

The teachers involved in our study received support in the form of interactive lectures (first line of support) and ready-made examples in the form of a written lesson plan (second line of support) to develop teaching practices that promote students' cognitive engagement and knowledge acquisition at higher cognitive levels. In addition, they reflected throughout the professional development program based on feedback on the success of their teaching practices derived from the lectures and implemented according to the prepared plans. An analysis of the video recordings of the lessons enabled feedback to be gathered, while learning communities facilitated critical discussions. The described imitates the model of reflective learning, which according to Vizek-Vidović & Vlahović Štetić (2007) comprises several phases. The first phase is the reflection that takes place during the planning and implementation of a particular activity (reflection in action – first level loop). The second phase is a reflection on what has been done and the identification of possible improvements (reflection on action – second level loop). Finally, there is a critical review and reflection on the reflection itself, which is the third level loop, and then the process circles back to the first level (Vizek-Vidović & Vlahović Štetić, 2007). Reflection enables teachers to take an active role in their own professional development, as individuals who monitor, supervise and guide their own professional growth (Labak, 2020).

Fostering pupils' cognitively active engagement during classes should become the central goal of teachers' professional development. In our study, teachers underwent active professional development to effect changes in teaching that ensured learners' cognitive engagement and knowledge acquisition at higher cognitive levels. To guide our research, we asked the following questions:

1. What are the initial needs of teachers to promote active pupil engagement and gain knowledge at higher cognitive levels?
2. What changes in teaching practice does each form of support trigger?
3. Do supportive and reflection-based professional development succeed in improving pupil academic achievement?

It is known that high-quality learning experiences that relate directly to the curriculum and instruction and involve active learning, practice and feedback can lead to changes in teachers' classroom practice. However, it remains uncertain whether these innovative ideas and practices have an impact on pupil learning (Desimone, 2023). Improving pupil learning is the most distant variable in a long causal chain of effects (Asterhan & Lefstein, 2024). Teachers who teach professionally experience changes in their knowledge and teaching skills, which are reflected in the introduction of changes to their teaching methods. During the introduction of these changes, teachers evaluate their effectiveness and modify their teaching practices accordingly. Active pupil engagement and knowledge acquisition at higher cognitive levels require complex learner-teacher interactions that often involve the introduction of major innovations in teaching practices. For new learning strategies to be effective, learners must learn to use them in class, discuss them, reflect on them, and explain under what conditions they are effective (Česi & Ivančić, 2019). While teachers are introducing innovations into their practice, students are at the stage of adopting and practising these innovations and are not yet using them as their typical learning methods. Therefore, in relation to the research questions posed, our hypothesis is that teachers will change their teaching practices. However, we expect that these changes in teaching will not result in improved pupil achievement while professional development is ongoing.

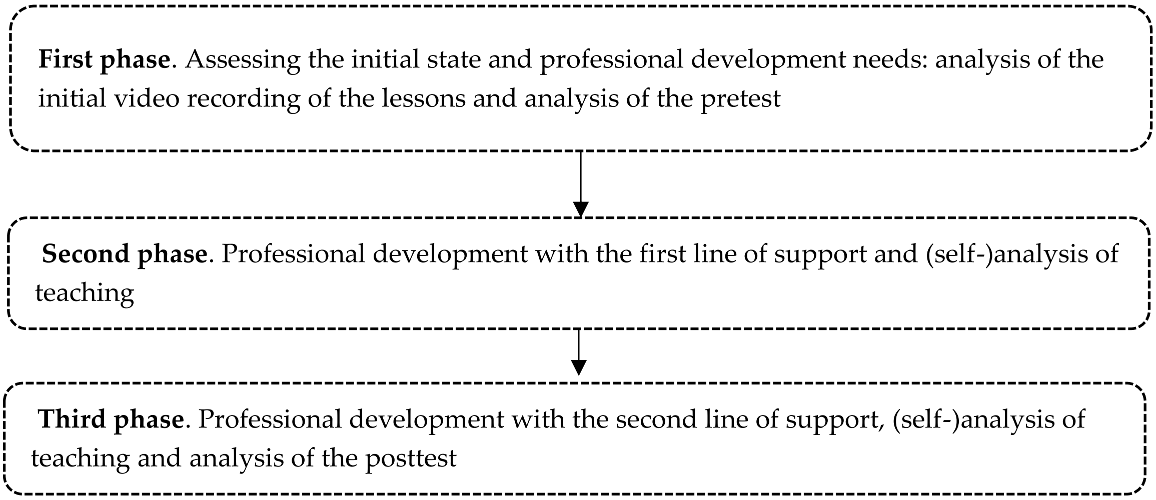
To verify the set hypotheses, we conducted a pretest and posttest before and after the professional development. The results of the posttest were compared with the results of the pretest. It created an experiment with a group where the success of a treatment is determined by comparing the pretest and posttest (Mills & Gay, 2019).

Methods

The research included four biology teachers and their 8th-grade pupils (mean age = 14.1; N = 134). Teachers underwent professional development during the second semester of the 2021/2022 academic year (from February to the end of May). We designed a professional development program that included the three phases listed in Figure 1.

Figure 1

Phases of the professional development program



First Phase

Before the implementation of professional development, one biology lesson was recorded for each teacher. These were regular lessons that were scheduled in the curriculum at the time of recording. The video recordings were analysed using the Teaching Observation Form (TOF). The TOF (Bezinović et al., 2012) assesses the presence of the teaching features that fall into six categories:

classroom atmosphere, the structure of the lesson, involvement and motivation, individualisation and differentiation of teaching, teaching metacognitive skills and learning strategies, feedback, and formative assessment. This research selected some of the TOF categories, i.e., features essential for the active involvement of learners in the teaching process which help them attain higher-level cognitive engagement (Table 1 and Table 2 in the Results, referring to the level of questions asked during teaching to attain student understanding and self-assessment). The lessons were analysed independently by two raters involved in the project and by the teachers themselves to determine the representation of certain features listed in the TOF. If a feature was not present, it was given a score of zero; if it was present but to an insufficient degree, it was given a score of 0.5; and if a feature was sufficiently present, it was given a score of 1. Table 1 shows the ratings of each teacher's teaching features (indicated by numbers from 1 to 4), and the numerical values in the columns marked RA indicate the average of the assessed feature from two raters. Inter-rater reliability was determined using Cohen's kappa coefficient, whose values can range from 0 (no agreement between raters) to 1 (excellent agreement between raters), with values below 0.20 indicating poor agreement, from 0.21 to 0.40 fair, from 0.41 to 0.60 moderate, from 0.61 to 0.80 good, and from 0.81 to 1.00 very good agreement (Landis & Koch, 1977). Table 1 also shows the average presence of teaching features, which was calculated by adding the self-assessment scores and the raters' average scores separately and dividing them by the number of teachers. If the average of a feature assessed by the raters was 0.5 or less, it was marked with a ↑ sign, which meant that it needed improvement. In this step, the pretest was conducted and evaluated to determine the students' prior knowledge. The pretest and the analysis of the lesson were the grounds for planning professional development.

Second Phase

The training programme began with an initial online learning community in which teachers critically reflected on the feedback they had gained from analysing the initial video recordings of all teachers' lessons. Following the learning community, the teachers took part in an interactive lecture. The outcome of the lecture was: *Discuss the didactic and methodological design of the lesson in which pupils respond to higher cognitive level questions, formulate observations and conclusions independently and make a self-assessment of the learning process and progress in relation to the objectives of the lesson*. The outcome of the lecture was determined based on the analysis of the recordings of the initial lessons and the pretest (see the arrows in Table 1 in the AZU column). After the learning community, the teachers applied what they had learned. Specifically, they independently planned a lesson that was recorded and analysed (by themselves) using the TOF. This independent lesson planning based on what was learned was the first line of support. In the second phase, there were two learning communities, and two lessons were recorded and analysed. The changes prompted by the first line of support were recorded and analysed following the same procedure as for the initial lesson The changes are presented as the average of the presence of the individual features of all teachers (Table 3).

Third Phase

After recording and analysing two lessons, teachers received a second line of support, viz ready-made examples in the form of a written lesson plan. The lesson plans included flipped classroom and inquiry-based learning, teaching approaches that can enhance all features of the lessons that were found to need improvement during the analysis of the recordings (Table 3, progress column compared to the initial recording). The lessons held after the second line of support were recorded as before and analysed in learning communities. All changes in relation to the first line of support are shown in Table 3 as the average of features for all teachers. Two lessons were recorded and three learning communities that analysed the recordings were held as the second line of support.

Statistical Analysis

For this study, we designed a pretest and posttest. Each test consisted of two questions to determine the first cognitive level (remember) and nine to examine higher cognitive levels (understanding, applying, analysing, evaluating and creating) determined according to a revision of Bloom's taxonomy of educational objectives (Anderson & Krathwohl 2001).

Before implementing the research instruments, we conducted a pilot study on a sample of students who did not participate in this research to examine their measurement characteristics. The pilot study for the pretest test was conducted on a sample of 288 students, and for the posttest test on a sample of 136 students. We calculated Cronbach's alpha coefficient as a measure of the reliability of both tests. For the pretest, the coefficient was 0.97, and for the posttest, it was 0.94. Considering these values, both tests are highly reliable (Bukvić, 1982). In addition, we calculated an item difficulty index (p) and a discrimination index (D) for each question in both tests. The item difficulty index indicates how easy or difficult a question is, while the discrimination index indicates how effective a question is in measuring differences between students (Cohen et al., 2007; Danuwijaya, 2018). Difficult and unacceptable questions were excluded from the test before the implementation with the pupils whose results we present in this study.

In both tests, the maximum score on the first-level cognitive questions was 2.5, while the maximum score on the higher-level questions was 22.5. Because the professional development programme was conducted with the expectation that the resultant teaching would elicit higher cognitive levels of learning, the tests evaluated mainly higher level of knowledge. In the tests, pupils were given the possible score next to each question and asked to estimate how many points they expected to score on each question. The ratio between the achieved and the expected score served as an assessment of the acquired self-assessment skills (Pavlin-Bernardić & Vlahović-Štetić, 2019).

The normality of the data distribution was calculated using the Kolmogorov-Smirnov test, while the homogeneity of variances was determined using the Levan homogeneity test. The overall performance in each written test is presented by descriptive statistics. Differences in the pretest scores between pupils from each teacher were determined by the ANOVA test, while differences in scores on the pretest and posttest were determined by the paired samples t test. Statistical tests were performed using the statistical software package Statistika 12 (Quest Software Inc., Aliso Viejo, CA, USA) with a significance level of $\alpha = 0.05$.

Findings

Initial Teacher Needs

The initial needs of the teacher were identified through the analysis of the first lesson and the pretest. The analysis of the initial lesson revealed that three out of five observed teaching features related to asking questions needed improvement. Two teachers needed to improve asking questions ($\bar{x}1$ indicated by bold numbers). For these two teachers, two of the five features are absent in teaching, while the other two teachers exhibited these features to a sufficient or insufficient degree. In relation to the teacher's willingness to respond to the pupils' questions and their free expression of ideas and asking questions, the teachers' self-assessment (SA) and the raters' assessment (RA) did not coincide. The teachers assessed features as being present when pupils asked about the rules for completing tasks and assignments, while raters assessed only questions and answers related to understanding the content being taught. All three observed teaching features related to content understanding need improvement and all four teachers needed to improve in this regard. The self-assessment and the raters' assessment in this latter part of the teaching observation correspond. The greatest discrepancy is in the average presence of the features related to independent notetaking. Teachers assessed copying from the board or presentation as independent notetaking, while raters rated only notes students made individually. The analysis of the initial recordings also revealed that all the observed features related to self-assessment needed to be improved. Regarding self-assessment features, teachers' and raters' assessments are largely similar, as shown in Table 1.

Table 1

Distribution of Students by Gender

Teaching features	SA1	RA1	SA2	RA2	SA3	RA3	SA4	RA4	$\bar{x}$ SA	$\bar{x}$ RA	AZU
Teaching features related to asking questions											
The teacher willingly answers the pupils' questions.	1	0	1	0.5	1	0.5	1	0.5	1	0.4	↑
Pupils are free to express their ideas or ask for clarifications.	0.5	0	1	1	1	1	1	0	0.9	0.5	↑
The teacher allows pupils enough time to answer questions	1	1	1	0.5	1	1	1	1	1	0.9	
The class is interactive (lots of questions and answers).	0.5	1	1	1	1	1	1	1	0.9	1	
The teacher asks thought-provoking questions (which stimulate higher-level cognitive processes).	0.5	0.5	0.5	1	0.5	0.5	0	0	0.4	0.5	↑
$\overline{x1}$	0.7	0.5	0.9	0.8	0.9	0.8	0.8	0.5			
Teaching features related to the understanding of the content being taught											
The teacher emphasises understanding and not just memorising concepts.	0.5	1	1	0	1	1	0	0	0.6	0.5	↑
The teacher encourages pupils to express in their own words how they understood the content being taught.	0.5	0	0	1	0.5	0.5	0	0	0.3	0.4	↑
The teacher encou-rages pupils to independently take notes and organise the content (e.g., by highlighting key ideas and concepts or making simple mind maps).	0.5	0.5	1	0	0	0	0	0	0.4	0.1	↑
$\overline{x1}$	0.5	0.5	0.6	0.3	0.5	0.5	0	0			
Teaching features related to self-assessment											
The teacher clearly states the objectives of the lesson (learning outcomes).	0	0	0	0	1	1	0	0	0.3	0.3	↑
The teacher encourages pupils to monitor and review their work (e.g., to identify and correct errors, to verify the solution they have reached).	0	0	1	0	0	0	0	0.5	0.3	0.1	↑
The teacher asks pupils to evaluate their own work and progress.	0	0.5	0	0	0	0	0.5	0	0.1	0.1	↑

Teaching features	SA1	RA1	SA2	RA2	SA3	RA3	SA4	RA4	$\bar{x}$ SA	$\bar{x}$ RA	AZU
$\overline{x1}$	0	0.2	0.3	0	0.3	0.3	0.2	0.2			

*Note.*SA – self-assessment of teaching features, RA – raters' assessment of teaching features, x̅SA – mean representation of teaching features of all teachers – self-assessment, x̅RA – mean representation of teaching features of all teachers – raters' assessment, AZU – aspect that needs to be improved; ↑ improvement necessary, $\overline{x1}$– mean representation of teaching features of an individual teacher; For Teacher 1, 1 Fleiss' kappa showed that there was good agreement between the raters (κ=.709 (95% CI, .695 to .722), p < .0005); for Teacher 2 moderate agreement (κ=.557 (95% CI, .543 to .571), p < .0005; for Teacher 3 moderate agreement κ=.585 (95% CI, .571 to .598), p < .0005, and for Teacher 4 very good agreement κ=.827 (95% CI, .812 to .841), p < .0005.

Figure 2

Pupils' scores on questions of different cognitive levels of the pretest

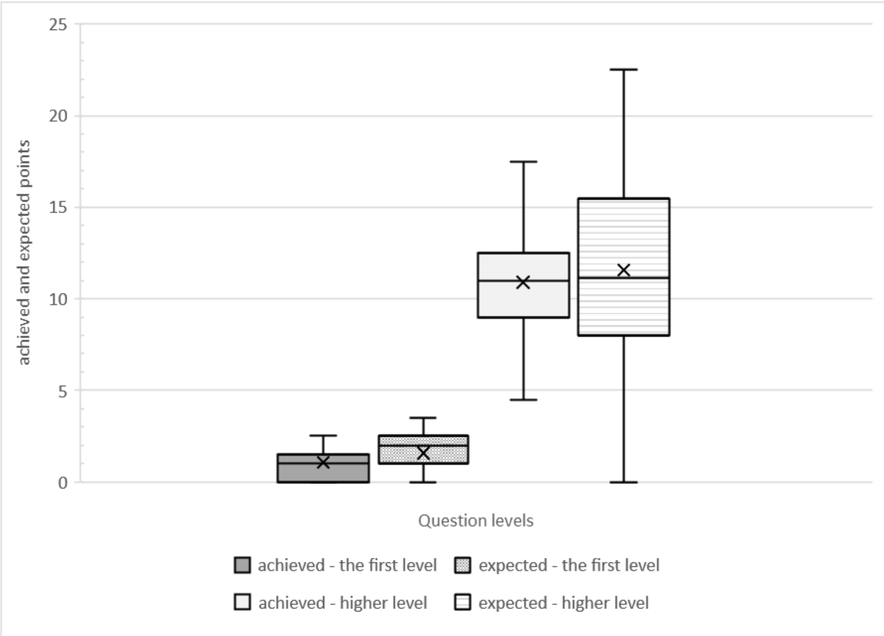


Figure 2 shows that pupils scored an average of 1.1 on the first-level questions, while the self-assessed average was 1.6. For the first-level questions, they could score a maximum of 2.5 points. The achieved score ranges from 0 to 2.5 points, with 25% of them scoring 0 points and 25% scoring 1.5 points or more. They overestimated themselves in the self-assessment. At the same time, 25% expected 1 point or less, while 25% expected 2.5 points or more. For the higher-level questions, the highest possible score was 22.5. The average score was 10.9 points, while the expected average score was 11.6 points. Pupils scored between 4.5 and 17.5 points while expecting 0 to 22.5. At the same time, 25% scored 9 points or less, and the same number expected 8 points or less. An equal number of students (25%) scored 12.5 points or more and expected 15.5 points or more. The students of the teacher with the number 3 achieve the best average results in the questions from both levels examined, but the difference to the students of the other teachers is not statistically significant.

Table 2

The scores of pupils in solving questions of different cognitive levels in the pretest of the knowledge of individual teachers

Question levels	Teachers	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
						Lower Bound	Upper Bound		
First- level	1.00	41	0.85	0.85	0.13	0.58	1.12	0.00	2.50
	2.00	39	1.24	0.91	0.15	0.95	1.53	0.00	2.50
	3.00	14	1.29	1.05	0.28	0.68	1.89	0.00	2.50
	4.00	40	1.05	0.85	0.13	0.78	1.32	0.00	2.50
Higher-level	1.00	41	10.60	2.57	0.40	9.79	11.41	4.50	16.00
	2.00	39	10.66	3.22	0.52	9.62	11.71	4.50	17.50
	3.00	14	11.50	3.05	0.82	9.74	13.26	6.50	16.50
	4.00	40	11.26	3.16	0.50	10.25	12.27	5.00	19.50

Changes in Teaching as a Result of Professional Development and Their Impact on Pupil Academic Performance

Two lines of support incited the changes – independent didactic-methodical design of lessons based on what was learned in the learning communities (first line of support) and the examples of lessons' didactic-methodical plan (second line of support). Table 3 shows the analysis of the third lesson, i.e., the application of the first line of support; and the analysis of the fifth lesson, i.e., the application of the second line of support. After that, the teachers completed their professional development programme.

Table 3

Analysis of the final recording regarding teaching features and changes as a result of teachers' professional development

Teaching features	1st line of support		Progress compared to the initial recording	2nd line of support		Progress compared to the 1st line of support
	$\bar{x}$ SA	$\bar{x}$ RA		$\bar{x}$ SA	$\bar{x}$ RA	
Teaching features related to asking questions						
The teacher willingly answers the pupils' questions.	0.8	0.2	↙	0.6	0.6	↗
Pupils are free to express their ideas or ask for clarifications.	0.7	0.7	↗	0.8	1	↗
The teacher allows pupils enough time to answer the questions he or she poses.	1	1	↔	1	1	↔
The class is interactive (lots of questions and answers).	1	1	↔	1	1	↔
The teacher asks thought-provoking questions (which stimulate higher-level cognitive processes).	0.7	1	↗	0.6	1	↔
Teaching features related to the understanding of the content being taught						
The teacher emphasises understanding and not just memorising concepts.	0.8	0.8	↗	0.8	0.8	↔
The teacher encourages pupils to express in their own words how they understood the content being taught.	0.6	0.7	↗	0.7	0.9	↗

The teacher encourages pupils to independently take notes and organise the content (e.g., by highlighting key ideas and concepts or making simple mind maps).	0.3	0.3	↔	0.9	0.9	↗
Teaching features related to self-assessment						
The teacher clearly states the objectives of the lesson (learning outcomes).	0.5	0.5	↔	0.7	0.6	↗
The teacher encourages pupils to monitor and review their work (e.g., to identify and correct errors, to verify the solution they have reached).	0.8	0.6	↗	0.7	0.7	↗
The teacher asks pupils to evaluate their own work and progress.	0.5	0.5	↔	0.4	0.5	↔

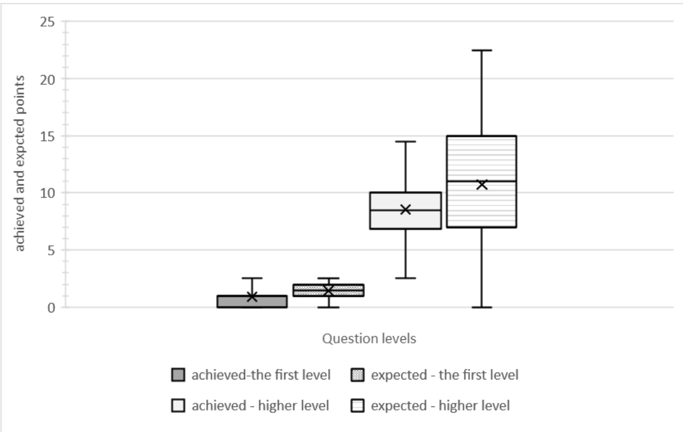
Note. x̄ SA – mean representation of teaching features of all teachers – self-assessment, x̄t RA – mean representation of teaching features of all teachers – raters' assessment, ↔ no progress, ↗ progress, ↙ decline.

On average, the first line of support led to progress on all teaching features that needed improvement, except for the teacher's willingness to answer pupils' questions, where there was a decline. For this feature, there are differences between the teachers' self-assessment and the raters' assessment that did not even out until after the second line of support, when this feature was present to a greater extent in the classroom. The first line of support resulted in progress in understanding. Only the feature related to pupils taking notes independently required further support. Clearly stating the objective and outcome of the lesson, which is a function of (self-)assessment, was partially represented after the first line of support, and a slight increase was observed after the second line of support. The incentive for learners to monitor and assess their own work and progress did not improve after the second line of support. In summary, on average, teachers made progress on all observed features by the end of their professional development programme. Pupil self-assessment could still be improved.

Although teachers made positive changes in teaching, these were not reflected in pupil performance. Comparing the posttest (Figure 3) to the pretest (Figure 2), they achieved a lower average score on first-level questions ($t(129)=2.03$; $p=0.045$, effect size Cochen's $d = 0.18$) and a lower average score on higher-level questions in the posttest ($t(129)=6.71$, $p < 0.001$; effect size Cochen's $d = 0.59$). In the first-level questions, they scored 0.9 points on average, while they expected to score 1.4. For higher-level questions, they scored an average of 8.6 points, while the self-assessed average was 10.7. The scores on higher-level questions in the posttest range from 2.5 to 14.5 points, which is less than the pretest. A quarter of the pupils scored 6.9 or less, and the same number scored 10 or more. Although the average of achieved and expected score is the same for the higher-level questions, the differences in expected distribution are visible, so they expected a range from 0 to 22.5, which is also the maximum score. A quarter of the pupils expected 15 points or more.

Figure 3

Students' score in solving questions of different cognitive levels in the posttest



Discussion

In this study, we observed the changes in teaching practice that promote pupils' active engagement and acquisition of knowledge at higher cognitive levels as an outcome of professional development for biology teachers. To bring about these changes, support was provided in the form of interactive lectures (first line of support) and ready-made lesson plans (second line of support). Throughout the training programme, teachers reflected on the success of the teaching practice learned in the lectures and implemented using the lesson plans provided, based on feedback. An analysis of the video recordings of the lessons enabled feedback to be gathered, while learning communities facilitated critical discussions. The design of the applied professional development programme tested the hypothesis that teachers would exhibit positive changes in instructional practice but that these positive changes would not result in improved pupil achievement while professional development is ongoing. After the first line of support, progress in lesson design and increased pupil activity were observed compared to the first lesson. With the introduction of the second line of support, almost all aspects that were not improved by the first line of support were improved. Despite the positive changes in teaching, the analysis of the post-test and its comparison with the pre-test showed no positive effects of the changes in teaching on the pupils' performance.

According to Asterhan & Lefstein (2024), it is unrealistic to expect to find a clear answer to the question of which approach to professional development is the most effective and to what extent. The approach must correspond to the desired change that one wants to bring about. For example, is it subject-specific knowledge, pedagogical knowledge or the development of teaching skills? Or is the aim to develop a teacher who carries out a self-evaluation of their teaching and takes action based on this? In this case, improving professional judgment may be best achieved through hands-on simulations or collaborative planning of practice presentations with like-minded colleagues (Horn & Garner, 2022). The effectiveness of the design depends critically on how it is implemented (Patfield et al., 2021). Whether something is effective depends on the professional and school environment in which teachers work, the professional knowledge, skills, judgment, and wisdom of leaders and teachers, and how all these factors interact (Asterhan & Lefstein, 2024). Therefore, in designing our professional development programme, we first identified the needs of the teachers involved in our study. By evaluating the pretest and analysing the video recordings of the first lesson, we gained partial insight into their usual teaching practices, and all of our future interventions were based on the aspects of teaching that we identified as needing improvement through these analyses. The pretest examined the pupils’ prior knowledge that they had acquired before teachers’ professional development program. The content included in the pretest was studied during the school year in which the pretest was administered and the year before when the pupils attended seventh grade. The relatively low pretest score suggests that many of them had forgotten some facts that are critical not only for answering first-level questions but also for application in solving tasks of higher cognitive level. The obtained scores can also be explained by the way teachers teach. Considering that the observation of the classes showed that, on average, pupils do not ask enough questions that contribute to the understanding of the content taught, that they do not express their ideas freely enough and do not ask enough for clarifications, and that teachers do not ask enough questions that stimulate thinking (Table 1), the lower pretest score was expected. On average, pupils’ active participation is also underrepresented or absent in expressing their understanding of what is taught or summarising and organizing notes independently. Self-assessment, essential for higher-level learning, is also poor on average. Pupils are not encouraged to monitor and review their work or self-assess, and there is no clear setting of the objective at the beginning of the lesson so that they can self-assess. The self-assessment results suggest that pupils are not accustomed to self-assessing their work and results, which may explain the differences in self-assessed and actual scores.

Although some features important for active engagement and knowledge acquisition at higher cognitive levels are present in the initial lesson such as interactive teaching in terms of alternating questions and answers, it is evident from the results of the pretest that they are not sufficient to contribute to better student learning outcomes. To achieve better understanding, instruction that promotes higher-level cognitive engagement of learners is required, which, according to Lee et al. (2019) and Mayer (2004), leads to better performance and deeper conceptual understanding. In such teaching, the presence and interaction of all observed features are essential. Indeed, the indeterminate difference in the scores achieved by students on the pretest (Table 2) suggests that all teachers provide similar teaching (Table 1) that leads to the same learning outcomes. According to Table 1 all teachers, except Teachers 2 and 3, need to improve teaching features related to asking questions, while all four teachers need to improve teaching features related to understanding and self-assessment. According to an equal score achieved on higher-level questions on the pretest it can be assumed that acquiring knowledge at higher cognitive levels requires teaching that involves the interaction of all features, not just some.

In the pretest, there was a discrepancy between the self-assessed score and the achieved score (Figure 2), indicating that the pupils had not developed self-assessment skills. Self-assessment is based on learners' metacognition. Unfortunately, teachers lack the knowledge to develop and implement it in the classroom (Ben-David & Orion, 2013; Labak, 2022; Seraphin et al., 2012). In addition to the barely present features that relate to self-assessment, there are also partially present features functioning as self-assessment (e.g., the learner seeking clarification and answering questions that stimulate thinking). These features are crucial for elaborating one of the strategies of independent learning and contributing to knowledge at higher cognitive levels (Pavlin-Bernardić & Vlahović-Štetić, 2019). They are also a tool for immediate feedback on pupil understanding and assessment of learning progress (Hattie, 2008). Independent notetaking and organising of acquired content are also strategies for monitoring lessons, which (like other student activities observed in this study) should be guided by metacognitive processes. The absence of the above teaching features makes it impossible to engage learners' metacognitive processes systematically and explicitly in learning. If teachers do not teach them metacognitive strategies that help them monitor their progress and take control of their learning, it will not ultimately lead to better educational outcomes (Ristić Dedić, 2019).

The Impact of Professional Development on Teaching Practice and Its Influence on Pupils' Academic Achievement

The training programme implemented in our study, which consisted of support and continuous reflection, led to positive changes in teaching. At the end of the programme, teachers showed all the characteristics during their teaching practice that contribute to active engagement and higher level learning through their interactions. The support we gave them could be likened to coaching and mentoring as described by Jin et al (2021). Contemporary training models have evolved into coaching and mentoring models that function like an apprenticeship where individuals observe and learn with and from others who are recognised as experts (Jin et al., 2021). Eshchar-Netz & Vedder-Weiss (2021) argue that novice teachers may refrain from sharing their work with others or seeking guidance from more experienced colleagues, while experienced teachers may be reluctant to disclose the challenges they face. Despite the sharing of teaching tips among teachers, it may prove difficult to establish constructive professional dialog for reflective collaborative inquiry (Eshchar-Netz & Vedder-Weiss, 2021). In our study, we fostered a culture of reflection and learning community where collaborative and friendly relationships were cultivated that allowed teachers to voice their observations, limitations and challenges. They were able to clearly articulate which form of support was of greater benefit to them and why. For example, they mentioned that the second form of support was helpful, but they found that a pre-packaged lesson plan did not quite suit their pupils (e.g. flipped classroom and inquiry-based learning, which also affected the final test score).

The first line of support for teachers contributed to the realisation of changes in their teaching, which related to almost all observed features (Table 3). The most progress (in the sense that all teachers exhibited a feature) was made in asking questions that stimulate thinking (Table 1 and Table 3). To ask such questions, teachers must possess adequate content knowledge. The progress achieved indicates the improvement in pedagogical content knowledge developed during professional development. Baumert et al. (2010) found a relationship between maths teachers' pedagogical content knowledge and pupils' cognitive involvement. The improvement in pedagogical content knowledge is also related to progress in changing the focus from teaching focused on memorising concepts to teaching focused on understanding as indicated by the recorded progress on the first two features related to understanding (Table 3). Only at the end of professional development programme, after the second line of support, did pupils begin to ask more questions about understanding the content they were learning (Table 3, first feature). It indicates that teachers needed clear instructions on how to create situations in which learners would ask questions, but also that learners needed time to adjust to the new teaching conditions To clearly articulate goals, teachers needed a different form of support, which resulted in a relatively small change in teaching practice. Even in the final recorded lesson, teachers only partially encouraged pupils to self-assess concerning the defined objective. Self-assessment is part of formative evaluation, which according to Vingsle (2015), is a complex process that is difficult to integrate into teaching practice and requires psychological and practical support (Yan et al., 2021). Encouraging learners to take notes independently and organise the content they have learned has been significantly improved through the second line of support. In our study, as researchers, we were able to tailor the programme to the teachers' needs, which corresponds to the model of professional development described in (Labak, 2020), through reflective discussions in learning communities. During the reflection, teachers recognised the challenge of applying what they had learned in the interactive lectures to their classroom practice. Therefore, we decided to introduce a second line of support for them. A similar result, especially among university teachers was also found in the study by Labak & Blažetić (2023).

According to Deibl et al. (2018), lesson planning is not an intuitive process, especially when we introduce innovations that require deep thought, observationand reflection. The adequate way to reflect is through analysis of teaching videos, as it provides an understanding of how pupils learn specific content (Grossman, 2014), which according to Boston & Smith (2009), is necessary for teachers so they could effectively address identified learners' educational interests. The professional development program designed for this study included learning community meetings with interactive lectures, implementation of what was learned in class, analysis of teaching videos and reflection, and implementation of a ready-made didactic-methodical teaching practices. Islami et al. (2022) refer to these approaches as something teachers commonly use during their professional development. There is a growing consensus that professional development needs to take a collaborative approach that goes beyond the traditional boundaries of training to include observational placements, skills enhancement, proactive planning, achievement of learning objectives and adaptive expertise. There is a newfound urgency to support teacher experimentation with inquiry-based learning, drawing on evidence, integrating reflection, embracing the concept of learning from mistakes, and extending professional development programmes over time (Blackmore & O'Mara, 2022; Mooney Simmie et al., 2024). The positive changes teachers experienced in this research should be seen as a product of the interplay of all the approaches used. Support and reflection were the backbone of teachers' professional learning and allowed them active participation in their learning process. Darling-Hammond et al. (2017) describe active learning as one including collaboration, coaching, feedback, reflection, and models and modelling. In our study experts and teachers were equally involved in learning communities, although their roles differed. Experts provided professional support to teachers in their presentations, the design of teaching examples, and feedback on the effectiveness of implementation, which Nugent et al. (2016) reported had a positive impact on teachers' confidence. Teachers supported each other in the form of discussion about how best to adapt the planned changes to students and specific teaching conditions.

Professional development for teachers should help them to understand and improve their teaching practice with the aim of improving pupil learning (Lozano Cabezas et al., 2022). Guskey & Yoon (2009) believe that teachers' professional development leads to better learner performance because it allows them to better understand what they teach and how learners learn. According to

Desimone et al. (2002), changes in teaching can help to improve learning. However, there is evidence that this does not necessarily lead to improved student academic achievement (Yang et al. 2020; Yoon et al., 2007). These results are not surprising given that improving learning performance is the most distant variable in the impact chain (Asterhan & Lefstein, 2024). The professional development programme is expected to have an impact on teachers' skills, beliefs, and/or knowledge, resulting in improved instructional practices that influence the cognitive, motivational, and/or affective aspects of learner engagement and ultimately translate into individual learner test scores (Kennedy, 2016). The assumption of our study, which we confirmed, is that positive changes in teaching do not necessarily result in better academic performance while teachers are in the professional development phase. Pupils scored lower on average on both cognitive level questions on the posttest than on the pretest. This setback may be related to the fact that they were exposed to the acquisition of two types of knowledge arising from their teachers' professional learning: content knowledge, determined by the biology curriculum outcomes, and metacognitive knowledge. Intending to improve the observed characteristics, teachers introduced changes such as inquiry learning and flipped classrooms, which were new to them and their students.

During a short period (from February to the end of May), the pupils were exposed to various changes in the classroom. During this time, they learned various biological content conceptually based on evolution, which according to Ross et al. (2010), is a concept of abstract but grounded ideas for understanding numerous processes and phenomena in biology. They adopted this concept at higher cognitive levels dictated by the subject curriculum, using strategies that enabled reaching higher cognitive levels and ensuring improvement in the teaching practices of the teachers involved in the study. Most of these strategies were new to learners. They were simultaneously experiencing new teaching strategies and learning biology content. Because the assessment of the effects of teachers' professional development on their academic performance occurred immediately after the implemented changes, learners did not have sufficient time to internalise the new learning practices. We hypothesise that effective teaching intervention needs more time to show positive effect. In other words, we might expect changes in teaching and educational outcomes would become more visible when everything teachers learned during their professional development became a well-established and common teaching practice and a way of learning students are familiar with. The lack of knowledge retention testing due to pupils' transition to higher levels of education is both a limitation of our study and an opportunity for further research.

Conclusion and Implications

The focus of our research has been on two aspects: first, we wanted to find out whether a developed professional development programme brings about positive changes in teaching and under what conditions these changes occur. Secondly, we wanted to gain insight into the conditions under which changes in teaching lead to improvements in student learning.

The implemented professional development programme appeared to be effective in changing teaching practices but did not show improved pupil academic performance. During professional development, teachers analysed the effectiveness of their teaching concerning the innovations introduced, and pupils were at the stage of accepting these innovations as a new way of learning. The effect of professional development on learners' academic performance would be good to test after teachers and learners have internalised the new learning approaches. Knowledge retention tests are likely to be a more effective and reliable means of testing the interdependence of teaching changes and the effectiveness of learning, and they are essential for critically considering cause-and-effect relationships, especially when introducing teaching changes that involve higher learner (meta)cognitive engagement and the acquisition of knowledge at higher cognitive levels. Unfortunately, it was impossible to achieve this in our study because the participants were pupils in the final grades of primary school who continued their education in high schools after the completion of this study. The applied design of the study included not only the question of how well professional development programmes work, but also why they (do not) work. Therefore, the results of our research support the critical discourse on professional development and offer perspectives on the complex construct of professional development.

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Differentiated instruction science learning for intellectually disabilities pupils at an inclusive primary school: A case study

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ABSTRACT
Differentiated instruction (DI) is an approach to learning that allows teachers to meet the unique needs of pupils in the classroom. This study aimed to explore the extent to which DI is implemented in learning to improve the science process skills (SPS) of Intellectually Disabilities (ID) pupils in inclusive primary school education. This research was of the qualitative study type with case study design in 5 inclusive primary schools in Indonesia. The subjects of the study were five teachers who had experience teaching in inclusive primary schools. The sampling method used was purposive sampling, while the data collection the technique used is an in-depth interview. For data analysis techniques, content analysis and descriptive qualitative analysis were used. The results showed that teachers still face challenges in implementing DI for ID pupils in science subjects in inclusive primary schools, despite efforts to understand and implement DI, teacher readiness is still limited, especially in terms of: 1) planning the implementation of learning according to the needs of ID pupils; 2) plan teaching materials that are in accordance with the abilities of ID pupils; 3) lack of DI-related teacher training and coaching in inclusive primary schools. The implication of this study is the need to increase teacher readiness in implementing DI effectively for pupils with special needs, especially in science in inclusive primary schools.

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Introduction

Within the framework of the curriculum, science education is designed to introduce the basic principles of science to pupils of school age. Science education in primary schools aims to train pupils to be able to investigate natural phenomena through a scientific process based on a scientific attitude (Trilling & Fadel, 2009). There are three important aspects of science learning, namely, science as a scientific attitude, science as a process, and science as a product (Pakombwele & Tsakeni, 2022). Science is delivered through the integration of scientific processes, the concept of process integration is explained as follows: science seeks explanations of nature systematically (Chiappetta & Koballa, 2010;

Hidayat et al., 2021). Science as a process or called Science Process Skills (SPS) refers to the main skills used by scientists to conduct research aimed at addressing scientific problems and providing explanations about natural phenomena (Darmaji et al., 2020). SPS is considered important not only for scientists but also for students in elementary school so that students can better answer various problems (Sideri & Skoumios, 2021).

Molefe and Aubin (2021) highlighting the focus of science education in several countries emphasized on the development of critical responsibility for the environment and the application of SPS in the investigation of natural phenomena. This method is believed to be effective as a structured scientific process for pupils to explore their knowledge (Chakravartty, 2023; Zulueta & Panoy, 2022). The ability of SPS in students is characterized by having competence for critical thinking, communication, collaboration, scientific problem solving skills, and being able to find solutions to problems that pupils face in everyday life (Çoruhlu et al., 2023; Kaymakcı & Can, 2021; Sujana & Wayan Puniawati, 2020). Pupils natural skills are an important foundation in a variety of cognitive experiences that enable students to build a deep knowledge and understanding of science (Özgelen, 2012). But unfortunately, the literature review on SPS in general focuses more on junior and senior high schools (Şenel et al., 2022).

Based on previous research and systematic reviews, few studies have focused on students with special needs in the process of learning science at the elementary school level. 17% of the 199 articles specifically focused on pupils with cognitive or Intellectual Disabilities (ID) (Comarú et al., 2021). The results of another study also showed that out of 100 articles that reviewed science education for students with special needs were still in the minimal category (Tosun, 2022). These findings illustrate the importance of focusing on pupils with special needs in the science learning process to ensure equity and opportunities in learning. By creating inclusive environments, pupils with special needs receive the necessary support to meet their educational requirements, also thereby fostering acceptance and tolerance for individual differences (Mendoza & Heymann, 2022; Sanger, 2020). Various schools and organisations have implemented inclusive programmes, placing pupils according to their needs and providing training for educators (Lawal et al., 2022; Maulida, 2019; Roldán et al., 2021; Sheehy et al., 2019; Utami et al., 2024). However, inconsistencies in placing children with special needs in inclusive settings have at times been observed (Krämer et al., 2021; Woodcock et al., 2022). The effectiveness of inclusion at primary school level remains debated, as findings indicate no significant impact on learning performance or psychosocial adjustment for pupils with special needs (Puomila, 2019). Inclusive schools may need to reassess and improve individualisation and differentiation to meet specific needs, especially for pupils categorised as ID (Dalgaard et al., 2022; Hanreddy & Östlund, 2020; Lindner & Schwab, 2020). Pupil ID in inclusive schools shows resistance to difficult science tasks, impact on learning motivation decreases (Bandura, 1977; Çoruhlu et al., 2023).

SPS are vital for constructing knowledge concepts (Faisal & Martin, 2019), requiring learning experiences that facilitate the discovery of facts and the development of understanding (Mcginnis, 2013; Sholahuddin et al., 2020). SPS significantly contribute to science learning outcomes, assisting learners in obtaining meaningful information both within and outside science classes (Bhakti et al., 2018). However, a recent study indicates that a lack of knowledge about SPS can hinder learners' preparedness to employ relevant problem-solving strategies. The challenge faced by ID learners in developing SPS lies in learning approaches that neglect individual differences in abilities. Teachers in inclusive primary school continuously strive to enhance teaching quality by acknowledging individual differences and recognising the underlying and intrinsic nature of special educational needs (Hornby, 2015). The holistic learning and teaching process considers the social and psychological factors influencing individuals in the intricate and diverse learning journey (Cologon, 2020). In the context of learning science, the acquisition of science process skills is imperative, as these skills play a crucial role in the formation of scientific understanding, combining knowledge development with practical scientific activities (Sess, 2008). This integration enables learners to enhance their comprehension of the surrounding environment and acquire skills applicable to diverse situations.

However, there are a number of challenges to implementing the science process in schools, principally the excessive emphasis on the content of science material. There is an excessive emphasis on rote memorisation of science content without a corresponding focus on understanding and practice (Dewi & Rahayu, 2023). This makes science come across as a collection of irrelevant information to IR learners. The science material taught is often unrelated to experience (Kala & Ayas, 2023). As a result, science learning becomes less interesting and less meaningful.

DI is an instructional approach that is pertinent for addressing the diverse learning needs within a classroom (Lawrence-Brown, 2020). Numerous studies have extensively documented the role of DI in the context of inclusive education (Lindner & Schwab, 2020; Vantieghem et al., 2020). It is based on a flexible curriculum (Suwastini, 2021). Previous study has shown that DI in inclusive education can improve learners' academic skills and increase their involvement in the learning process. However, the implementation of DI needs to be tailored to the needs and characteristics of learners, as well as involving sufficient support and training for teachers to be able to implement DI effectively (Demir, 2021; Kamila et al., 2023; Okutan & Eryilmaz, 2021). Studies focusing on the application of DI to process science skills in inclusive primary schooling is still very limited (Çoruhlu et al., 2023; Sideri & Skoumios, 2021). Therefore, there is a need for advanced study that explores the implementation of DI in science process skills for ID learners in inclusive primary schools This study focused on whether and how DI can be used to improve the science process skills of primary is learners. The research question is: To what extent, if any, does the implementation of DI improve the SPS of ID learners in inclusive primary education?

Literature Review

Differentiated Instruction

DI is an instructional approach that is responsive to the individual needs of learners based on their ability. One measure cannot be used for all learners, which means that one way of teaching or learning will not be suitable or appropriate for all learners (Tomlinson, 2003). Starting from this diversity, teachers should accommodate and differentiate (Tomlinson, 2001). DI uses a variety of methods, materials, and strategies to make learning more relevant and engaging for pupils with different needs (Dunn & Dunn, 2018). DI accommodates diverse learning styles and increases pupil engagement with learning content suitable for everyone (Sayuti, 2021). In DI, teachers respond positively and actively to pupil needs, both individually and through small groups (Tomlinson & Eidson, 2003). DI includes planning, execution and evaluation that focuses on the needs of individual learners; with this model, teachers can tailor materials, assignments, and feedback to ensuring that all pupils have a fair chance of succeeding (Pozas et al., 2020). By paying attention to the observations of teachers, they will focus on changing the way in which the curriculum is delivered (Hidayat & Wardat, 2023; Liu, 2021) State- or nationally approved curricula may determine the content of lessons taught (Jonker et al., 2020). However, teachers could adjust curriculum material so that it suits the learning style of their charges (Hasanah et al., 2022).

Teachers must ensure that the material delivered is available in various forms to meet diverse learning needs, such as listening to lessons, watching videos, doing practical exercises, and others (Pozas et al., 2020). The use of learning materials allows teachers to see which pupils have mastered the material and who may need further assistance (Maeng & Bell, 2015). Some topics have four or five different types of projects that pupils can choose from to demonstrate their knowledge of the topic (Algozzine & Anderson, 2010). Teachers strive to make elements of classroom instruction flexible to meet learner needs effectively. Teachers can prepare by evaluating the extent of pupils' readiness to work on the material to be taught and adjusting the material to meet their needs. In addition, teachers can tailor material to meet learner needs based on their learning profiles, such as learning styles, cultural or gender-based preferences, and group orientation. DI has four aspects that can be controlled by teachers, namely content, processes, products, and the learning environment or climate in the classroom (Tomlinson, 2003).

Educators are urged to customise their teaching methods based on the diversity of learners, promoting a learning process rooted in individual styles, abilities and interests (Castiblanco et al., 2023). DI employs a range of techniques, materials and strategies to render learning pertinent and captivating for learners with varied needs, accommodating different learning styles and enhancing engagement. This approach entails teachers actively addressing pupil needs, undertaking planning, execution, and evaluation with a specific focus on individual requirements. This model enables teachers to personalise materials, assignments, and feedback, ensuring equal opportunities for success (Pozas et al., 2020). By comprehending and adapting to learner' readiness, interests, and learning profiles, educators can optimise the learning experience, adjusting elements of classroom instruction to flexibly meet diverse learner needs. DI, which teachers can control in terms of content, processes, products, and the learning environment, empowers instructors to deliver a more effective and pertinent learning experience for each student in their classroom (Maeng & Bell, 2015).

Inclusive Education

Inclusive education facilitates the participation of all pupils in one class, by ensuring that but DI often involves different activities for different ability groups without discrimination. The basic principle of an inclusive education system is that all children can learn together regardless of any differences that may exist between them (Sulasmi & Akrim, 2020). Inclusive education aims to create collaborative learning environments where pupils with special needs learn together with other pupils (Sen & Shahi, 2021). Based on the results of meta-analysis conducted by Carlberg and Kavale (1980) of 50 studies, Wang and Baker (1985/1986) of 11 studies, and Baker (1994) of 13 studies, inclusive education produces positive benefits for both the academic and social development of children with special needs and their peers (Carlberg & Kavale, 2016:24). (Daniel et al., 2023). Pupils with special needs have certain cognitive, behavioural, or physical needs issues that can interfere with the ability to learn, follow lessons, and interact with the school environment.

A special needs category is that of intellectual disabilities. The term ID is used in this study to describe pupils who need special help because they have learning difficulties arising from their limited intelligence (Fidler et al., 2022). Children who are categorised as intellectually deprived require special education services based on related individual and social needs (Williams et al., 2022). Charles Palmer Ingram categorised children who are slow learners as feeble minded (IQ less than 50), mentally disabilities (IQ 50-70), and mentally backward (IQ 75-89) (Ingram, 1941). The diagnosis for intellectual development disorders is the equivalent term for diagnostic ID. Although the term is widely used in the DSM V, both terms are also associated with other classification systems (Lennox et al., 1997). Children with IR need more time to absorb information related to the stimulus present in their situation.

In summary, inclusive education is a pedagogical approach that aims to facilitate the participation of all pupils in a single classroom, ensuring accessible learning activities without discrimination (Alkharraz, 2022). It asserts the right of individuals, irrespective of age, gender, ability, or background, to fully engage in community life. Restructuring schools is essential to create an environment supportive of fulfilling children's special needs in terms of subject matter, learning resources, and collaborative support from teachers, parents, and the community. The fundamental principle of inclusive education is the integration of all children into shared learning experiences, emphasising collaboration and understanding among learners with varying abilities (Wilson et al., 2017). There are learners with diverse characteristics in schools with an inclusive education system, namely those who exhibit normal development and those with special needs (Barbra & Joyline, 2014). Special needs pupils may present cognitive, behavioural, or physical limitations. Children with intellectual disabilities require specialised educational services tailored to their individual and social needs (Corby et al., 2022).

Science Process Skills (SPS)

The most dramatic shift in science education in the last forty years has been a paradigm shift from an approach focused on factual knowledge to practices (Sabah et al., 2023). This marks a fundamental transformation in science education that not only emphasises what learners know, but also how they can learn and understand science more deeply through practical and interactive experiences. Science learning aims to cultivate scientific inquiry skills that are important for learners to gain their own experience (Kim, 2023).

SPS fall into two categories, namely basic process science skills (BSPS) and integrated process science skills (ISPS). BSPS provide an intellectual basis in scientific inquiry, such as the ability to sequence and describe natural objects and events through observing, classifying, measuring and predicting. BSPS is a prerequisite for integrated process science skills (Yap & Yap, 2020). ISPS is a terminal skill for solving problems or conducting scientific experiments. Examples of ISPS are identifying and defining variables, collecting and transforming data, creating tables and graphs of data, describing relationships between variables, interpreting data, manipulating materials, formulating hypotheses, designing investigations, inferring, and generalising information (Sideri & Skoumios, 2021). SPS are among the most important basic skills required in science experiments such as inferring, measuring, predicting, observing, communicating, and experimenting. Such skills help learners to understand the scientific phenomenon under investigation, find information and increase their sense of responsibility for their own learning (Idris et al., 2022). Pupils with special needs are taught to solve problems, communicate effectively, work together in groups, and explore the world around them through lessons such as science (Sibic & Sesen, 2022; Faisal & Martin, 2019) (Faisal & Martin, 2019b) science products (Solé-Llussà et al., 2022). Science learning in inclusive primary and secondary schools needs to pay attention to the characteristics and readiness of learners.

SPS that are very important for primary school pupils to master are the elementary stage skills intended for children aged 5-8 years (Mutlu & Kağan, 2013): observation, sorting, classification, serial ordering, operational definition and communication (Muhammad & Herdiyana, 2017). SPS is one of the most frequently used thinking skills, so individuals who cannot use SPS may have difficulty in their daily lives. According to the results of previous studies, the SPS of school children in some regions in Indonesia is very low (Irwanto et al., 2018). There are still many teachers who focus mainly on achieving learning outcomes than developing science process skills (Wilujeng et al., 2020). This is quite worrying because process skills involve organising and managing time, using learning strategies, planning and evaluating. Without proper science process skills, learners will not be able to achieve optimal science learning outcomes (Pratono et al., 2018). But much science education continues to emphasise the delivery of information through teacher explanations as the main source of learning. Learning activities tend to focus on copying knowledge from one teaching material to another so that learners are more likely to memorise the substance of the material than develop thinking process skills. Pupils with special needs relating to communication quickly forget the material learned because they lack the opportunity to participate in learning activities. They may become demotivated (Rusmini et al., 2021). In addition, SPS also increase feelings of responsibility and confidence in acquiring knowledge independently, increase knowledge retention, and provide opportunities for students to develop effective research methods (Sarıoğlu, 2023).

Science learning is directed to pupils to construct their own knowledge (Larison, 2022). IR pupils are able to learn science meaningfully through the exploration of science process skills (So et al., 2022). The implication for science teachers is that teachers must provide a learning environment with contextual activities that allow learners to develop and master science process skills according to their individual abilities and interests (Applefield et al., 2001). SPS encompass basic and integrated skills, forming a crucial foundation for scientific inquiry. ISPS on the other hand, involve problem-solving and experimental techniques such as defining variables, collecting and transforming data, and formulating hypotheses. In inclusive primary schooling, attention to children's characteristics and readiness is crucial, particularly for those ID learners. The mastery of elementary stage SPS, such as observation, sorting, classification, and communication, is vital for children aged 5-8, influencing their understanding of science content. However, SPS proficiency is reportedly low in some Indonesian regions, emphasizing the need to focus on learning process skills in inclusive education. The traditional approach of information delivery limits students' engagement and hindered skill development, leading to reduced motivation and accomplishment. DI is proposed as a relevant strategy to enhance the science process skills of students with ID in inclusive elementary school.

Methods

This study used qualitative methods with a case study design. Using a case study approach (Nasir et al., 2022), researchers can explore experiences and perspectives from various related parties, such as teachers and pupils, with a view to identifying factors that influence the success or failure of DI implementation in learning SPS for ID pupils in inclusive primary schools (Yin, 2018; Wang et al., 2021). The research took place over a period of four months, spanning from January to May 2023.

Data in this study were collected using interview protocols and documents. The interview protocols were designed with open-ended questions to facilitate the free and in-depth expression of respondents. The interview questions can be indicated in Table 1.

Table 1

Interview questions

Aspects	Question	Duration
Interview		
Application of DI	Tell us about your experience applying DI in science learning for ID pupils.	1 hour per respondent
SPS enhancement	How do you assess the science process skills of ID pupils after applying the DI?	
Challenge	What are some of the challenges you face in implementing DI in science learning for ID pupils?	

The sampling procedure in this study was purposive. The population was teachers in inclusive primary schools. From that population, 5 teachers were randomly selected. This study used observation sheet instruments, interview sheets, and teacher-prepared documents (Merriam & Tisdell, 2015). This interview included a discussion of lesson plan, implementation related to lesson plan, and content of material taught. Through this interview, the aim was to gain a deeper understanding of teacher preparation in planning and executing learning, as well as understanding the approaches and strategies used in teaching and evaluating students. Observation was carried out to directly observe the DI process carried out by the teacher in the classroom. The process of data analysis in study used thematic analysis. The data was analysed to identify key themes that emerged from interviews (Noble & Heale, 2019).

Findings

Teacher readiness in applying DI

The results presented in this research offer a summary of teacher preparedness and instructional methods in implementing Differentiated Instruction (DI) in primary schools, as outlined in Table 2.

Table 2

Teacher readiness theme

Aspects	Challenges	Frequency of study respondents				
		R1	R2	R3	R4	R5
Teacher pedagogy	Readiness of teacher pedagogy in DI		x	x		x
Learning plan	Lesson implementation plan guidelines in accordance with DI principles for ID students	x	x		x	
Valuation system	Revision of the SPS scoring system in DI			x	x	x

Below are instances demonstrating the preparedness of teachers to implement Differentiated Instruction (DI).

How do you see the challenges in improving teacher pedagogy capabilities and learning innovation training, especially in the context of inclusive education?

> *"I need DI guidelines and supportive teaching materials. Even though we have implemented DI, it is still not right with the SPS needs of ID pupils because of my limited ability to facilitate DI. We feel that we still need further debriefing."* (R2)
>
> *"I have attended DI training, but not optimally, because only in general, not specific to children with special needs"* (R3)
>
> *"Implementing DI requires skills that we have not fully mastered. So I still find it difficult to implement it, as much as I can, one of which is accommodating children based on readiness, but for the others I still explain"* (R5)

Have you created a lesson plan that contains DI principles?

> *"I still have difficulty in making a DI implementation plan, because specific examples for pupils with special needs are still limited, especially IR pupils."* (R1)
>
> *"I made the learning implementation plan simple by containing one of the DI principles, namely continuous assessment, but sometimes it is not realised in the learning process, because I do not fully understand the technique"* (R2)
>
> *"I made it, but it's not good [haha], because I'm confused about integrating it, with such time and the DI principle, I can't adjust yet, unless there are guidelines"* (R4)

How do you plan a science process skills assessment system in different instructional contexts?

> *"I realise some pupils need different assessments to achieve SPS moreover SPS will be more appropriate if formative assessments are based on process, but it will take a long time to have to prepare different assessments for each student, so I use the final results through multiple-choice question tests"* (R3)
>
> *"The SPS assessment system that I do is not consistent, sometimes I use tests, sometimes I use observations of activities that pupils do. The form of assignment is still the same for all pupils, but the assessment results are differentiated according to student ability especially ID pupils, it is certain that the score is lower than other students"* (R4)

"I made it in the form of a test at the end of the lesson, because ID pupils are more likely to be passive" (R5)

Table 3 explains the lesson plan used by the teacher.

Table 3

Lesson plan

Subjects	Information
Subject	Changes in the shape of objects
Class	V
Competency standards	Understand and explain the concept of deformation of objects
Achievement indicators	1. Identify the main components in an object. 2. Analyse changes in the shape of objects. 3. Demonstrate an understanding of the changing shape of objects
Learning steps	1. Introduction: - A brief introduction to the concept of deformation of objects. - Introduction activities through open-ended questions and short discussions. 2. Core learning: -Class discussion on the concept of changing the shape of objects. - Case study analysis of changes in the shape of objects. - Small group activities to discuss changes in the shape of objects. 3. Field Activities: - Field trips to the school garden for observation of types of objects. 4. Project assignment: - Pupils are given the task of making a small project in the form of an experiment on an object.

Skills to Process Differentiated Science Learning for ID Students

Teacher expertise plays a crucial role in the successful execution of DI, however not all educators possess equal proficiency in this regard, despite the acknowledgment from respondents regarding their competence in DI management. The findings in this study describe teacher skills in the differentiated science learning process for ID students described in Table 4.

Table 4

Teacher skills managing learning

Aspects	Challenge	Frequency of study respondents				
		R1	R2	R3	R4	R5
Attention of the teacher	Teacher initiative in dealing with ID pupils in DI	x				
Teacher's perception	Teacher's perception of DI			x		
Teacher reception	Emotions regulation				x	
Teacher's attitude	Teacher's enthusiasm in processing DI		x			

"Um, it still needs adjustments to apply DI to the learning environment of ID pupils, because so far only regular pupils have been accommodated, while ID pupils must be more given guidance in every activity" (R1)

"The implementation of DI in class sometimes does not match the lesson implementation plan that I have made, adjusting the conditions and situations of pupils. If you want to differentiate, of course there must be supporting resources." (R3)

"In handling students with intellectual disabilities (ID) during learning sessions, it's essential to exercise additional patience, particularly when they frequently seek assistance. Sometimes, meeting each

pupil individually can be exhausting. Consequently, I endeavour to foster collaboration among students, encouraging them to support each other and work collectively during lessons." R4
"I think DI is good to be applied in the learning environment of inclusive primary school pupils, until now I am still trying to continue to learn to understand different pupils, especially ID pupils so as not to be neglected again in class." (R4)

Learning Resources that Facilitate DI in Pupil SPS

The aspects asked regarding Learning Resources available to teachers are as follows contained in Table 5.

Table 5

Learning resource used in DI

Aspects	Challenge	Frequency of study respondents				
		R1	R2	R3	R4	R5
Availability	The available learning resources can meet the needs in DI					x
Quality	Learning resources are accurate, relevant and interesting to learners.				x	
Conformity	Available learning resources must match science learning objectives (SPS)	x				

"The available learning resources use book teaching materials facilitated by the Ministry of Education, Culture, Research, and Technology, as well as from the internet. If asked whether it meets or not, of course not, the teaching materials available are still general, not differentiated for the needs of each pupil." (R5)
"The learning resources used today are more appropriate if used by pupils with normal development, the content and activities emphasise critical thinking, so they are less relevant when used by ID pupils." (R4)
"The learning objectives and activities of SPS are appropriate, but the level of difficulty is not relevant to the learning objectives for ID pupils." (R1)

Discussion

Our initial discovery pertains to teacher preparedness in utilizing DI. According to the findings, enhancing teacher competencies is pivotal in establishing a learning environment that accommodates pupil diversity effectively. Training in learning innovations focused on new strategies and differential teaching methods is a crucial step to ensure teachers can more effectively respond to the unique needs of each learner. There is a requirement for special endeavours to align lesson implementation plan guidelines more closely with DI principles, particularly for students with special needs, specifically those with special needs (IR). Clear guidelines are needed that guide teachers in identifying and designing lesson plans that can be tailored to students' individual ability levels and learning styles. Furthermore, the revision of the school assessment system is also a crucial aspect that needs to be in line with DI principles. A DI-compliant assessment system can provide a more accurate picture of a student's progress and provide support for their individual development. To implement these changes, concrete steps such as regular teacher training programs, the development of inclusive learning guidelines, and revisions to assessment systems that consider the diversity of students' abilities are needed. Cooperation between schools, government, and evaluation teams is essential in providing resources and supporting this transformation process. Through this joint effort, it is hoped that a learning approach that accommodates the needs of diverse students, improves the quality of education, and ensures equal access to education for all.

Regarding the skills required to facilitate differentiated science learning for ID students, our research identified the critical importance of teacher attention, perception, reception, and attitude. The study findings underscore the intricate dynamics involved in teachers' endeavours to support students with ID within the framework of DI. ID students necessitate more intensive guidance, underscoring significant disparities in learning requirements between typical students and those with ID. This prompts inquiries regarding the readiness of learning environments to address these needs and underscores the necessity for more inclusivity-focused strategies to be developed. Simultaneously, the presence of a disconnect between planning and implementation underscores the influential role played by factors related to the student's condition and circumstances. Engaging students in the planning and execution phases, such as in extracurricular endeavours, has the potential to cultivate favourable attitudes and enhance the overall well-being of the school environment (Jägerbrink et al., 2022). Furthermore, the absence of supportive resources underscores the necessity for increased investment in facilities and tools that facilitate differentiated approaches. Hence, it is imperative to identify and implement policy changes and allocate resources accordingly to enable teachers to effectively implement DI.

The emotional aspects of teachers opened a window into the personal challenges they faced in dealing with ID students. The extra patience, the adjustment of roles from simply providing instruction to being a more active companion, and the teacher's efforts to create collaboration among students demonstrate the complexity of inclusive classroom dynamics. Teacher emotional management becomes an important element in maintaining a positive and supportive learning environment and emphasizes the importance of emotional and mental support for educators involved in this context. Studies have underscored the importance of teachers' emotional regulation and interpersonal demeanour when interacting with these students (Alevriadou & Pavlidou, 2015). Teachers' attitudes toward inclusive education, particularly regarding students with emotional and behavioural disorders and intellectual disabilities, have a significant influence on the efficacy of inclusive practices (Moberg et al., 2019). Teachers need to be encouraged and empowered through training, collaboration, and empowerment that can strengthen their passion and commitment to DI implementation. Therefore, a holistic and collaborative approach is needed to ensure that every student, including those with special needs, has a meaningful and inclusive learning experience.

In the context of Instructional Differentiation (DI), findings from interviews show that the available learning resources, have not fully met the needs of each student. Respondents stated that the teaching materials available are still general, not differentiated for the needs of each student. This highlights the importance of developing more differential teaching materials in order to accommodate students' individual learning needs in inclusive classrooms. Further, interviews with Respondent 4 revealed the mismatch of learning resources used today to the needs of ID pupils. Learning resources tend to be more appropriate if used by students with normal development, emphasizing aspects of critical thinking. However, this lack of relevance creates a mismatch in supporting the learning needs of IR students. Therefore, there is a need for adjustments and revisions to learning resources to ensure relevance to the special needs of ID students.

From the point of view of science learning objectives (SPS), the interview with Respondent 1 highlighted the difference in the difficulty level of learning resources with learning objectives. Although SPS learning objectives and activities are considered appropriate, difficulty levels irrelevant to ID students are a concern. This indicates the need for adjustments to the difficulty level of learning resources to match the abilities of ID learners. To improve the effectiveness of DI, next steps may involve the development of more differential teaching materials, teacher training in selecting and adapting learning resources, curriculum review, and close collaboration between teachers and education specialists.

The findings highlight several critical implications for teachers working with ID pupils in inclusive primary schools. Firstly, there is a pressing need for enhanced teacher readiness in implementing DI, particularly regarding planning learning experiences tailored to the specific needs of ID students. Secondly, teachers should focus on developing teaching materials that are appropriately aligned with the abilities and learning styles of ID pupils, which may require additional training and resources. Thirdly, addressing the lack of DI-related teacher training and coaching in inclusive primary schools is crucial for improving the efficacy of DI implementation. These implications underscore the importance of ongoing professional development and support for teachers to effectively meet the diverse needs of ID students in inclusive educational settings.

The study presents several notable limitations that warrant careful consideration. Firstly, the relatively small sample size may restrict the applicability of the study findings to a wider population. Researchers are encouraged to expand the sample size to enhance the study's generalizability, which could be achieved through conducting multicentre studies or collaborating with multiple institutions to access larger and more diverse participant pools. Additionally, it is crucial to recognize the limitations inherent in the instruments used for data collection, as well as the potential for bias introduced by researchers during both data collection and interpretation phases. Researchers should thoroughly assess and possibly refine the data collection instruments to mitigate inherent limitations and enhance measurement validity. Moreover, efforts should be made to address potential biases introduced during data collection and interpretation by implementing rigorous research methodologies, such as blinding procedures or independent validation of findings. Furthermore, the study solely relies on interview data, which may restrict the breadth and depth of insights obtained from alternative sources or methodologies. These limitations emphasize the importance of exercising caution when interpreting the study findings and suggest avenues for future research to mitigate these constraints and bolster the reliability of conclusions drawn. To address the reliance on interview data, future studies could integrate complementary data sources or methodologies, such as observational studies or quantitative surveys, to offer a more comprehensive understanding of the research topic.

Conclusion

The findings indicated persistent challenges for teachers in implementing Differentiated Instruction (DI) for ID students in science subjects within inclusive primary schools. Despite endeavours to comprehend and apply DI, teacher preparedness remains constrained, particularly concerning: 1) orchestrating learning implementation tailored to the requirements of ID students; 2) devising teaching materials aligned with the capabilities of ID students; and 3) insufficiency of DI-focused teacher training and mentoring in inclusive primary school settings. A major obstacle in DI implementation is related to the limited availability of resources, which hinders the provision of individualized support and customized instructions. Therefore, efforts to overcome these obstacles are essential in creating an effective inclusive learning environment. In addition, the study found that assessment practices in inclusive schools were less consistent in applying the DI approach to evaluating the abilities of students with intellectual disabilities in SPS. Inconsistent application of DI in assessment hinders accurate and inclusive assessment of this student's progress and ability. These findings provide valuable insights into the challenges that exist in inclusive primary schools in Indonesia. It emphasizes the need for modification of learning models that prioritize the unique needs of intellectually disabilities students. In addition, overcoming resource constraints and improving the implementation of DI strategies within the SPS framework can be considered an important step towards developing an inclusive learning environment. To improve educational experiences and outcomes for intellectually underdeveloped students in SPS, education stakeholders, including school administrators, policymakers, and teachers, should focus on developing and implementing flexible curricula. Adequate allocation of resources and consistent application of DI approaches in assessment should also be prioritized to ensure accurate evaluation and inclusive support for these students. By addressing these identified limitations and promoting inclusive practices, inclusive primary schools can create an environment that can support the learning and development of students with intellectual retardation, enabling them to thrive academically and reach their full potential.

The study's findings have significant implications for inclusive schools, emphasizing the need for flexible learning and provision of DI to intellectually disabilities students within the SPS framework. To achieve this, it is important to allocate sufficient resources and maintain consistency in the implementation of the DI during assessment and evaluation. The study highlights the importance of scaling up inclusive approaches and promoting learning development among students with intellectual retardation. By incorporating DI within the SPS framework, inclusive schools can effectively support these students in acquiring and honing their science process skills. Based on the research findings, several recommendations can be made. First, it is imperative to provide support to inclusive schools in designing learning models that facilitate the implementation of DI within the SPS framework. Second, adequate resources, both human and material, must be allocated to support the implementation of DI. Teachers should receive appropriate training and professional development to enhance their knowledge and skills in applying DI techniques effectively. This will enable them to meet the unique needs of intellectually disabilities students, promoting an inclusive and effective learning environment. In addition, it is important to maintain consistency in the application of DI during assessment and evaluation. This ensures that the abilities and progress of IR students within the SPS framework are assessed accurately and inclusively. Consistency in assessment practices allows educators to track the growth and development of these students, providing valuable insights for further support and intervention. By implementing these recommendations, inclusive schools can create an environment that fosters academic success and the overall well-being of students with intellectual retardation, promoting inclusive education and equitable opportunities for all learners.

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Progress in developing experimental design skills among junior high school learners

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ABSTRACT
This paper reports the findings of the second year of a four-year empirical research project. Its aim is to modify 'step-by-step' instructions for practical activities in a way that may enable the development of experimental design skills among junior high school learners. Each school year pupils spend six lessons doing practical activities using worksheets we provide. At the beginning of the research, the Grade 7 (12–13-year-old) pupils were divided into three groups. Group 1 (control group) followed step-by-step instructions. Group 2 followed the same instructions as Group 1, but after the experiment, they answered a series of questions on their worksheets concerned with the design of the experiment. Group 3 was required to design the experiments, guided by a similar set of questions.The impact of the intervention on pupils' experimental design skills (EDS) and disciplinary content knowledge (DCK) was measured using structured tests at the beginning of the project and at the end of both school years. Seven hundred fifty-six (756) Grade 8 pupils completed the test at the end of the second school year (April-May 2023). Over the first two years, the intervention resulted in a medium effect size positive change in the EDS of Group 3 compared to the control group (Group 1), (Cohen's d: 0.23). By the end of the second year of the project, there was only a small difference in the change in DCK between the experimental groups and the control group (Cohen's d value for Group 2: 0.10 and for Group 3: 0.12).

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Introduction

Disciplinary Content Knowledge and Inquiry-based Activities

The Rocard Report (2007) recommended inquiry-based methods to increase interest in school science, as policymakers across Europe were concerned that a decline in young people's interest in certain science studies was leading to a shortage of scientists and that not all young people were developing at school the key analytical skills that would prepare them for the future. Inquiry in science is the intentional process of diagnosing situations, formulating problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers using evidence, and presenting coherent arguments (Linn, Davis, & Bell, 2004). Banchi and Bell (2008) outline four levels of inquiry. The highest level is the open inquiry, where learners are asked to formulate the research question, design and follow through with a developed procedure, and communicate their findings and results. Open inquiry is certainly authentic, but often considered to be too challenging even at undergraduate level (Farley et al., 2021). One level down is the guided inquiry (Schoffstall and Gaddis, 2007), where the question to be investigated is given by the teacher and learners have to design a procedure to find the answer given guidelines. Guided inquiry is more realistic at school level and it is an improvement on the even lower level of structured inquiry, where the initial question and an outline of the procedure are given to the learners, who are only required to formulate explanations for their finding. The lowest level, which Xu and Talanquer (2013) do not even call an inquiry, is the confirmation inquiry, when the teacher develops the question to be investigated and a procedure that guides the learners through an activity where the results are already known. Banchi and Bell (2008) suggest that teachers should start teaching inquiry at lower levels and work their way up to open inquiry in order to effectively develop students' inquiry skills. The development of skills, habits and attitudes for scientific inquiry is widely seen as an important goal of science education (e.g. Koomson et al., 2024).

However, according to the PISA 2015 results (OECD, 2016), enquiry-based science activities (that are also referred to in the literature as inquiry-based, as the latter term is used in both North American English and British English, see Oxford Learner’s Dictionaries, 2024) are associated with lower test scores in science among students who work in the context of disorderly classrooms (Mostafa et. al., 2018). This is unfortunate, because the same analysis also showed that introducing pupils to these activities seems to be the most promising approach to developing a positive attitude towards science (see also e.g. Wheatley, 2018). However, Lavonen et al. (2021) warned that although results show that these science practices have a positive impact on situational interest, several research projects on the topic (European Union, 2016) had not supported the development of students' interest in physics and science careers at upper secondary level. These results suggest that not all inquiry-based teaching methods produce the expected positive results in all circumstances.

Mostafa et al. (2018) also report that greater exposure to teacher-led science education is positively associated with science achievement in almost all countries, even after accounting for socio-demographic characteristics of learners and observed and unobserved school characteristics (OECD, 2016). Therefore, they recommend that teachers with strong classroom management skills and professional knowledge should guide learning in science by explicitly teaching basic concepts. They can then encourage pupils to engage in enquiry or inquiry-based activities to consolidate their knowledge. There are known methods for learners to purposefully integrate scientific knowledge (disciplinary core ideas) and scientific activities (science and engineering practices) to understand aspects of their learning (National Research Council, 2012; NGSS Lead States, 2013). These include e.g. asking questions, developing and using models, designing and carrying out experiments, analysing and interpreting data. This should be productive for making sense of phenomena, while learners adopt epistemologies for science (Russ, 2014), which can turn out to be useful in post-school life. These are skills that all STEM undergraduates should develop (Reynders et al., 2019). Therefore, teaching materials should provide opportunities for learners to surface ideas and build meaningfully on their reflections about the phenomena they experience (Schafer et al., 2023). Exemplars were based on different models, such as the Science Writing Heuristic (Burke et al., 2006), the Process Oriented Guided Inquiry Learning (Moog et al., 2008) and the Argument Driven Inquiry (Walker et al., 2013). These emphasise asking scientific questions, designing appropriate procedures to test those questions, supporting conclusions with experimental evidence, and communicating ideas clearly (Reynders et al., 2019).

In terms of laboratory exercises, it has been known for a long time that step-by-step (or “cookbook-style”) instructions that tell students exactly what to do while carrying out an experiment (which fall under the category of structured inquiry) have limited effects on learning (Kirschner, 1992). This approach usually targets the cognitive, psychomotor and affective domains to ensure meaningful learning. However, the social and epistemic domains are often ignored or dismissed altogether, even in undergraduate laboratories (Hendra, 2022). Therefore, guided inquiry may be an option that represents an improvement over a structured inquiry, but is still less challenging than an open inquiry.

Literature Review

Experimental Design in Pre-university Chemistry Education

There are many different ways to implement a guided inquiry (e.g., Moog et al., 2008), but controlling for variables while designing an experiment is always essential (Arnold et al., 2018; Arnold et al., 2021; Cannady et al., 2019). At school level, where pupils' prior knowledge of chemistry and laboratory competences is extremely limited, it is important to use pedagogical procedures that allow for different levels of support to provide pupils with appropriate scaffolding. Appropriate teaching models can be summarised as not recipe-like instructions, where tasks are more learner-centred, cooperative learning is supported and the preparatory phase plays an important role (van Brederode et al., 2020). The objectives move away from the acquisition of concrete subject content and the use of laboratory equipment towards higher order cognitive skills such as designing experiments, scientific reasoning, linking science and social contexts, and developing critical thinking.

However, Akuma and Callaghan (2019), in their systematic literature review, characterised a number of intrinsic challenges related to the design and implementation of inquiry-based practical work (e.g., negative views about science and practical work, difficulties in designing such activities, persuading learners to reflect on their experiences and outcomes, and concerns about the assessment of practical inquiry). Learners often have to cope with too many instructions in the laboratory (Agustian and Seery, 2017; Johnstone, 1997), and cognitive overload can easily occur. Johnstone (2006) suggested that this could be reduced by pre-laboratory preparation plays. A meta-analysis of studies on guided inquiry instructions suggested that more specific guidance results in higher quality learning products (Lazonder, Harmsen, 2016). Therefore, van Brederode et al. (2020) used two different ways to treat their pre-university students (17–18 year-olds) to find out what level of support works better. In the "critical thinking" pre-laboratory group, students started to develop an experimental plan using the information provided and the criteria for a good experimental design. Hints for designing the experiment were given to the students in the other "paved road" group as information for answering the pre-laboratory questions, while they were also given compact laboratory instructions for carrying out the experiment. The results showed that students of the "critical thinking" group were motivated to think more deeply about the meaning of their measurements than the "paved road" group.

Hennah et al. (2022) found that placing greater emphasis on dialogic processes as a tool prior to completing a practical-based activity helped learners to score significantly higher on the GCSE chemistry examination practical-themed questions than students who prepared for the practical task by watching videos during the lesson. It therefore seems useful for the group of students to discuss the procedure before carrying out a laboratory experiment.

Potier (2023) introduced guided inquiry to enable 15–16 year-old learners with minimal background knowledge of a topic to design and carry out an experiment. He found that guided inquiry can be an effective tool to give students control over their own learning and support their engagement and progress in high school science.

Tseng et al. (2022) argued that since experimental design is a systematic thinking process that involves configuring the relationship between control, and independent and dependent variables (Pedaste et al., 2015), students can learn this by reflective reading of scientific articles rather than performing practical hands-on laboratory activities. In their research project, the "comparison group" (control) learned how to read and understand scientific articles without a direct focus on their inquiry practice. Both "experimental groups" read and discussed scientific articles and designed their own experiments. Evaluative reflection on their peers' experimental designs was emphasized for one of the experimental groups, while the recognition of variables in designing experimental procedures was emphasized for the other group. The results showed that students' scientific inquiry performance in formulating research questions and designing experimental procedures can be effectively improved by reading and reflecting on experimental design.

Addressing the Problem of Motivation

A systems thinking approach can help learners link their knowledge of chemistry with other disciplines and the skills needed to tackle complex global problems (Szozda et al., 2022). These activities can illustrate e.g. the dynamic relationships between processes, the variables that control them, the emergent behaviour of the system, and how that behaviour changes over time (Orgill, 2019). They provide opportunities for learners to use their knowledge of chemistry to explain a more complex and unfamiliar phenomenon. This can also create an experience that has the potential to engage learners (Allred et al., 2022). This can be very useful, especially in a longitudinal study, when it is crucial to find ways to stimulate and sustain interest, as pupils' performance cannot be rewarded with marks. Several studies have shown that for many high school pupils, motivation to learn chemistry is first and foremost obtaining good marks (see among the latest e.g. Zhang, Zhou, 2023).

Context-based learning in general, and addressing socio-scientific issues in particular, can lead to a better understanding of chemistry and help learners to relate chemistry to their everyday lives (Chen, Xiao, 2020; del Mar López-Fernández et al., 2022). It can also develop critical thinking skills, which are essential for students to become competent citizens who can make informed decisions in different situations. Jiménez-Aleixandre & Erduran (2007) point out that critical thinking involves elements of argumentation, such as the search for and use of evidence. The systems thinking approach is well suited for this purpose, since chemical reactions and processes are an integral part of dynamic and interconnected systems. This way learners can realise that because sustainability has a molecular basis, chemistry plays a central role in addressing the challenges facing the Earth and societal systems (MacDonald et al., 2022). However, to ensure the appropriate development of critical thinking skills, it is important to create a spiral scaffolding while applying a systems thinking approach (Mahaffy et al., 2018). Therefore, at the age of 13–14, phenomena can be explained mostly in qualitative terms and some elements of systems thinking can be introduced. Examples include identifying the components of a system and their connections, flows and cycles, causality and feedback loops (MacDonald et al., 2022). It is best to start simple and then gradually increase the complexity (del Mar López-Fernández et al., 2022).

Social media is also a goldmine to provide topics for motivating context-based learning and systems thinking, as it often contains (e.g. for marketing purposes) science-related information that is based on non-scientifically-proven sources or outright fabrications. Research by Belova & Krause (2023) has shown that it is worthwhile preparing school learners against science-based manipulation strategies. As well as stimulating interest, it can show pupils that seeking to understand how science works can be an activity that protects them from being deceived or misled.

Previous Results

Four studies (Szalay et al., 2020; Szalay et al., 2021; Szalay et al., 2023; Szalay, Tóth, 2016) have provided preliminary results for the research described in this paper. A common feature is that the experimental group or groups learned how to design the experiments, while the control group simply followed step-by-step recipes i.e. structured inquiry. The experimental design tasks of (at least one) of the experimental groups can be categorised as guided inquiry, as the research questions were always given, but the pupils had to design the method, the way to find the answer. The earliest brief empirical research (Szalay, Tóth, 2016), in which pupils in the experimental group aged 14–15 had to design experiments without any help, showed positive results, as their experiment design skills as measured by tests improved significantly compared to those of the control group. However, the same approach did not prove to be successful by the end of the first school year of a longitudinal study in case of 12–13-years-old students (Szalay et al., 2020). Accordingly, from the second year onwards, pupils in the experimental groups were taught the relevant principles of experimental design. This scaffolding produced positive results for 13–14 year-old students, since the experimental groups' experimental design skills seemed to develop more than that of the control group's. However, this effect disappeared in the long term when the students turned 14–15 (Szalay et al., 2021). This led to the conclusion that students probably need more help and more motivation in designing experiments than they received in the previous longitudinal project. Gott and Dugan (1998) warned that not all inquiry based laboratory tasks are appropriate to engage students in scientific practices, as they depend on their structure and requirements. This is in agreement with Baird's view (1990) that purposeful inquiry does not happen spontaneously – it must be learned. Students obviously need scaffolding to solve inquiry type tasks (e.g. Puntambekar and Kolodoner, 2005; Blanchard et al., 2010; Crujeiras-Pe´rez and Jime´nez-Aleixandre, 2017). This might help to alleviate the increased cognitive load.

Therefore, in the present four-year project that began in September 2021, pupils in the experimental groups answer a series of questions concerned with the design of the experiment about the fair testing (t.e. changing one factor at a time while keeping all other conditions the same) on their worksheets. This is a simplified version of the Experiment Design Diagram described by Cothron et al. (2000). After the first school year of the present project, it was clear that the applied type of instruction had a significant positive effect on the results of the pupils who were required to design the experiments, guided by that set of questions (Szalay et al., 2023).To increase motivation in the present longitudinal research project, context-based tasks with elements of systems thinking were also introduced in the worksheets under the heading "Let's think!". These are the same for all groups.

Aims and Objectives

Since the method used in the first year of the present four-year longitudinal research (Szalay et al., 2023) seemed to improve the experimental design skills of the experimental group (Group 3) who had to answer questions about the design of the experiments before they planned the steps of the experiments they carried out, it was decided to apply the same research model in the following years to see what changes happen in the longer term. It is also interesting to see how the performance of the other experimental group (Group 2) who answer the questions after completing the step-by-step experiments changes over the course of the tests.

Research Questions (RQ)

Therefore, in the second school year of the present project, answers to the same research questions as in the previous year were sought.

RQ1: Did the intervention result in a significant change in pupils' ability to design experiments (experiment design skills, EDS) in either of the experimental groups compared to the control group in long term, by the end of the second year of the present project?

RQ2: Did the pupils in the experimental groups score significantly differently on the disciplinary content knowledge (DCK) questions because of the intervention compared to the students in the control group in long term, by the end of the second year of the present project?

RQ3: Was there a difference in EDS between students in the two experimental groups in long term, by the end of the second year of the present project?

Methods

Research Design and Participants

A quasi-experimental design with a non-equivalent control group is applied in this empirical research. The research team consisted of thirty-four serving chemistry teachers and five university chemistry lecturers at the beginning of this four-year project (in September 2021). Thirty-one of the teachers taught the participating students in the first year of the project. Three teachers did not teach the students in the sample. One of them, as a member of the research team, tried out the tests with her pupils and prepared worksheets. Another teacher is involved in correcting the marking of the tests that had been done by other teachers. A third teacher only prepared one of the worksheets. Of the thirty-four in-service chemistry teachers, five teachers have left the research team since the end of the first year of this project. Two teachers from the participating schools who replaced two of the five teachers who left became members of the research team. Therefore, the research team now consists of thirty-one serving chemistry teachers and five university chemistry lecturers. All teachers are voluntary participants.

Participating pupils must attend a school where they are taught chemistry from Grade 7 to Grade 10 (from age 12–13 to age 16–17), so that their learning of chemistry over four school years can be followed in the present longitudinal research. The 931 seventh-grade pupils who were involved in the beginning of this project (in September 2021) came from twenty-five Hungarian secondary schools and thirty-eight classes. Class sizes varied between 14 and 36, reflecting the typical class sizes in Hungarian schools. The students who remained in the project in the second year came from twenty-three Hungarian secondary schools and thirty-six classes. Class sizes varied between 13 and 33 in the second school year.

At the beginning of the project (September-October 2021), 931 participating seventh-grade pupils completed one test (called Test 0, T0). The 38 classes were grouped into Groups 1, 2 and 3 after the evaluation of the results of Test 0 to ensure that there were no significant differences among them neither in the initial performance (previous knowledge), nor in terms of the hypothesised parameters (school ranking, mother's education, gender). Pupils stay for four years in the same group they were in when the project started. By the end of the first school year (May-June 2022), 890 of these students completed another test (called Test 1, T1). The 756 remaining eighth-graders completed the third test (Test 2, T2) by the end of the second school year (April-May 2023).

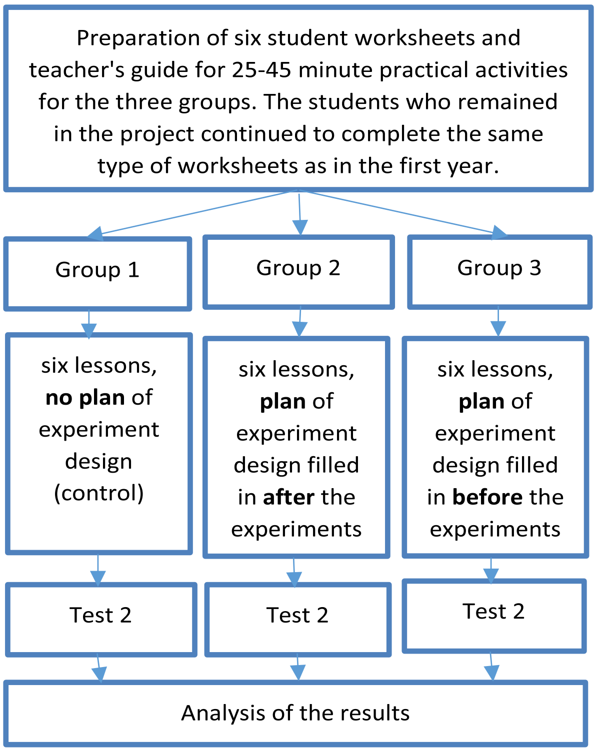
Six pupil worksheets and teacher's guides were produced in both school years 2021/22. and 2022/23. Each worksheet was written in three versions for the three groups of students.

The research model used in the second year of this project is summarised in Figure 1. The teachers chose when the lessons took place, in which the worksheets and the tests provided were used.

Group 1 (the control group) only did step-by-step experiments that Banchi and Bell (2008) called “structured inquiry”. An abbreviated and simplified version of the Experiment Design Diagram (Cothron et al., 2000), applying the ‘fair testing’ method (i.e. changing one factor at a time while keeping all other conditions the same), was used to help experimental groups learn to design experiments. The questions concerned the control of variables, the discussion of hypotheses and the definition of the steps of the experiments. Group 2 carried out the same step-by-step experiments as Group 1, but after performing the experiments, they had to answer questions on the worksheets about the design of the experiments, following the relevant parts of the fair testing plan described above. Their answers were discussed with their teachers. This instruction method could be considered as a much-simplified version of the approach used by Reynders et al. (2019) who linked the discussion questions of the experimental procedure to the lab report. Group 3 were given guided inquiry tasks on their worksheets, since it is more realistic to introduce guided inquiry (Schoffstall and Gaddis, 2007) practicals at school level, where the question to be investigated is given by the teacher and pupils have to design an experiment to find the answer than the open inquiry that is often considered too challenging even at undergraduate level (Farley et al., 2021). Group 3 students' experiment design was supported by questions from the fair-testing plan mentioned above. The answers were discussed with Group 3 by their teachers before the experiments were carried out. The treatment of Group 3 is similar to that of the "critical thinking" pre-lab group described by van Brederode et al. (2020), as they had to design the experiment to be performed. The "paved-road" pre-lab group of the same study (van Brederode et al., 2020) on the other hand, was given compact lab instructions to carry out the experiment, similarly to Group 2. (Although Group 2 had to discuss aspects of the experiment design after the experiment was completed.)

Figure 1

Research procedure applied in the second school year of the current project



Ethical Considerations

In the absence of institutional ethics committees or local procedures, our research team had to develop its own ethical protocol to ensure that informed consent was obtained and that the privacy and confidentiality of the individuals were protected (Lawrie et al., 2021). A letter describing the key features of the research was drafted in accordance with the General Data Protection Regulation (GDPR) in the European Union and sent to the mother or guardian of each participating student by their chemistry teachers to ask for written consent for their children to participate. Teachers also had written permission from school principals to participate. Teachers told the pupils that the test results would not count in their school's chemistry assessment, but that they were participating in a project to improve chemistry education.

Instrumentation

Worksheets

The pupil worksheets and teacher's guides describe practical activities involving pupil experiments, designed to take about 25-45 minutes. All twelve worksheets and their teacher's notes titled "Student sheets 1-6 and their teacher's notes" for the first year of the present project and "Student sheets 7-12 and their teacher's notes" for the second year of the present project are available in English on the research team's website (https://ttomc.elte.hu/publications/92). These were piloted with students working in small teams.

Topics of the experiments and the context-based systems thinking tasks ("Let's think!") were related to the National Core Curriculum of Hungary (2020), together with the experiment design tasks given to Group 3 on the worksheets (Szalay et al. 2023) and see Table 1 in Appendix for those used in the second year.

Each topic of the worksheets had been agreed by all participating teachers. The first versions of each worksheet were read by four university lecturers (who are experts in the development of chemistry teaching materials for primary and secondary school learners. The worksheets were then improved by the authors based on the experts' suggestions. This second version was proofread by one of the experts and the leader of the research team, who then agreed on the final changes.

Each worksheet continued to include a context-based task under the heading 'Let's think!', designed to maintain interest, engagement and develop systems thinking skills (e.g. Chen, Xiao, 2020; del Mar López-Fernández et al., 2022; Klemeš̌, et al., 2021; MacDonald et al., 2022).

The basics of the correct terminology (independent and dependent variables, constants, hypotheses) were introduced for both experimental groups (Groups 2 and 3) in the second school year, in the hope that students would be old enough to master these abstract concepts. Based on answers given to attitude questions in the first year, other minor changes were made to the worksheets, highlighting the importance of experimentation in science. Groups 2 and 3 teachers were also asked to encourage their pupils to answer questions about experimental design by highlighting its usefulness and praising them for thinking well.

Tests

Based on the results of the end-of-year test in the first (Test 1, i.e. T1) and second (Test 2, i.e. T2) year of the project, pupils' achievement should be compared with the performance of the previous year (Test 0, i.e. T0): a test at the beginning of the project and Test 1, (i.e. T1): end-of-year test in the first year of the project, respectively) to see how their DCK and EDS have changed. Tests were designed using the same recommendations as described in the previous studies (National Research Council, 2001; Szalay et al., 2023) and they were all paper based (Cannady et al., 2019). The tasks had to integrate content knowledge that learners are familiar with (DCK) and focus on the ability to apply scientific practices (Zimmerman, 2000; Zimmerman, 2007; OECD, 2017; Cannady et al., 2019; Tosun, 2019) while solving the experimental design tasks (EDS). EDS tasks had to provide the content knowledge needed to solve the tasks (Cannady et al., 2019).

Before designing the EDS task, various assessment criteria (Sirum & Humburg, 2011) assessment tools (Chen et al., 2019; Tseng et al., 2022) and the experimental design checklist for Science Olympiad (2020) were consulted for guidance. The collection and use of data from the text, the identification of independent, dependent and controlled variables, and the procedure were considered most important. The EDS tasks were set in the context of everyday life in a way that was designed to engage the students' interest.

The following EDS task was used in Test 2 to compare the development of pupils' EDS across the three groups.

"Imagine you are on holiday with relatives in a small village and you have filled a swimming pool in the yard with water. The water needs to be disinfected with a tablet that can work in the pH=7-8 range, but the pH of the local water is higher than 8. There is a chemical that needs to be added to the pool in such quantities that the bathing water reaches the desired pH range. However, the test strip to check the pH of the water is out of stock and is only available in a remote town. Remember, however, that red cabbage juice can act as an acid-base indicator and can be made from cabbage at home. According to the Internet, red cabbage juice is yellow at pH ≥12, green and greenish blue around pH=9-11, blue between pH=7-8, lilac or purple between pH=4-7, and red in the pH≤3 range. This allows you to adjust the pH of the pool water to the pH range that the disinfectant tablets will work. You cannot pour the cabbage juice into the pool, but you can use cups to take a water sample from the pool, even several times. There is also a shovel to mix the water in the pool. Use your answers below to help design the experiments to get the right pH range.

a) What can you change about the total content of the pool during the experiments (i.e. what should be added to the total content of the pool in each experiment)?

b) What property of the pool water depends on the change you cause?

c) How can you test for this property of the pool water mentioned in b) above?

d) From what observation can you conclude that more material needs to be added?

e) Why is it always important to mix the pool water carefully?

f) In which case can you conclude that you can now put the disinfectant tablets in the pool water?

g) Put a (+) sign in front of the statement(s) in the list below that is/are important and a (-) sign in front of the statement(s) that is/are not important. (You can write a different sign after a clear strike-through if you change your mind.)

The water should be always taken out from the same point in the pool by the cup.

Always the same volume of water should be taken out from the pool by the cup.

Always the same cup should be used to take out the water from the pool."

The test questions were structured according to the levels of the revised Bloom's Taxonomy (Bloom et al., 1956; Krathwohl, 2002) cognitive process dimension categories as interpreted in previous publications (Szalay et al., 2020; Szalay et al., 2021; Szalay et al., 2023). Each test consisted of eighteen compulsory items, each worth 1 point. Nine were used to assess EDS and the other nine to assess DCK (three each for recall, understanding and application), as both experiment design skills (EDS) as part of inquiry skills and disciplinary content knowledge (DCK) had to be assessed (e.g., Cooper, 2013; Reed, Holme, 2014; Rodriguez, Towns, 2018; Underwood et al., 2018). To measure the development of the experimental design skills (EDS) problem solving tasks were used that required the application of the components of experimental design skills defined by Csíkos et al. in 2016 (i.e. identification and control of variables, including the principle of "how to vary one thing at a time" or "other things/variables held constant"; choosing equipment and materials).

The instruments used were 40 minutes paper-based tests. The papers were coded so that teachers would know the the respondent's name and gender, but the researchers only received anonymous data coded for statistical analysis. These codes and the Excel spreadsheets containing the codes and marks are used throughout the project. Participating teachers marked the tests, recording the marks in an Excel spreadsheet as instructed (see on the research group website (https://ttomc.elte.hu/publications/95) under the titles "T0 test and instructions for teachers", "T1 test and instructions for teachers" and "T2 test and instructions for teachers", respectively). As there was an element of subjectivity in the marking protocol, the research group tried to standardise the marking to ensure that the application of the marking key is the same for each corrected test of the same kind, as done by Goodey & Talgar (2016). An experienced chemistry teacher reviewed all the teachers' marking and suggested modifications to the marking instructions. After discussions within the team, alterations were made. Based on these, the teachers' marks were changed to ensure that a unified marking process, free from individual teachers' decisions was used. The scoring procedure is consistent with the recommendation of reaching complete consensus through negotiated agreement (Watts, Finkenstaedt-Quinn, 2021).

Validity

Evidence for content validity was established by a panel of domain experts judging whether the items appropriately sample the domain of interest (Crocker & Algina, 2006). It can be used to argue against construct underrepresentation that is one of the main threats to construct validity (Wren & Barbera, 2013). To avoid construct-irrelevant variance, each task of Test 2 could be completed after finishing the tasks on the six worksheets for the second school year of the present project. Table 2 shows how each task of Test 2 can be matched with the relevant content of certain worksheet.

In Test 2, the tasks had to be different than in previous tests to avoid repeated testing effects and to measure transferable EDS (Cannady et al, 2019; Schafer et al., 2023; Szalay et al, 2020; Szalay et al, 2021; Szalay et al, 2023). The chances of the successful solution of a task would be higher if it was used the second time, since pupils might discuss it with others in between times. (This could have caused construct-irrelevant easiness.)

Table 2

Matching the content of the tasks of t2 test and the topic(s) of the worksheets for the second year

No. of task in Test 2	No. of student worksheet and topic
1.a-b	8. Hardness of water, use of water softeners (precipitation reactions)
2. a-g	10. Modelling environmental processes (acid base reactions, pH, effects of acid rain)
3. a-b	9. Modelling industrial processes (production and use of quicklime and slaked lime)
4.a-b	7. Reactivity series of metals and hydrogen (redox reaction, electron transfer)
5.	12. Plastics - pros and cons (raising environ-mental awareness)
6.	9. Modelling industrial processes (production and use of quicklime and slaked lime)
7.	11. Modelling qualitative analysis (health and diet)

The first version of Tests 2 and its marking key was devised by the research team leader. Then the same university educators in the research group who checked the content of the student worksheets and the T0 and T1 tests checked the marking instructions of the T2 test. Alterations were made according to their suggestions. This process of item evaluation and revision took place for all items of all the three tests. Expert feedback on item content, wording, and consensus of the correct answer are all sources for evidence of expert response process validity and against construct-irrelevant variance, both construct irrelevant difficulty and easiness (Wren & Barbera, 2013).

Test 2 was trialled with two classes (N1=29, N2=29, altogether 58) of 13 year-old pupils not participating in the research in the autumn 2022. (Test 0 and 1 had been tried out on the same two classes in the previous school year). The chemistry teacher organising this pilot and marking each test gave detailed suggestions how to improve the wording of the tasks and the marking instructions based on her experiences. T2 test and their marking instructions were further revised in response to results of the trial before they were filled in by the pupils participating in the sample.

Participating teachers had not seen Test 2 before piloting the six student worksheets of the school year. The aim was to ensure that the tasks in Test 2 did not subconsciously influence teachers' teaching behaviour, which could have affected pupils' responses to the test questions.

The test scores of Groups 2 and 3 were compared with those of Group 1 (control group) to eliminate the risk of maturation (Shadish et al., 2002).

Data Collection

The number (N) completing all three tests (T0, T1 and T2) in each group is as follows: Group 1: 242; Group 2: 273; Group 3: 241, altogether 756. Following the incompletion of a test, that pupil was excluded from the analysis and future tests. Further, two entire classes no longer participated in the second year of the research because their teachers resigned, and the new teachers did not volunteer to continue working in our research team.

The following data were collected and analysed statistically:

- Total scores for Test 0, Test 1 and Test 2.
- Scores for EDS tasks Test 0, Test 1 and Test 2.
- Scores for DCK tasks Test 0, Test 1 and Test 2.
- Gender.
- School ranking. The student's school ranking amongst Hungarian secondary schools, according to the website 'legjobbiskola.hu'. The participating schools were grouped into high, medium, and low-ranking categories and a categorical variable was used according to these three levels. This allowed a statistical assessment of the impact of participating schools "quality" on the development of the pupils' knowledge and skills.
- Mother's education. Two categories were formed depending on whether or not the student's mother (or guardian) had a degree in higher education. This categorical variable was intended to characterise the student's socioeconomic status.

Statistical Methods

In constructing the three groups, care was taken to ensure that they did not differ in terms of the previous knowledge (measured by Test 0) and neither of the hypothesised parameters (school ranking, mother's education, gender). This was checked by a chi-square test.

Cronbach's alpha values (Cronbach & Meehl, 1955) for the three tests were acceptable: 0.742 for T0 test, 0.692 for T1 test and 0.694 for T2 test.

Statistical analysis of data was done by the SPSS Statistics software. ANOVA and ANCOVA analyses were also performed. According to Howell (2012), ANCOVA can be used to adjust for the initial difference and to reflect the effect on the dependent variable. Raw mean scores (before ANCOVA analysis) and their standard deviations (SD) for the three groups were calculated for all the three tests (T0, T1 and T2) in the whole test ('TOTAL'), the DCK tasks and the EDS tasks. The effect of the intervention on the development of the experimental groups (Group 2 and Group 3) was shown by the Cohen's d effect size (Cohen, 1988). The Cohen's d effect size values were calculated taking into consideration the means and standard deviations of the three types of difference between the three test scores (T1 – T0, T2 – T1 and T2 – T0).

Although the Cohen's d effect size can be used to characterise the effect of development, it was assumed that apart from the three types of instructional methods used during the intervention for Group 1, 2 and 3, other hypothesised parameters (school ranking, mother's education, gender) and a covariate (prior knowledge, i.e. student scores for T0 test) had also influenced the results. Therefore, the statistical analysis of data was also accomplished by analysis of covariance (ANCOVA) to examine the effect in more detail. Effect sizes in the ANCOVA analysis were characterised by the calculated Partial Eta Squared (PES) values. In the case of multiple comparisons Bonferroni correction was applied. While testing the differences among groups and sub-groups, a significance value of $p<0.05$ was applied. However, a significance value of $p<0.025$ was used in the comparison of the results of Test 0 and Test 1, Test 1 and Test 2, Test 0 and Test 2, respectively (according to the Bonferroni correction).

It has also been considered that the results may be biased by the number of chemistry lessons per week that the groups of students in the sample have. Therefore, an ANCOVA analysis was conducted in which the sum of the number of chemistry lessons per week was also a covariate. However, the resulting PES values varied between 0.000-0.003 and were not significant.

Findings

According to the chi-squared test, there is no significant difference in the composition of the groups with respect to mother's education [X^2 (2, N = 756) = 2.844, p = 0.241)] and gender [X^2 (2, N = 756) = 2.523, p = 0.283)]. However, there is a significant difference in the composition of the groups with respect to school ranking [X^2 (4, N = 756) =13.86, p = 0.008)], as the difference is significant between Group 1 and Group 3 [X^2 (2, N = 517) =11.81, p = 0.003)]. This may be mainly due to the fact that Group 3 has a higher proportion in high ranking schools and a lower proportion of pupils in medium ranking schools than the other two groups.

Table 3 shows the raw mean scores, prior to ANCOVA analysis, and their standard deviations (SD) for the three groups for the T0 test for the whole test ("TOTAL"), the DCK tasks ("DCK"), the EDS tasks ("EDS") and the results of the ANOVA analysis. High standard deviations show that the sample was very heterogeneous according to their knowledge and skills as measured by the tests. ANOVA analysis revealed no significant difference between groups in the performance of either $T0_{TOTAL}$ or $T0_{DCK}$ or $T0_{EDS}$.

Table 3

The means of scores and their sd-s for the whole test ("total"), the dck tasks and the eds tasks of t0 and the results of the anova analysis (n=756)

Group	$T0_{TOTAL}$ (SD)*	$T0_{DCK}$ (SD)**	$T0_{EDS}$ (SD)**
Group 1	11.39 (3.76)	5.57 (1.77)	5.82 (2.64)
Group 2	11.47 (3.21)	5.65 (1.76)	5.82 (2.40)
Group 3	11.04 (3.55)	5.54 (1.69)	5.51 (2.57)
F(2, N = 756)	1.05	0.287	1.25
p	0.350	0.750	0.286
Sign.	-	-	-

Note: *Maximum scores: 18; **: Maximum scores: 9

Table 4 shows the mean raw scores, their standard deviations and the results of the ANOVA analysis for the three groups for T1 test. In all cases, the average raw scores for T1 were lower than for T0 tasks. This is understandable, as the knowledge and skills measured by T1 (and T2) were different to those measured by T0. (The three tests contained different tasks for the reasons explained earlier under the heading "Validity"). There is a significant difference among the performance of groups in $T1_{TOTAL}$, $T1_{DCK}$ and $T1_{EDS}$. The achievement of Group 3 exceeded that of the other two groups in the end of the first year (Grade 7) of this project., whereas Group 2 performed worse in T1 (because they scored significantly lower in $T1_{DCK}$) than the control group (Group 1) and the other experimental group (Group 3). These results are consistent with previously published trends (Szalay et al., 2023).

Table 4

The means of scores and their sd-s for the whole test ("total"), the dck tasks and the eds tasks of t1 and the results of the anova analysis (n=756)

Group	$T1_{TOTAL}$ (SD)*	$T1_{DCK}$ (SD)**	$T1_{EDS}$ (SD)**
Group 1	9.16 (3.66)	4.52 (2.14)	4.64 (2.15)
Group 2	8.55 (3.15)	4.04 (1.71)	4.50 (2.08)
Group 3	9.94 (3.40)	4.55 (2.00)	5.39 (2.11)
$F(2, N = 756)$	10.75	5.50	12.68
p	0.000	0.004	0.000
Sign.	2 < 1 < 3	2 < 1, 3	1, 2 < 3

Note: *Maximum scores: 18; **: Maximum scores: 9

Table 5 shows the mean raw scores and their standard deviations for the three groups for T2 test. Group 3 again outperformed the other two groups at the end of the second year of the project (Grade 8) in the experimental design tasks ($T2_{EDS}$) and thus in the whole test ($T2_{TOTAL}$). There was no significant difference between Group 2 and Group 1 in the results of the T2 test ($T2_{TOTAL}$) and its sub-tests ($T2_{DCK}$ and $T2_{EDS}$).

Table 5

the means of scores and their sd-s for the whole test ("total"), the dck tasks and the eds tasks of t2 and the results of the anova analysis (n=756)

Group	$T2_{TOTAL}$ (SD)*	$T2_{DCK}$ (SD)**	$T2_{EDS}$ (SD)**
Group 1	9.12 (3.36)	3.33 (2.05)	5.79 (2.03)
Group 2	9.53 (3.06)	3.60 (1.95)	5.92 (1.89)
Group 3	9.79 (3.17)	3.64 (2.18)	6.15 (1.85)
$F(2, N = 756)$	2.73	1.61	2.27
p	0.066	0.201	0.104
Sign.	1 < 3	-	1 < 3

Note: *Maximum scores: 18; **: Maximum scores: 9

For further analysis, the dependent variable was the difference between the three test scores (T1 – T0; T2 – T1 and T2 – T0). Based on the means and standard deviations of the differences between the three test scores (T1 – T0; T2 – T1 and T2 – T0), Cohen's d effect size values were also calculated that are presented in Table 15 in Appendix. These results clearly show that Group 2 developed better than the other two groups, especially in DCK tasks in the second year of the project. However, when comparing the results of the three groups over the first two years, the change in performance of Group 3 was still significantly better than the performance in the other two groups in the EDS tasks.

Previous experience had shown that performance can depend on several factors, not only on the intervention. Therefore, an ANCOVA analysis was conducted with test scores as the dependent variable. Group (the type of instruction methods), school ranking, mother's education and gender were the parameters. The covariate was prior knowledge (T0 test scores). This was also necessary because, after the two classes were omitted from the project in the second year, there was a significant difference in the composition of the groups in terms of school ranking. This adjustment can clarify the treatment effect in a research study. Partial Eta Squared (PES) values characterising the effect sizes are shown in Table 6-8.

Initially, as published earlier (Szalay et al., 2023) it was mainly the school ranking and, to a lesser extent, in the DCK tasks, the mother's education that had a significant effect on the scores. After the intervention in the first year (in the T1 test), three parameters were found to have significant effect sizes (PES) on the changes for the whole test and both sub-tests: group, school ranking and prior knowledge. Of these, prior knowledge had the largest effect size on the whole test (Table 6) and in the EDS tasks (Table 8). School ranking, however, had more effect in the DCK tasks than in the EDS tasks, while the instruction methods (“Group”) appeared to have more effect on performance in the EDS tasks than in the DCK tasks.

In the end of the second school year (in the T2 test), the same three parameters still seem to be important in the whole test (Table 6). However, only prior knowledge had a significant effect on changes in DCK tasks (Table 7). As for the changes in the EDS tasks in the second year, mother's education showed a significant but small effect. Among the other three parameters, school ranking had the largest and instruction methods ("Group") had the smallest effect size (Table 8).

Table 6

The effects of the assumed parameters (sources) and the covariate (prior knowledge, $t0_{total}$) on the changes for the whole test (“total”) in the beginning of the project (t0), in the end of grade 7 (t1) and in the end of grade 8 (t2) (n=756)

Parameter (Source)	PES (Partial Eta Squared)		
	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$
Group	0.005	0.042*	0.012*
School ranking	0.109*	0.046*	0.009*
Mother’s education	0.010*	0.004	0.001
Gender	0.006	0.000	0.000
Prior knowledge ($T0_{TOTAl}$)	-	0.136*	0.102*

Note: * Significant at p < 0.025 level (Bonferroni correction)

Table 7

The effects of the assumed parameters (sources) and the covariate (prior knowledge, $t0_{dck}$) on the changes for the dck tasks (“dck”) in the beginning of the project (t0), in the end of grade 7 (t1) and in the end of grade 8 (t2) (n=756)

Parameter (Source)	PES (Partial Eta Squared)		
	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$
Group	0.001	0.018*	0.004
School ranking	0.033*	0.079*	0.001
Mother’s education	0.021*	0.002	0.002
Gender	0.009*	0.000	0.001
Prior knowledge ($T0_{DCK}$)	-	0.053*	0.049*

Note: * Significant at p < 0.025 level (Bonferroni correction)

Table 8

The effects of the assumed parameters (sources) and the covariate (prior knowledge, $t0_{eds}$) on the changes for the eds tasks (“eds”) in the beginning of the project (t0), in the end of grade 7 (t1) and in the end of grade 8 (t2) (n=756)

Parameter (Source)	PES (Partial Eta Squared)		
	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$
Group	0.006	0.040*	0.011*
School ranking	0.113*	0.023*	0.059*
Mother’s education	0.001	0.005	0.010*
Gender	0.001	0.001	0.002
Prior knowledge ($T0_{EDS}$)	-	0.070*	0.045*

Note: * Significant at p < 0.025 level (Bonferroni correction)

The effects of the assumed parameters “Group” and “School ranking” estimated by the model of the ANCOVA analysis (absolute mean scores) for the whole test, the DCK tasks and the EDS tasks, as well as the significance of their differences for the three tests are shown in the Tables 16-17 in

Appendix. These data show that there is no significant difference among the achievement of the three groups in the DCK sub-test of T2 (Table 16). However, Group 3 significantly outperformed the control group in the EDS tasks in the first two years.

The relative estimated average scores (ratios of the estimated mean scores of the experimental groups compared to that of the control group's) for the whole test and for the sub-tests in the beginning of the project (Grade 7, T0) are shown in Table 9, in the end of first school year (Grade 7, T1) in Table 10 and in the end of second school year (Grade 8, T2) in Table 11.

Table 9

The estimated mean scores of the experimental groups divided by the estimated mean scores of the control group for the whole test ("total"), in the dck tasks ("dck") and eds tasks ("eds") in test 0 (n=756)

Ratio	$T0_{TOTAL}$	$T0_{DCK}$	$T0_{EDS}$
Group 2 / Group 1	1.00	1.01	1.00
Group 3 / Group 1	0.96	0.99	0.93

The data in Table 10 show that, taking the changes in DCK tasks into account, Group 2 performed poorly at the end of the first year compared with the other two groups (Szalay et al., 2023).

Table 10

The estimated mean scores of the experimental groups divided by the estimated mean scores of the control group for the whole test ("total"), in the dck tasks ("dck") and eds tasks ("eds") in test 1 (n=756)

Ratio	$T1_{TOTAL}$	$T1_{DCK}$	$T1_{EDS}$
Group 2 / Group 1	0.93	0.89	0.97
Group 3 / Group 1	1.10	1.00	1.17

However, at the end of the second year (Table 11), the ratio of DCK scores was almost the same in both experimental groups. A significant increase in the performance in the EDS tasks was observed in Group 3 at the end of the first year (Table 10, Szalay et al., 2023). At the end of the second year, both experimental groups performed better in the EDS tasks than the control group, but Group 3 still achieved better results than Group 2 (Table 11).

Table 11

The estimated mean scores of the experimental groups divided by the estimated mean scores of the control group for the whole test ("total"), in the dck tasks ("dck") and eds tasks ("eds") in test 2 (n=756)

Ratio	$T2_{TOTAL}$	$T2_{DCK}$	$T2_{EDS}$
Group 2 / Group 1	1.04	1.07	1.03
Group 3 / Group 1	1.09	1.08	1.08

Next, an ANCOVA analysis was conducted with the changes in test scores (T1 – T0, T2 – T1, T2 – T0) as the dependent variables, group (instruction methods), school ranking, mother's education, and student's gender as the parameters, and the student's prior knowledge (T0 test scores) as the covariate. The results of that ANCOVA analysis are presented in Table 18 in Appendix. These data also show that, among the assumed parameters, mostly the group (type of instruction methods), school ranking and prior knowledge had a significant effect on pupils' performance on the tests. The values estimated by the ANCOVA model showing the effect of the assumed parameters on changes in their performance in the whole tests and sub-tests are shown in the Tables 19-22 in Appendix. Table 19 in Appendix shows that there was no significant difference among the three groups in the development of DCK tasks in the first two years of the project. However, Group 3 performed significantly better in the EDS tasks than the control group during this period. In the second year of this project, school ranking had a significant effect on scores (Appendix, Table 20). It is interesting to note, however, that the higher the school rank, the lower the change in performance in terms of scores in the DCK tasks in the second year, while in terms of changes in scores in the EDS tasks, students from low-ranking schools performed significantly worse than students from medium- and high-ranking schools. It might also be noteworthy that students with a graduate mother showed weaker progress in the second year in the DCK sub-test than the others, but better progress in the EDS sub-test during the two years (Appendix, Table 21). No significant difference was found between the changes in boys' and girls' performance at any time or in any type of test scores (Appendix, Table 22).

The Cohen's d effect size values calculated by the ANCOVA model from the estimated changes in students' performance in the tests are presented in Table 12 for the whole test, Table 13 for the DCK tasks and Table 14 for the EDS tasks.

Table 12

Cohen's d effect size values calculated by the ancova model from the estimated changes in students' performance on the tests for the whole test ("total") (n=756)

Cohen's d	$T1_{TOTAL} – T0_{TOTAL}$	$T2_{TOTAL} – T1_{TOTAL}$	$T2_{TOTAL} – T0_{TOTAL}$
Group 2 / Group 1	-0.19	0.27	0.12
Group 3 / Group 1	0.25	-0.01	0.24
Group 3 / Group 2	0.44	-0.28	0.12

Table 13

Cohen's d effect size values calculated by the ancova model from the estimated changes in students' performance on the tests for the dck tasks ("dck") (n=756)

Cohen's d	$T1_{DCK} – T0_{DCK}$	$T2_{DCK} – T1_{DCK}$	$T2_{DCK} – T0_{DCK}$
Group 2 / Group 1	-0.24	0.28	0.10
Group 3 / Group 1	0.01	0.10	0.12
Group 3 / Group 2	0.24	-0.18	0.02

Table 14

Cohen's d effect size values calculated by the ancova model from the estimated changes in students' performance on the tests for the eds tasks ("eds") (n=756)

Cohen's d	$T1_{EDS} – T0_{EDS}$	$T2_{EDS} – T1_{EDS}$	$T2_{EDS} – T0_{EDS}$
Group 2 / Group 1	-0.07	0.13	0.09
Group 3 / Group 1	0.34	-0.12	0.23
Group 3 / Group 2	0.41	-0.26	0.14

Discussion

Based on these data, it appears that Group 2 had caught up with Group 3 in the second year in terms of a positive, but quite small, change in performance in DCK tasks compared to that of the control group's (Table 13). Group 2 also improved better than the control group in terms of performance in the EDS tasks in the second year (Table 14). However, over the two years, Group 3 of the two experimental groups still developed better in the EDS tasks than Group 2. It appears, therefore, that both using the questions while designing the experiments to be carried out (for Group 3) and answering the questions after carrying out the step-by-step experiments (for Group 2) can help students to achieve better results in the EDS tasks but using the questions to help to design the experiments in practice (Group 3) still produced better results in long term. Changes in EDS were higher than changes in DCK. These results are in line with Bredderman (1983), who reported that the use of inquiry-based methods had a greater effect on science process than on science content.

These results might have been caused by the different treatments of the two groups. Group 2 students did not have to plan experiments. Those classes had to discuss with their teacher why the experiments were designed as they were (according to the questions on their worksheets). This could be seen as a "theoretical" method for learning about experimental design, which might take longer for students to realise how to apply it in practice, which could have happened by the end of the second year. We can fully support Potier's (2023) claim that the skills needed to succeed with guided inquiry approaches take time to develop. On the other hand, Group 3 had to design experiments, in teams, while they were answering questions helping to learn experimental design. This can be seen as a direct "practical" way of learning experimental design. This may be the reason why it made an impact in the first year and had a significant positive effect on the experimental design skills by the end of the two years period. The treatment of Group 3 is similar to that of the "critical thinking" pre-laboratory group described by van Brederode et al. (2020). On the other hand, the treatment of Group 2 resembles to the "paved road" pre-laboratory group of the same study. The present findings show that the intervention for Group 3 produced better results, as was the case for the "critical thinking" group. These results are also consistent with the study by Tseng et al. (2022), where evaluative reflection on peers' experimental designs improved students' scientific inquiry performance in formulating research questions and designing experimental procedures more than the recognition of variables in designing experimental procedures. The present findings seem to support Matthews' (2018) claim too that learners can gain meaningful insights into the construction of scientific knowledge through processes of inquiry, reasoning and planning, but only if they are properly organised and reflected upon. The findings in connection with Group 3 also support that adequate and appropriate scaffolds should be provided for students coming from a traditional teaching style to successfully complete an investigation task based on inquiry-based learning (Seery et al., 2019a).

The ANCOVA model calculations show that the mother's education had only a weak significant effect on the development of the experimental design skills in this project in the first two years. This seems to contradict the Education and Training Monitor (2020) report, which shows that socio-economic background is a strong predictor of student performance. This can be explained by the fact that the sample of the present study is not representative of the cohort, as these pupils had gone through a very tough selection process when they took the entrance exam to their current school.

School ranking is still an important parameter according to the present results, as it had a significant impact on EDS scores in both years. This is understandable, as Siegler et al. (2010) argue that school is the microsystem that, alongside the family environment, has the strongest influence on youngsters' development. Within this context, the interaction between teachers and learners has a profound influence on pupils' motivation towards chemistry as a subject.

The gender still did not seem to have any significant effect on the achievement in any type of the test scores in the present study. This is in line with the results of other authors, who did not find any significant difference in students' acquisition of science process skills (SPSs) with respect to gender (Ofoegbu, 1984, Walters & Soyibo, 2001; Böyük et al., 2011; Güden & Timur, 2016). However, Tosun's (2019) study revealed that the most important predictive variables on SPS level were gender, grade level and mothers' education level from the examined demographical features. Onukwo (1995) also found a significant gender difference in the levels of SPS.

The means of the T1 test scores estimated by the ANCOVA model at the end of the first year (Szalay et al., 2023) and the means of the T1 test scores estimated by the ANCOVA model at the end of the second year (after the sample composition changed) were compared. The difference was found to be very small, ranging from 0.2 to 3.6%, with an average difference of 2.0%. Thus, it seems that the changes in the composition of the groups were handled well by this analysis.

Conclusion and Implications

Summary of the Results and Answers to the Research Questions

The statistical analysis of the results measured at the end of the second year of the present four-year project showed similar results to those measured at the end of the first year, in the sense that four of the assumed parameters had a significant effect on the Grade 8 pupils' scores in the tasks intending to measure the experimental design skills: the intervention, the school ranking, the prior knowledge and, to a much lesser extent, the mother's education. Of these four, school ranking seemed to have the biggest impact on performance in the second year. Prior knowledge, which had the highest PES value at the end of the first year, still appears to have a larger effect than the intervention. The intervention did not seem to have a significant effect on scores in the tasks measuring disciplinary content knowledge at the end of the second year of the project.

The answers to the research questions are as follows.

RQ1: By the end of the second year, the intervention resulted in a significant positive change in the experimental design skills (EDS) of Group 3 participants compared to the control group (Group 1), as measured by the tests (Cohen's d: 0.23). It is reasonable to assume that this was due to the fact that the Group 3 worksheets included questions to support experimental design. Although the change in the performance of Group 2 in EDS tasks by the end of the second year was also positive compared to that of the control group's (Cohen's d: 0.09), it was not found significant.

RQ2: By the end of the second year of the present project, no significant difference in the change in disciplinary content knowledge (DCK) among the three groups could be measured (Cohen's d for Group 2: 0.10 and Group 3: 0.12, respectively).

RQ3: No statistically significant difference was found between the mean scores of the two experimental groups, considering the extent to which their experimental design skills developed during the first two years of the project (Cohen's d: 0.14).

It should be noted that in the first year, the change in performance of Group 3 on the EDS tasks was significantly better than the change in performance of Group 2 students (Cohen's d: 0.41). In the second year, however, this trend was reversed, and Group 2 improved better than Group 3 (Cohen's d: -0.26).

Currently, the use of the Group 3 worksheets and similar experimental design tasks using the set of questions can be relatively confidently recommended to practising teachers. However, since Group 2 in the second year of the project performed significantly better than the Group 3 in the EDS tasks of the test, it may be useful for colleagues who are reluctant to teach the experimental design directly to try using the worksheets for Group 2 and to have their pupils answer the questions after completing the step-by-step experiments.

Limitations

Compared to the previous year's sample size, the number of participants decreased. This was due to the two missing full classes and many pupils missing from other classes at the time of the T2 test. This is unfortunate, but the reasons mentioned earlier were beyond the control of the research team.

The sample was not representative of the examined cohort of learners (Grade 8, 13-14 years old). Rather, it was representative of higher achieving students, as they were selected by entrance exams to the participating schools. The reason for this is that the pupils have to stay in the same school for the four years of the project. This only allows those from schools that teach chemistry as a separate subject from Grade 7 to Grade 10 to participate.

No single study can evaluate every variable and every theoretical relationship underlying an instructional model (Mack et al., 2019). In addition, the instruments used (40 minutes paper-based tests) could only provide a limited picture of how pupils had benefited from the interventions. As reading comprehension is key to performance in science (Neri et al., 2021), it may have also influenced the results.

Performance on any assessment is at least partially driven by the learners' motivation for success on the measure and test taking abilities (Cannady et al., 2019). There is a well-documented positive relationship between affective dimensions (and within these, attitudes, motivation and interest) and academic performance in chemistry (e.g. Wang & Lewis, 2022). This is a particular problem when it comes to measuring change in longitudinal studies such as this one, as learners' motivation to learn science often declines as they move from one grade to the next (Schunk et al., 2014; Vedder-Weiss & Fortus, 2011; Vedder-Weiss & Fortus, 2013). Although the research team tried to find contexts that were likely to be of interest to the learners (see Table 1 in Appendix), probably not everyone was equally engaged.

This research will continue for two more years, following the same research model. It is possible that different results or even different trend changes may be observed in the coming years. There are many random events that can affect the final data. Although the relatively large sample size should compensate for most of these, we can never be absolutely sure (Lawrie, 2021).

Implications

The trends in the development of the two experimental groups in the second year of the project were different from those observed in the first year (Szalay et al., 2023). The experimental design skills of Group 2 seemed to improve significantly more than that of the Group 3 in the second year, while the reverse was true in the first year. From the start of the project to the end of the second year, however, still only Group 3 showed significantly more improvement in experimental design skills than the control group. Therefore, the current results still show that it is probably useful to base practical activities on designing experiments by answering questions to help them through the process. This is because significantly more pupils in Group 3 than in Group 1 seemed to have understood how to do a fair test correctly during the two years of the project. The usefulness of an experimental design plan, a simplified version of the one described by Cothron et al. (2000) seemed to be still justified. When no such scaffolding was used, in the first year of the previous longitudinal study, the development of EDS was not detectable by the tests (Szalay et al., 2020). This is in agreement with Baird's view (1990) that purposeful inquiry does not happen spontaneously – it must be learned. It is also interesting to note that providing scaffolding in problem-based learning also had a positive impact on creative thinking even at university level (Ernawati et al., 2023). Similar to the results published by other authors (e.g. Reynders et al., 2019), the results of the first two years of the present project suggest that school learners need further support to understand the skills of cognitive processes and to see how these skills manifest in their laboratory work. This might help to alleviate their cognitive load.

Social variables, prior knowledge and "school effects" (including the teacher's effect), which the literature (e.g. Snook et al., 2009) considers as variables affecting performance, were also found to be important in both years of this research.

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Conflicts of Interest

There are no conflicts of interest to declare.

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Appendix

Table 1

Topics and context of the worksheets and teacher guides used in the school year 2022/2023

No	Topic	Experiments that Group 1 and Group 2 pupils had to do following step-by-step instructions, but Group 3 pupils had to design before doing the experiment	Context and elements of systems thinking in the "Let's think!" parts for motivation purposes. These are the same on the student worksheets of all the three groups.
7.	Reactivity series of metals and hydrogen, (redox reaction, electron transfer)	Pupils are given household hydrochloric acid, a piece of copper wire, a piece of aluminium foil, 2 test tubes or other containers and tweezers. Group 3 pupils have to design experiments to find out whether copper and aluminium are on the left or right side of hydrogen in the reactivity series. They are told that the metals and hydrogen are positioned in the reactivity series in the order of decreasing reducing power, from left to right.	Unlike the oxide layer on the surface of aluminium, the rust that forms on the surface of iron cannot protect it from the environment because it does not form a solid protective layer. Therefore, iron must be protected from rusting, for example by metal coatings made of tin or zinc. Pupils have to decide (using the reactivity series) whether such coatings can (theoretically) be produced by immersing the iron sheet in a solution containing tin (II) ions or zinc ions.
8.	Hardness of water, use of water softeners (precipitation reactions)	Pupils are given mineral water with high calcium ion content, trisodium phosphate, washing soda, soap solution, 3 test tubes with stoppers, 2 beakers, a measuring cylinder, 2 laboratory spoons, a Pasteur pipette and a ruler. Pupils watch a video to demonstrate the effect of cations that cause the hardness of water by measuring the height of the soap foam after shaking. Using a table that shows which anions form precipitates with the various cations, Group 3 pupils must work out which compounds could be used as water softener and show this by experiment.	1. According to several websites, commonly used household baking soda ($NaHCO_3$) is also suitable for water softening. After watching a video about the experiment, pupils have to decide whether this is true or false. 2. Pupils are explained that carbon dioxide dissolves in water and reacts with calcium carbonate in limestone. This converts it into water-soluble calcium bicarbonate, forming hard water. When the hard water loses some of its carbon dioxide content, the calcium carbonate precipitates as limescale or in form of stalactites. Pupils have to work out which of these processes is favoured by a rise or fall in temperature.
9.	Modelling industrial processes (production and use of quicklime and slaked lime)	Pupils are given distilled water, a piece of limestone, another piece of stone that is not limestone, phenolphthalein solution, 3 beakers or glasses, a Pasteur pipette, tweezers, an alcohol burner and matches. Pupils are explained how calcinated or quicklime /CaO/ and slaked or hydrated lime /Ca(OH)2/ are prepared of limestone. Pupils look at the reaction equations to understand that slaked lime is an alkaline substance. They then have to decide which of the stones on the trays is limestone that could be used to produce quicklime.	Pupils are explained that slaked lime mixed with sand and water forms mortar that can be used to fix bricks or plaster walls. In both cases, the slaked lime binds carbon dioxide in the air while converting into calcium carbonate and producing water. Next, pupils have to decide whether water and carbon dioxide are used or produced in the different steps of the process of making and using slaked lime.
10.	Modelling environmental processes (acid base reactions, pH, effects of acid rain)	Pupils are given tap water, pulverized limestone, sand, vinegar, red cabbage juice, 3 glasses, 2 Pasteur pipettes or eye droppers, 2 (lab) spoons. Pupils are explained that acid rain is mainly caused by the combustion of sulphur-containing carbon. They then need to investigate how the pH change in the lake water caused by acid rain is affected by the material (limestone or sandstone) on the lakebed.	Pupils are explained that calcium carbonate is the main component of limestone and the skeleton of calcareous aquatic organisms because limestone was formed from these organisms. Pupils are then asked to work out how acid rain affects the living conditions of calcareous animals (e.g. mussels, snails, corals) living in natural waters and how this effect may be influenced by the amount of sulphur-containing carbon burnt by humans.

11.	Modelling qualitative analysis (nutrients, health and diet)	Pupils are given granulated sugar, glucose, birch sugar (xylitol), 3 test tubes, test-tube rack, alcohol or Bunsen burner, matches, watch glass or ashtray. Pupils are explained that sugars can be caramelized, and the topping of a famous cake is made of that shiny caramel. Pupils are then shown that it is written on a website that a caramel cake topper for diabetics is made from birch sugar. Pupils have to decide whether this is true or false (i.e. whether birch sugar is really sugar or not).	Pupils are explained the dangers of diabetes when blood glucose levels are higher than 3.5-6 millimoles per litre. They also read that insulin lowers blood glucose levels. On the other hand, they learn that it is important to have enough glucose in the blood at all times. In case of stress, when cells use up a lot of glucose from the blood, blood glucose level drops. Glucose must then be replaced from the liver. Finally, using a few words and numbers given on the worksheet, pupils should complete a diagram showing how these opposing processes keep the blood glucose level within the range given.
12.	Plastics - pros and cons (household waste, raising environ-mental awareness)	Pupils are given 2 beakers/glasses with 100-100 cm^3 distilled water, 2 beakers/glasses with 0.1-0.1 g superabsorbent polymer (SAP), 1 measuring cylinder, 1 glass rod, 1 stand with clamp and ring, 1 glass funnel, 2 filter papers, 1 (lab) spoon, stopwatch/mobile phone with stopwatch function, 1 g sodium chloride. Pupils are told that superabsorbent polymers (abbreviated as "SAP") used in disposable paper nappies and sanitary pads are nowadays considered by many people indispensable. These plastics can absorb up to several hundred times their weight in various water-containing liquids. Then pupils have to determine whether the SAP in nappies and pads can absorb larger volumes of distilled water or body fluids such as urine or blood.	Pupils are told that in recent years more and more parents are choosing washable nappies to protect the environment. However, many people question whether these products are really environmentally friendly, for example because of the potential waste of water during washing. Pupils are given data to calculate whether using washable nappies requires more or less water than disposable nappies, generates more or less waste and is therefore a more or less environmentally friendly choice. They should also calculate which is more cost-effective. Finally, they have to decide which option they would choose.

Table 15

The Cohen's d Effect Size Values Calculated from the Means and Standard Deviations of the Differences Between the Test Scores (T1 - T0; T2-T1 and T2-T0) for the Whole Test ("TOTAL"), the DCK Tasks ("") and the EDS Tasks ("EDS") (N=756)

	TOTAL			DCK			EDS		
	T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0
Group 2/ Group 1	-0.19	0.29	0.09	-0.25	0.34	0.09	-0.05	0.12	0.05
Group 3 / Group 1	0.32	-0.03	0.26	0.06	0.11	0.14	0.40	-0.16	0.26
Group 3 / Group 2	0.51	-0.25	0.19	0.28	-0.20	0.06	0.44	-0.31	0.21

Table 16

The Effects of the Assumed Parameter "Group" (Instruction Methods) Estimated by the Model of the ANCOVA Analysis (Absolute Mean Scores) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK"), the EDS Tasks ("EDS") and the Significance of their Differences for the Three Tests (N=756)

Group	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$
Group 1	11.01	8.90	9.00	5.32	4.40	3.43	5.69	4.47	5.55
Group 2	11.06	8.26	9.40	5.37	3.91	3.66	5.69	4.32	5.73
Group 3	10.55	9.75	9.0	5.25	4.41	3.71	5.311	5.24	6.02
Significant difference*	-	2 < 1 < 3	1 < 3	-	2 < 1, 3	-	-	1, 2 < 3	1 < 3

Note: * p<0.05

Table 17

The Effects of the Assumed Parameter "School Ranking" Estimated by the Model of the ANCOVA Analysis (Absolute Mean Scores) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK"), the EDS Tasks ("EDS") and the Significance of their Differences for the Three Tests (N=756)

School ranking	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$
1. Low	9.76	8.30	8.98	5.13	3.64	3.69	4.63	4.47	5.11
2. Medium	10.43	8.70	9.50	5.06	4.15	3.51	5.37	4.44	5.91
3. High	12.43	9.91	9.73	5.74	4.94	3.61	6.69	5.12	6.27
Significant difference*	1 < 2 < 3	1, 2 < 3	1 < 3	1, 2 < 3	1 < 2 < 3	-	1 < 2 < 3	1, 2 < 3	1 < 2 < 3

Note: * p<0.05

Table 18

The Effects of the Assumed Parameters (Sources) and the Covariate ("Prior Knowledge", T0) on the Changes in Test Scores (T1 - T0, T2 - T1, T2 - T0) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK") and the EDS Tasks ("EDS") in the Beginning of the Project (T0), in the End of Grade 7 (T1) and in the End of Grade 8 (T2) (N=756)

Parameter (Source)	PES (Partial Eta Squared)								
	TOTAL			DCK			EDS		
	T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0	T1 – T0	T2 – T1	T2 – T0
Group	0.042*	0.023*	0.012*	0.018*	0.018*	0.004	0.040*	0.014*	0.014*
School ranking	0.046*	0.015*	0.009	0.079*	0.057*	0.001	0.023*	0.019*	0.059*
Mother's education	0.004	0.001	0.001	0.002	0.006	0.002	0.005*	0.000	0.010*
Gender	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.003	0.002
Prior knowledge (T0)	0.333*	0.003	0.365;	0.335*	0.000	0.270*	0.464*	0.005	0.565*

Note: * Significant at p < 0.025 level (Bonferroni correction

Table 19

The Values Estimated by the ANCOVA Model Showing the Effect of the Assumed Parameter "Group" (Instruction Methods) on Changes in Performance (T1 – T0, T2 – T1, T2 – T0) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK") and the EDS Tasks ("EDS") (N=756)

Group	$T1_{TOTAL}$ – $T0_{TOTAL}$	$T2_{TOTAL}$ – $T1_{TOTAL}$	$T2_{TOTAL}$ – $T0_{TOTAL}$	$T1_{DCK}$ – $T0_{DCK}$	$T2_{DCK}$ – $T1_{DCK}$	$T2_{DCK}$ – $T0_{DCK}$	$T1_{EDS}$ – $T0_{EDS}$	$T2_{EDS}$ – $T1_{EDS}$	$T2_{EDS}$ – $T0_{EDS}$
Group 1	-2.40	0.09	-2.31	-1.19	-0.97	-2.16	-1.25	1.08	-0.17
Group 2	-3.05	1.15	-1.90	-1.67	-0.25	-1.92	-1.40	1.41	0.01
Group 3	-1.56	0.05	-1.51	-1.18	-0.70	-1.88	-0.48	0.77	0.30
Significant difference*	2 < 1 < 3	1, 3 < 2	1 < 3	2 < 1, 3	1, 3 < 2	-	1, 2 < 3	3 < 2	1 < 3

Note: * Significant at p < 0.025 level (Bonferroni correction)

Table 20

The Values Estimated by the ANCOVA Model Showing the Effect of the Assumed Parameter "School Ranking" on Changes in Performance (T1 – T0, T2 – T1, T2 – T0) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK") and the EDS Tasks ("EDS") (N=756)

School ranking	$T1_{TOTAL} - T0_{TOTAL}$	$T2_{TOTAL} - T1_{TOTAL}$	$T2_{TOTAL} - T0_{TOTAL}$	$T1_{DCK} - T0_{DCK}$	$T2_{DCK} - T1_{DCK}$	$T2_{DCK} - T0_{DCK}$	$T1_{EDS} - T0_{EDS}$	$T2_{EDS} - T1_{EDS}$	$T2_{EDS} - T0_{EDS}$
1. Low	-3.01	0.68	-2.33	-1.95	0.05	-1.90	-1.25	0.64	-0.61
2. Medium	-2.61	0.80	-1.81	-1.43	-0.64	-2.08	-1.28	1.47	0.19
3. High	-1.40	-0.18	-1.58	-0.65	-1.33	-1.98	-0.48	1.15	0.55
Significant difference*	1, 2 < 3	3 < 1, 2	1 < 3	1 < 2 < 3	3 < 2 < 1	-	1, 2 < 3	1 < 2, 3	1 < 2 < 3

Note: * Significant at $p < 0.025$ level (Bonferroni correction)

Table 21

The Values Estimated by the ANCOVA Model Showing the Effect of the Assumed Parameter "Mother's Education" on Changes in Performance (T1 – T0, T2 – T1, T2 – T0) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK") and the EDS Tasks ("EDS") (N=756)

Mothers' education	$T1_{TOTAL} - T0_{TOTAL}$	$T2_{TOTAL} - T1_{TOTAL}$	$T2_{TOTAL} - T0_{TOTAL}$	$T1_{DCK} - T0_{DCK}$	$T2_{DCK} - T1_{DCK}$	$T2_{DCK} - T0_{DCK}$	$T1_{EDS} - T0_{EDS}$	$T2_{EDS} - T1_{EDS}$	$T2_{EDS} - T0_{EDS}$
1. No degree in higher education	-2.61	0.60	-2.01	-1.47	-0.40	-1.87	-1.24	1.04	-0.20
2. Has a degree in higher education	-2.07	0.26	-1.81	-1.22	-0.88	-2.10	-0.84	1.14	0.29
Significant difference*	-	-	-	-	2 < 1	-	-	-	1 < 2

Note: * Significant at $p < 0.025$ level (Bonferroni correction)

Table 22

The Values Estimated by the ANCOVA Model Showing the Effect of the Assumed Parameter "Gender" on Changes in Performance (T1 – T0, T2 – T1, T2 – T0) for the Whole Test ("TOTAL"), the DCK Tasks ("DCK") and the EDS Tasks ("EDS") (N=756)

Gender	$T1_{TOTAL} - T0_{TOTAL}$	$T2_{TOTAL} - T1_{TOTAL}$	$T2_{TOTAL} - T0_{TOTAL}$	$T1_{DCK} - T0_{DCK}$	$T2_{DCK} - T1_{DCK}$	$T2_{DCK} - T0_{DCK}$	$T1_{EDS} - T0_{EDS}$	$T2_{EDS} - T1_{EDS}$	$T2_{EDS} - T0_{EDS}$
1. Boy	-2.29	0.35	-1.95	-1.32	-0.61	-1.93	-0.99	0.97	--0.03
2. Girl	-2.38	0.52	-1.87	-1.37	-0.66	-2.04	-1.09	1.21	0.12
Significant difference*	-	-	-	-	-	-	-	-	-

Note: * Significant at $p < 0.025$ level (Bonferroni correction)

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Preschool children's mental models of the environment: A cross-level study

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ABSTRACT
This study, aiming to reveal preschool children's mental models of their environment, was carried out with the participation of 225 children aged 36–72 months attending 8 different preschool education institutions. It is based on qualitative research designed around a case study. The Word Association Test and Drawing were used as the data collection tools. In the study, it was observed that 36-48-month-old children mostly focused on the visuals they saw in the park (garden) and traffic in their environmental drawings, and in addition to these visuals, 49-60-month-old children included the forest in their environmental drawings, and 61-72-month-old children included home and school in their environmental drawings. The most prominent environments/elements observed with both data collection tools were the house, traffic, park, and sky for the 36–48-month-old children; house, traffic, park, sky, and rural-village for the 49–60-month-old children; and house, traffic, park, sky, rural-village, forest and nearby settlement (market, store, etc.) for the 61–72-month-old children. The common elements that children associate with the environment in their mental models are the concepts of house, traffic, park, and sky.

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Introduction

Scientific literacy is the fundamental vision of contemporary science curricula and is among the main objectives that all individuals should acquire, regardless of their differences (MoNE, 2005; 2013; 2018). Specific skills and competencies have been defined to help learners at different levels of education achieve this goal. The efforts focus on developing these various competencies from primary education on. They include educational outcomes such as scientific process skills, scientific method and scientific argumentation. One of the most important learning environments where these competences can be acquired is the natural environment we live in. But this environment we live in has recently been exposed to pollution and needs to be protected and awareness should be raised about it. Therefore, environmental education should be given from an early age (Gülay & Önder, 2011). In this context, environmental education has been integrated directly or indirectly into curricula, regardless of the branch of study. In addition, many governments, institutions, and organizations, that focus on developing environmental awareness, support research to develop environmental literacy among children (Karatekin & Aksoy, 2012).

Environmental Education in Early Childhood in Turkey

Robertson (1993) made a point of the need to provide children with the necessary knowledge and skills to protect and improve the environment with all its living and non-living components as one of the important goals of environmental education and proceeded to note the importance of understanding the factors that shape children's understanding of the environment. A similar emphasis is inherent in the current curriculum, with the preschool education programme noting the need for instilling environmental awareness and correct attitudes towards the environment, in children (MoNE, 2013).

To ensure that environmental education in Turkey continues in a systematic and programmed manner from preschool to subsequent stages of education, the Ministry of Environment and the Ministry of National Education on 14.10.1999 signed a "Cooperation Protocol on Studies to be Conducted on Environmental Education" (Bakar, 2019). The protocol is particularly noteworthy in the context of this study, given its call for the 'focus on applied environmental education to raise environmental awareness in preschool and primary school children'. Şimşekli (2001), referring to the said protocol's other provisions regarding primary education, stated the importance of addressing issues such as protecting the environment, recycling, and preventing environmental pollution within the scope of applied environmental education at preschool and primary education institutions. Despite the emphasis on environmental education in various reports drawn up in the past few years, no curriculum other than the 'Minik TEMA Education Programme' exists in the environmental education scene in preschool education in Turkey. Still, it is seen that in the Preschool Education Programmes of 2002 and 2006, as well as the updated 2013 version, the subject of environment is covered on certain days and weeks, with emphasis on this element in the outcomes and explanations thereof (Bakar, 2019). In this context, teachers carry out environmental education in various environments and contexts, such as museum visits, picnics, school yards, and house gardens, and stimulate children's pre-existing interest and curiosity on the topic (MoNE, 2006).

Overview of Studies on Environmental Education in Early Childhood

The preschool period is a starting point for the attainment of environmental knowledge, attitudes, awareness, and skills (Ayvacı et al., 2021). For this reason, it is important to plan and implement educational activities that increase children's awareness of the environment, encourage them to take responsibility, and are based on the principle of 'environment first' (Gezgin Vural & Kılıç Mocan, 2022; Kıralioğlu & Ürey, 2023).

The basis of an effective environmental education programme is to know how individuals perceive the environment and the factors affecting these perceptions (Kıvrak & Uyanık, 2020). At birth, the individual perceives his/her environment through environmental stimuli and interactions (Çabuk, Teke & Baş, 2020). However, the perception of the environment depends not only on the characteristics of the environment but also on the needs, actions, motives, and cognitive processes of the individual (Barraza, 1999; Brawn et.al., 1980). Bloom (2012) emphasizes the learner's cognitive input behaviors and prior knowledge about the subject. Ayvacı et al., (2021) also state that for effective environmental education and practice, it is necessary first to determine and reveal the current state of children's mental processes and perceptions about the environment. Therefore, for an effective environmental education program to be prepared for preschool children, it is important to determine the perceptions of children of that age toward the environment.

In the literature, we find studies addressing the views of teachers (Güzelyurt & Özkan, 2018, Türkoğlu, 2019) and pre-service teachers (Güsta-Şahin & Doğu, 2018; Öztürk & Öztürk, 2015) on environmental education and ecological awareness (Okyay et al., 2021; Üstün & Ürey, 2024), primary school children's awareness-attitudes towards the environment (Çelikler et al., 2019; Çetin & Badem, 2015, Durkan et al., 2015; Kıvrak & Uyanık; 2020, Yurttaş & Erdal-Kartal, 2021) and the impact of environmental education activities/courses on children's ecological awareness were examined (Akbayrak & Kuru Turaşlı, 2017; Emsal Aydın, 2018; Gezgin Vural & Kılıç Mocan, 2022; Kazu & Ödemiş, 2023; Polat & Demirci, 2021; Yılmaz et al., 2020). There are also studies finding that nature-based early childhood programmes develop a basic appreciation for the natural world (Larimore, 2016), that spending time in nature strengthens all areas of children's development (Gill, 2014), contributes to general health (Twohig-Bennett & Jones, 2018) and even to children's emotional regulation (Tillmann et al., 2018). In Turkey, although environmental education studies have been analyzed (Ogelman & Güngör, 2015; Gülay & Ekici, 2010; Alkan et al., 2022) and scale development and adaptation studies on the environment have been conducted (Aslan et al., 2008; Cevher Kalburan, 2009; Koçak Tümer, 2015), and also preschool children's science-related learning needs and their teachers' science activity practices have been investigated (Yıldız Taşdemir & Güler Yıldız, 2024), a limited number of studies examining preschool children's perception of nature (Köşker, 2019) and environment (Ahi, 2017; Ahi & Alisinanoğlu, 2016; Bakar, 2019; Konur & Akyol, 2017; Yurttaş, 2023) have been identified. In the literature, although the mental model is an internal representation of children's conceptual understanding (Batlolona et al., 2020), no longitudinal-comparative study has been encountered to reveal the mental models of children in the preschool period. This study is thought to provide information about 4-5-6-year-old children's mental models of the environment, fill the research literature gap and contribute to environmental education programmes, and may expand the scope of previous studies.

The study also contributes to the literature in terms of data collection tools. Because, in the limited number of studies trying to determine preschool children's mental models of the environment, interviews, and checklists were mostly used to collect children's environmental knowledge (Kara et al., 2015; Yılmaz et al.,, 2020). However, while preschool children have difficulty expressing themselves verbally due to their age, they are more comfortable expressing their feelings and thoughts through artistic activities such as music, dance, and painting. Especially drawing is a particularly important activity where the child does not feel any pressure to understand and express his/her feelings (Minkof & Riley, 2011; Yavuzer, 2005, 2009). Considering the emphases of Franco & Colinvaux (2000), who draw attention to the implicit structure of mental models, and Cronin-Jones (2005), who state that the applications of the drawing technique provide important data about the child's cognitive structure, especially in the preschool period, it can be said that the study will make qualified contributions to the relevant literature in terms of data collection processes. In studies with similar emphasis, children's drawings are accepted as a powerful tool in analysing the images in their minds and are used as an important data collection tool (Ahi & Alisinanoğlu, 2016; Rodari, 2007). Accordingly, this study, in which mental modelling of the environment was determined by drawing and WAT, is also important in terms of data collection tools.

In conclusion, considering the literature on early childhood environmental education and cognitive development processes, it is necessary to determine the level of environmental knowledge to raise environmentally conscious individuals (Yurttaş & Erdaş-Kartal, 2021). This study is thought to make a significant contribution to the field by revealing the mental models of 4-5 and 6-year-old children about the environment separately and providing information about their needs, motives, and cognitive processes. According to the results to be obtained from this study, it will be possible to diagnose the cognitive development towards the concept of environment in the early childhood period, where the educational outcomes between the levels are most visible. In addition, considering the dynamic structure of education programs, the findings of this study will contribute to the shaping of the environmental outcomes aimed to be gained in early childhood. In other words, it is valuable as it will reveal the possible readiness levels of children for the environment before moving on to the next level, primary school. Therefore, the study will pave the way for 4-5-6-year-old children to reach their mental models about the environment, and it is thought that it will provide input to the environmental education programs and policies to be developed in Turkey.

Purpose and Research Questions

The present study aimed to reveal the mental models of preschool children in different age groups towards the environment through the word association test (WAT) and the drawing. The main problem of the study is "What are preschool children's (36–48-month-old, 49–60-month-old, 61–72-month-old) mental models about the environment?"

Methods

Research Design

The method of the study, conducted with 36–72-month-old problem: 72 months takes you to preschool children, is based on a qualitative research pattern designed as a case study. According to Stake (1974) cited by Çepni (2010), case studies can be designed to examine a suitable situation with defined boundaries. In doing so, multiple data collection tools can be used for the research. Yin (2003) defined a case study as the activity of uncovering a social fabric, the individuals who make up this fabric, the patterns, the environment, and individual experiences. By these definitions, the present piece of research was designed as a case study aiming to reveal the mental models of 36-72-month-old preschool children towards the environment, with the help of various data collection tools.

Research Group

The study group was selected by convenience sampling, a non-random sampling method. According to Büyüköztürk et al., (2009) the convenience sampling method is based on selecting the sample from among easily accessible and applicable units due to the limitations in terms of time, money, and labour. In this context, 225 children studying in 8 preschool education groups operating in Uşak province in the academic year 2022-2023 were included.

Data Collection Tools

The data collection tools used to determine 36-72-month-old preschool children's mental models of the environment were the Word Association Test (WAT) and the Drawing.

Word Association Test (WAT)

This is a data collection tool used to examine the schemas, models, concepts, and conceptualisations in children's minds, as well as the relationships between them, often applying labels such as 'cognitive structures', 'mental models', and 'mental images' to refer to these relationships? (Gündoğan & Taşdere, 2021). In WAT, children were asked about the words/phrases that come to mind when they think of the concept of ENVIRONMENT. The words/phrases mentioned by the children were recorded by the researchers. The WAT card prepared for each child, containing the stimulus word and the response words provided by the children, is presented in Figure 1:

Figure 1

WAT for the concept of environment

WAT for the Concept of Environment
ENVIRONMENT..............................
ENVIRONMENT..............................
ENVIRONMENT..............................
ENVIRONMENT..............................
ENVIRONMENT..............................
ENVIRONMENT..............................

Drawing

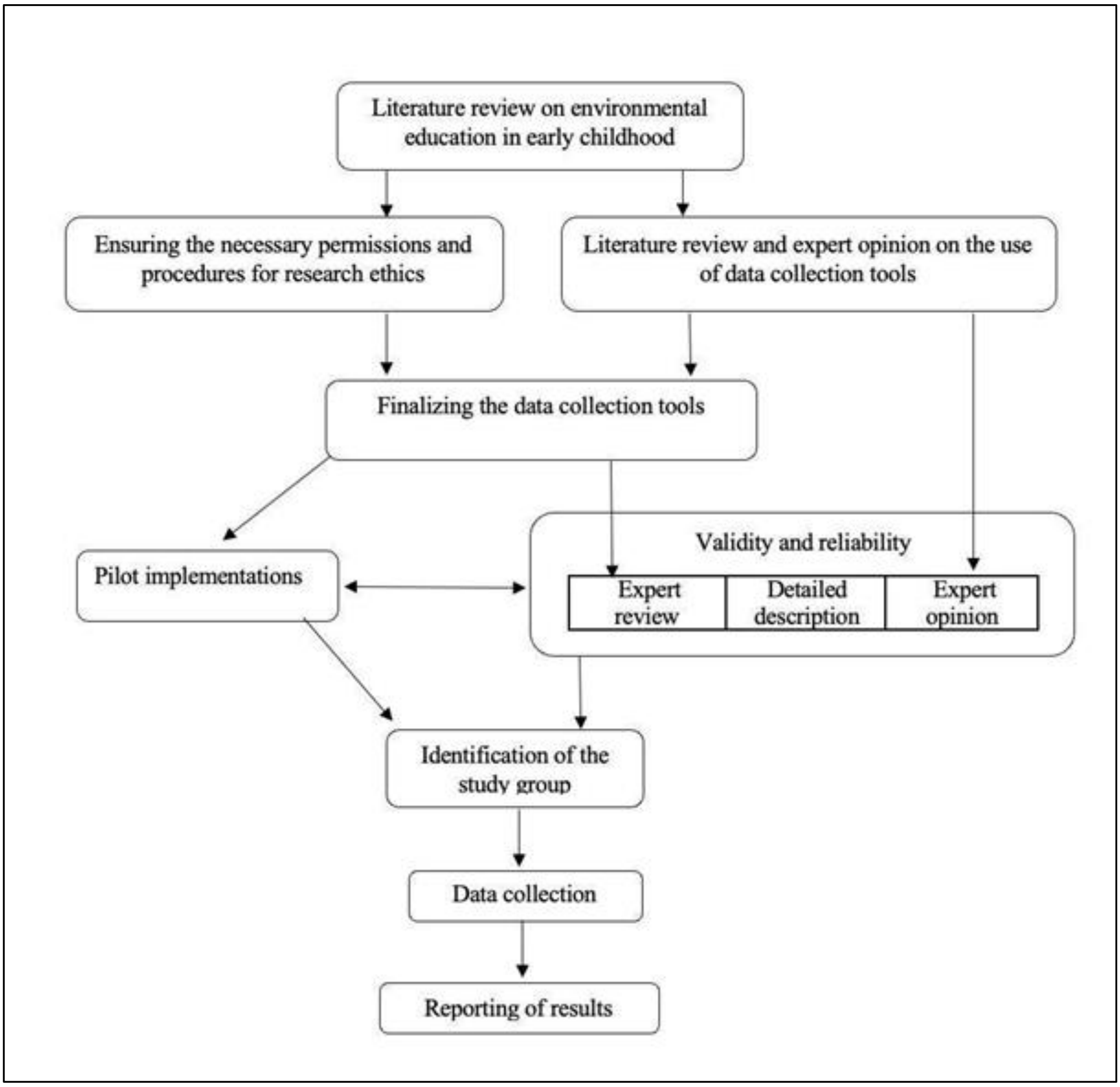
It is a data collection tool to determine children's mental models regarding the environment. Pridmore and Bendelow (1995) noted the importance of drawing, which is frequently used to reveal children's mental models for various themes at all levels of education, and stated that it serves as a window to children's feelings and thoughts. Rennie and Jarvis (1995) stated that drawing can be an alternative technique for pupils who have difficulty expressing their thoughts verbally. Drawing gives study participants –both adults and children– another way of communicating with each other, which can lead to important findings (Einarsdottir et al., 2009). In this study, drawing was used to complement and complete the findings reached through the WAT, concerning the mental models 36-72-month-old preschool children had about the concept of environment.

Data Collection

During the data collection process, the children enrolled in 8 preschool education institutions were interviewed individually, and the WAT and the drawing activity were conducted. Since the children were not yet able to read and write during the implementation of WAT, each word/phrase they uttered was written on the WAT card by the researcher. Moreover, the words/phrases spoken by the children were recorded with a voice recorder to prevent possible loss of data and to provide a means to check them. In the literature, various time frames (e.g., 30 seconds, 45 seconds) are provided for the subject to respond (Bahar & Özatlı, 2003). Since the research group covered in the present study consisted of younger children compared to other studies in the literature, each child was given 2 minutes for the application of the WAT. In the literature, there are many studies in which varying durations were given depending on the level of education (primary school, secondary school, high school, higher education, etc.). Since the study group of this study consisted of early childhood children of similar age groups at the same educational level, the longest duration of 2 minutes was envisaged. Later, the children were presented with a form asking them to 'Draw the image of the environment in your mind' and were asked to draw the 'Environment' as they imagined it in the space provided in the form. After the drawings, the researchers asked the children what the images they had drawn were and took notes next to each image according to the children's answers. In this process, it was stated that children could use their imagination and creativity, draw anything that came to their minds, draw the objects, beings, environments, etc. they wanted, and instructions were given in this direction. The data collection process was carried out after the environmental activities (environmental pollution, protection of the environment and nature, etc.) were included in the preschool curriculum. In this context, it is thought that children of all age groups have familiarity with and awareness of the concept of environment. The relevant drawing form is attached (Appendix 1). The flowchart (Figure 2) showing how the data collection process was implemented holistically is as follows.

Figure 2

Data collection process



Data Analysis

Analysis of WAT Data

In the analysis of the WAT data, the frequency of children's responses to the stimulus word environment was determined. The response words thus provided were categorised according to similarity and closeness of meaning. The following categories appeared: sky elements, rural Elements, living Elements (plant, human, animal, fruit sub-categories), and non-living elements (park, traffic, house, place, school, and water sub-categories). Words with similar/close meanings comprising each category were visualised with the mind map created by the researchers. The cut-off point (CP) technique introduced by Bahar et al. (1999) was used to visualise children's cognitive structures in the process of constructing mind maps. In this technique, the cut-off point is established at 3 to 5 instances less than the actual frequency of the most frequently mentioned term in response to any given stimulus word. The answers above the said level are recorded in the first part of the mind map (the part with the highest number of responses provided). The cut-off point is then lowered at certain intervals, and the process continues until all stimulus words appear in the mind map (Ercan et al., 2010).

Analysis of the Drawing Data

In the analysis of the drawing data, each image drawn by the children was subjected to content analysis. The researchers asked questions about the images to verify the children's drawings and took notes on the drawings to examine them during the analysis process. This provided for an assessment of the consistency of children's thoughts and images. Each child's drawing was checked repeatedly, and associated codes were assigned by two researchers. In this process, the first researcher listed 53 codes, and the second researcher listed 49 codes. The researchers concurred or expressed similar assessments concerning 47 codes but disagreed concerning 6, resulting in a consensus rate of 0.88. Miles & Huberman's (1994) formula in the form of Consensus/(Consensus+Disagreement) was used to measure the consensus rate. Since the literature underlines the need for a consensus rate of 0.80 or more, the analysis process is reliable (Miles & Huberman, 1994). The codes that emerged from the analysis of the drawing data were collected in a higher category and presented in a related structure in separate mind maps for each age group. These categories (Environments forming the environment) were grouped and presented in a related structure in mind maps for each age group separately. Some common codes appeared in several distinct categories. For example, some images assigned to the child code included School environments, while others covered Park-Garden environments. Thus, the codes were connected to both the School and the Park-Garden categories in the context of mind maps. Examples of the pictures representing the relevant codes are provided in the findings section. The codes obtained were analysed and comparatively concerning the categories identified with the WAT, to come up with an understanding of the children's mental models.

Findings

Findings are presented under two headings: the findings reached through the WAT, and the data obtained with the help of the drawing, for 36-48, 49-60, and 61-72 months-old children.

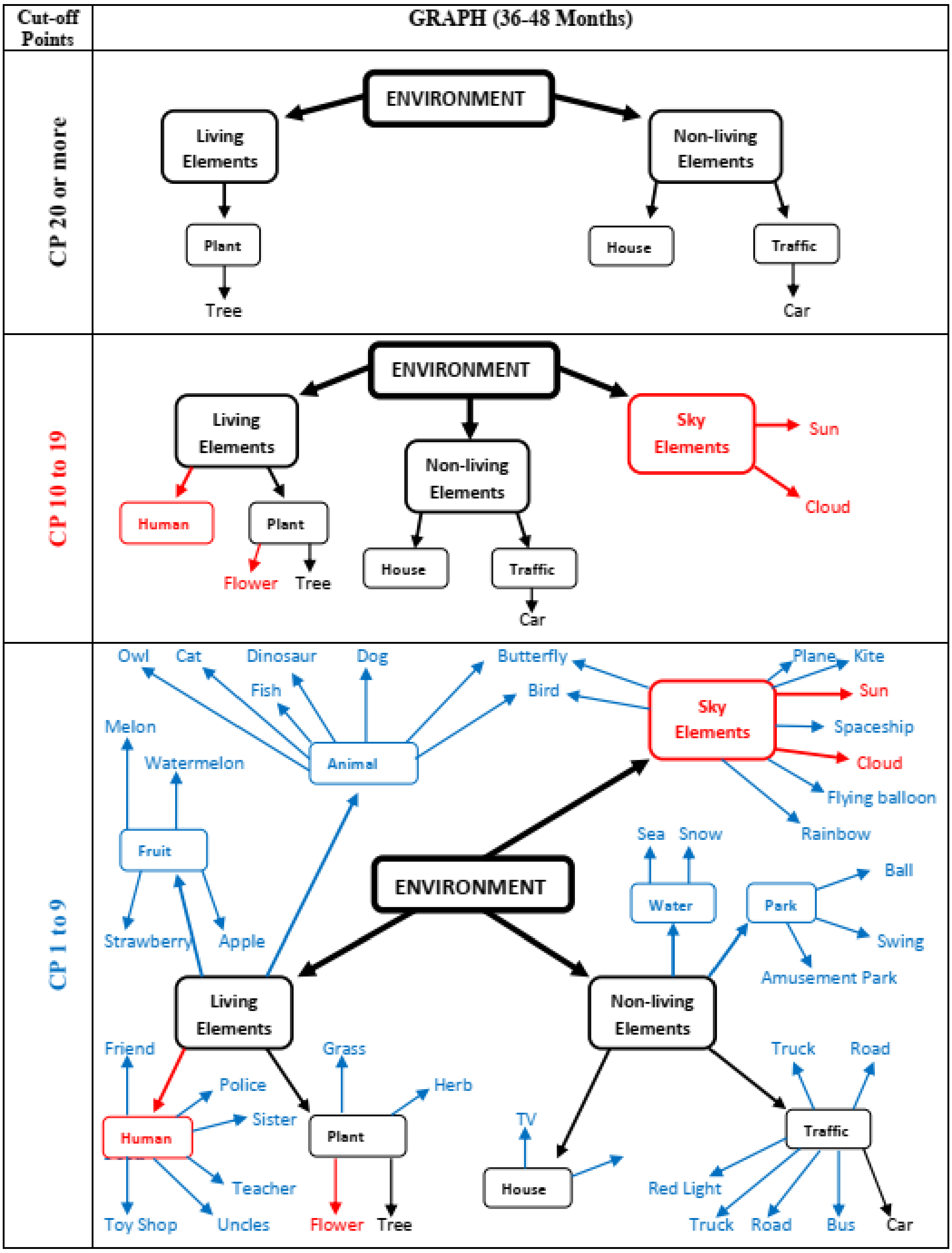
Findings on 36-48 Months-old Children's Mental Models of the Environment

Findings Reached through the WAT Data

The words that the concept of environment associated in the minds of 36-48 children were grouped under 3 themes: living elements, non-living elements, and sky elements. The connotation words that make up each theme are shown in the mind map below, which was developed with the Cutt of Points (CP) technique.

Figure 3

36-48 months-old children's mental model throught WAT



CP 20 or more; in this range, the word "tree" stood out in the Plant category among living elements, and the word "car" and the category "house" appeared in the traffic category, along with the house category among non-living items. To put it differently, tree, house, and car were the words the children most frequently produced.

CP 10 to 19; in this range, the Sky element emerged as a new theme. In this context, the words "sun" and "cloud" were pronounced frequently by the participating children. In addition, the word "flower" in the plant category and the category human also appeared as distinctive elements of the children's cognitive structure in this range.

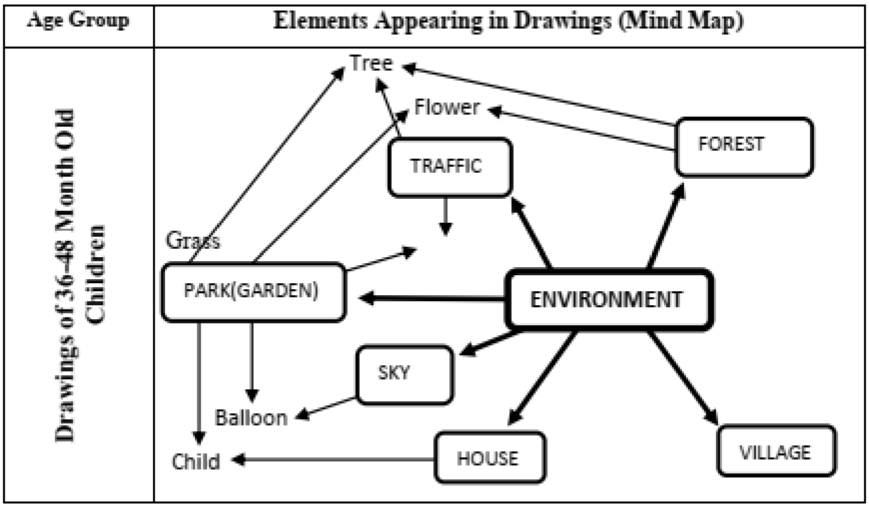
CP 1 to 9; in this range, all themes, categories, and words appeared. Accordingly, the words “melon”, “watermelon”, “strawberry”, and “apple” were produced for the fruit category; “owl”, “cat”, “dinosaur”, “fish”, “dog”, “butterfly” and “bird” for the animal category; “friend”, “police”, “sister”, “teacher”, “uncle” and “toymaker” for the human category; and “grass” and “turf” for the plant category. Among non-living elements, the words produced by the participants were “television” and “food” for the house category; “truck”, “road”, “red light”, “road” and “bus” for the traffic category; “ball”, “swing”, “amusement park” for the park category; “sea” and “water” for the water category. The common words produced for each category were as follows: "airplane", "kite", "spaceship", "flying balloon" and "rainbow" for the sky category; "butterfly" and "bird" for the animal category; "snow" for the water category.

Findings Reached with the Help of the Drawing

The analysis of the drawing data entailed an inquiry into the meaning of the images drawn by the children, followed by the coding of each image. The structure of the categories representing the relevant codes in children's minds is presented below with a visualised mind map.

Figure 4

36-48 months-old children’s mental model throught drawings



Drawings of 36-48 Month-Old Children: Children in this age group drew images of traffic, parks, forests, sky, houses, and village settings in their environmental drawings. While flower images were found in park (garden) and forest environments, tree images were found in forest, park, and traffic environments. In addition to these, grass images appeared in traffic and park (garden) environments, balloon images were observed in sky and park (Garden) environments, and children’s images were noted in house and park (garden) environments. In this context, one can argue that the images drawn by 36-48-month-old children in their environmental drawings focus mostly on park (garden) environments.

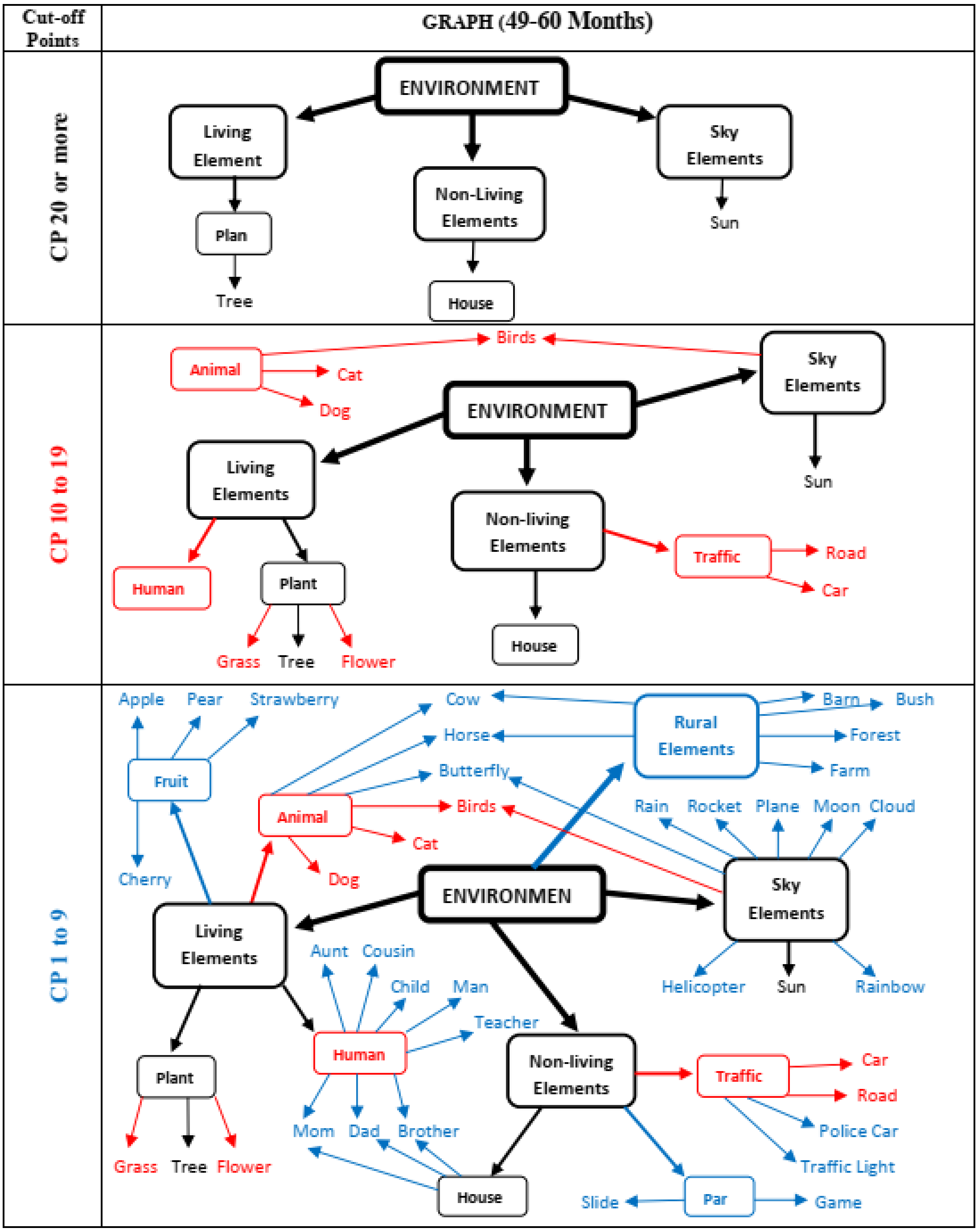
Findings on 49-60 Months-old Children's Mental Models of the Environment

Findings Reached through the WAT Data

The words that the concept of the environment associated in the minds of 49-60 months-old children were grouped into three themes: Living elements, non-living elements, and sky elements. The connotation words that make up each theme are shown in the mind map below, which was developed with the CP technique.

Figure 5

49-60 months-old children's mental model throught WAT



CP 20 or more; in this range, the word "tree" stood out in the Plant category among living elements, and the category "house" appeared among non-living items, along with the word "sun" in the sky elements category. To put it differently, house, car, and sun were the words the children most frequently produced.

CP 10 to 19; in this range, the word "birds" was the common response word produced for the Sky element and the Animal category. For the animal category, the response words "cat" and "dog" were also generated. Among living items, the Human category, as well as the words "flower" and "grass" in the Plant category drew attention. Within the scope of non-living items, "car" and "road" response words were produced for the Traffic category.

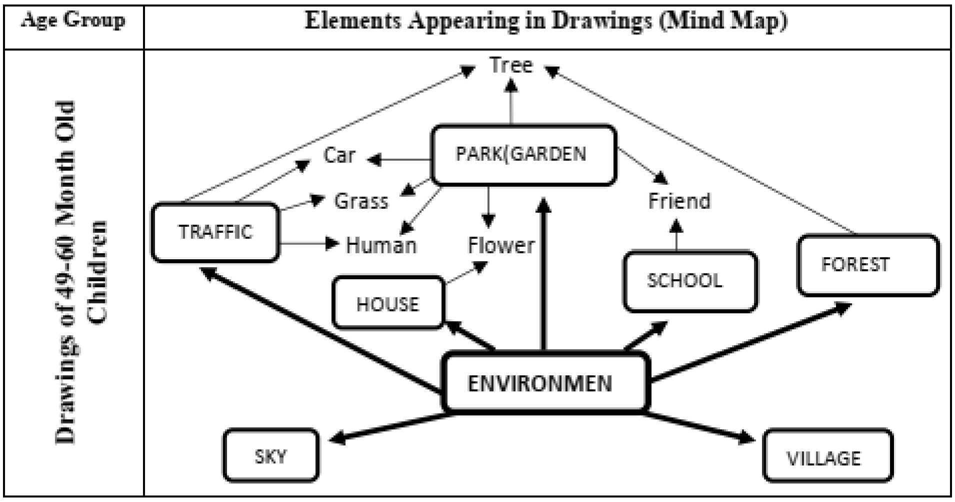
CP 1 to 9; in this range, all themes, categories, and words emerged. In this context, Rural-Village elements emerged as a new theme. The words "cow" and "horse" produced within the scope of Rural-Village elements were also included in the Animal category. Similarly, the word "butterfly" was a common response word for both the Animal category and the Sky item. In addition, the words "barn", "bush", "forest", and "farm" were also produced within the scope of Rural-Village elements. The words "cherry", "apple", "pear" and "strawberry" were produced for the Fruit category, and the words "aunt", "cousin", "child", "man" and "teacher" were produced for the Human category. The response words "mom", "dad" and "brother" were the common response words produced for both the Human and House categories. Within the scope of non-living items, the response words "slide" and "game" were produced for the Park category, and the response words "police car" and "traffic light" were produced for the Traffic category. Within the scope of sky elements, the response words "rain", "rocket", "plane", "moon", "cloud", "rainbow" and "helicopter" were produced in this range.

Findings Reached with the Help of the Drawing

The analysis of the drawing data entailed an inquiry into the meaning of the images drawn by the children, followed by the coding of each image. The structure of the categories representing the relevant codes in children's minds is presented below with a visualised mind map.

Figure 6

49-60 months-old children's mental model throught drawings



In this age group, children included images from traffic, parks (garden), forests, sky, house, village, and school settings in their environmental drawings. Tree images appeared in Forest, Park (Garden), and Traffic environments, while car, grass, and human images appeared in Park (Garden) and Traffic environments. Similarly, images of flowers were found in the House and Park (Garden) environments, while images of friends were found in the Park (Garden) and School environments. In this context, one can argue that the images drawn by 49-60-month-old children in their environmental drawings focus on park (garden) and traffic environments.

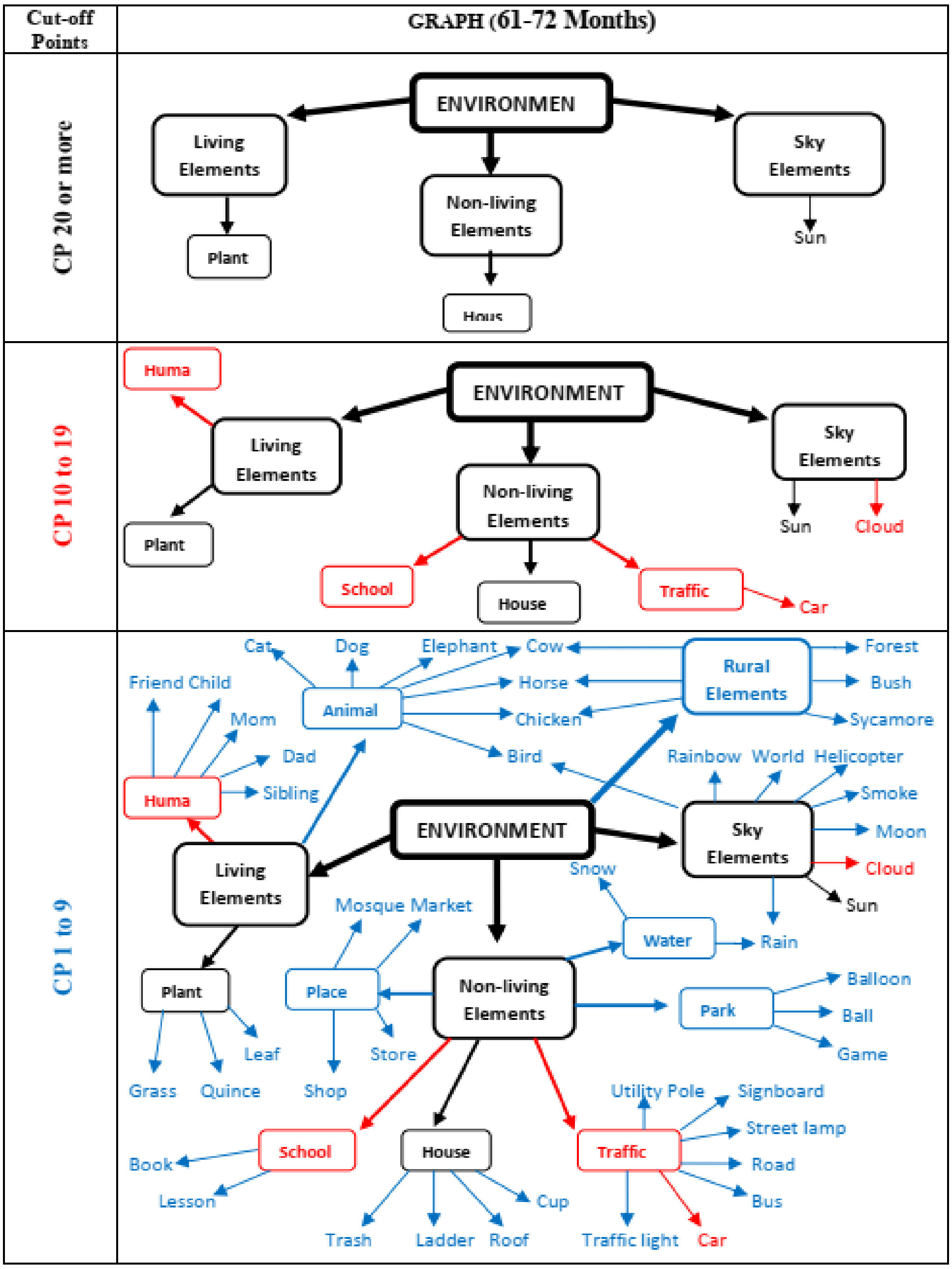
Findings on 61-72 Months-old Children's Mental Models of the Environment

Findings Reached through the WAT Data

The words that the concept of the environment associated in the minds of 61-72 children were grouped under 4 themes: Living Elements, Non-living Elements, Sky Elements and Rural Elements. The connotation words that make up each theme are shown in the mind map below, which was developed with the CP technique.

Figure 7

61-72 months-old children's mental model throught WAT



CP 20 or more; in this range, the word "plant" was produced as a response word among living items; the word "house" was produced as a response word among non-living items; and the word "sun" was produced as a response word among sky items. A mind map quite similar in structure to the cognitive structure of 49-60-month-old children emerged.

CP 10 to 19; in this range, within the scope of living elements, the category "human" stood out. Among non-living elements, the word "car" was produced for the "traffic" category. However, the word cloud was produced for the Sky element.

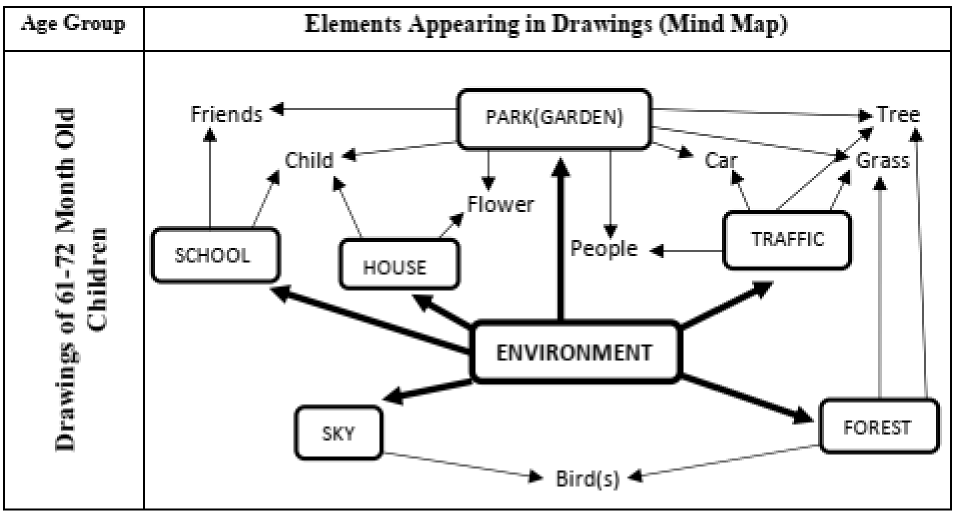
CP 1 to 9; in this range where all themes, categories, and words emerged, Rural-Village elements appeared in the mind map as a new theme. The words "cow", "horse", and "chicken" produced within the scope of Rural-Village elements were also included in the Animal category. The words "forest", "bush", "forest", and "sycamore" were also produced within the scope of Rural-Village elements. Similarly, the word "bird" was produced for both the Animal category and the Sky item, and the word "rain" was produced as a common response word among the Sky items and the Water category. Within the scope of living elements, the words "cat", "dog", and elephant were produced for the Animal category; the words "friend", "child", "mom", "dad", and "sibling" were produced for the Human category; and the words "grass", "quince", and "leaf" were produced for the Plant category. Within the scope of non-living elements, the response words "balloon", "ball", and "game" were produced for the Park category; the response words "traffic light", "bus", "road", "street light", "street lamp", "signboard" and "lamppost" were produced for the Traffic category; the response words "trashcan", "ladder", "roof", and "glass" were produced for the House category; the response words "book" and "lesson" were produced for the School category; and the response words "mosque", "market", "market", and "shop" were produced for the Place category. Within the scope of sky elements, the response words "rainbow", "world", "helicopter", "smoke" and "moon" were produced in this range.

Findings Reached with the Help of the Drawing

The analysis of the drawing data entailed an inquiry into the meaning of the images drawn by the children, followed by the coding of each image. The structure of the categories representing the relevant codes in children's minds is presented below with a visualized mind map.

Figure 8

61-72 months-old children's mental model throught drawings



In this age group, children included images from traffic, parks (garden), forests, sky, houses, and school settings in their environmental drawings. Tree and grass images appeared in Forest, Traffic, and Park (Garden) settings, while car and human images appeared in Park (Garden) and Traffic settings. Children included bird images in both Forest and Sky drawings and included friend images in Park (Garden) and School drawings. Flower images were included in Park (Garden) and House drawings, while children's images were included in Park (Garden), School and House drawings. The focus of the environment drawings of 49-60-month-old children formed a more interrelated and holistic structure compared to those of other age groups. In other words, while the environmental drawings of the children in this age group mostly involved elements from the Park (Garden) and Traffic settings, the images associated with the Forest, House, and School settings were also included in a related and holistic manner, albeit partially. Examples of drawings representing each age group are presented in the Table 1 below.

Table 1

Examples of Drawings

Examples of Drawings by 36-48 Months-old Children	Examples of Drawings by 49-60 Months-old Children	Examples of Drawings by 61-72 Months-old Children
		

Discussion, Conclusions and Recommendations

In this study, which aims to reveal the 36-72 months-old preschool children's mental models about the environment, the findings are presented and discussed separately for 36-48, 49-60, and 61-72 months-old children.

36-48 Months-old Children's Mental Models of the Environment

In this age range, house, traffic, park, and sky environments/elements emerged as common findings in both data collection tools. Sky-bird and traffic-car were indisputable parts of children's mental models as common and direct associations. However, the words/drawings of human, friend, grass, flower, and tree appeared in both data collection tools, in close but different categories. For example, while "grass" and "tree" were produced as response words for the category of plants in WAT, they appeared in the forest and park (garden) settings in the drawings. On the other hand, different categories/environments without common elements also appeared. For example, the categories of fruit, animal, and water emerged in the WAT, while the school and forest environments emerged in the children's drawings.

49-60 Months-old Children's Mental Models of the Environment

In this age range, house, traffic, park and sky and rural-village environments/elements emerged as common findings in both data collection tools. However, in both data collection tools, images/words associated with rural-village settings, and traffic-car associations emerged as common and direct associations in children's mental models. Moreover, the words/images of human, grass, flower, and tree elements emerged in different categories with close meanings in both data collection tools. For example, while "tree" and "grass" were produced as response words for the category of Plants in WAT, they appeared in the park (garden) settings in the drawings. On the other hand, different categories/environments without common elements also appeared. For example, the fruit category emerged in the WAT, while the school and forest environments emerged in the drawings.

61-72 Months-old Children's Mental Models of the Environment

In this age range, more interrelated and complex mind maps emerged in the findings obtained from both data collection tools. House, traffic, park, and sky environments/elements emerged as common findings in both data collection tools. Sky-bird and traffic-car were indisputable parts of children's mental models as common and direct associations. However, the words/drawings of human, friend, child, grass, flower, and tree appeared in both data collection tools, in close but different categories. For example, while "flower" was produced as a response word for the category of plants in WAT, it appeared in the house and park (Garden) settings in the drawings. On the other hand, different categories/environments without common elements also appeared. For example, while the categories of place, water, and rural elements emerged in the WAT, the school and forest environments emerged in the drawings.

As a result of the study, it is possible to say that there are common elements in children's mental models, although the details vary according to their age range. “House, traffic, park, and sky” are seen as common concepts that children associate with the environment. Thomson (2008) states that children raised in urban versus rural settings differ in their perception of the environment, while Hart & Moore (1973) notes that in the 4-11 age group, the children's mental models of the environment vary depending on the accessibility of the areas close to their homes. The findings reached in this study conducted in the province center of Uşak concerning the concepts of traffic, park, house, and sky in children's perception of the environment coincide with the findings of other studies. With fewer natural, unstructured outdoor spaces in urban areas today, children's ability to engage in active experiences in natural environments is diminishing (Sobko et al., 2018). Therefore, young children living in urban environments who are more likely to have contact with and participate in activities in nature. Deniz (2020) noted trees as the most pronounced element in children's perceptions of the environment. Again, Bonnett and Williams (2006) and Burgess and Smith (2011) found that plants and animals are the things that children think of when they think of the environment. In the present study, in which each age group was evaluated separately, it was observed that children always included the tree element as part of their expressions of the environment. On the other hand, children exhibited variations based on their age groups: 61-72-month-old children drew more realistic elements, while 49-60-month-old children drew more abstract images, but often provided a narrative alongside their drawings.

It is possible, based on the findings reached, to say that the number of items referred to increases with age. This study underlines the existence of common elements in children's mental models of the environment across different age ranges. These findings also highlight the need for targeted interventions to strengthen children's interactions with nature to promote holistic development and environmental awareness from an early age.

In the drawings by children in the 36-48 months-old age group, house, traffic, park, sky, sky, people, friends, grass, flowers, and trees were the elements that appeared. In the drawings 49-60 and 60-72 months-old children, school, forest, and fruit were added to this set. In the literature on children's perception of the environment, it is seen that children define the environment with inanimate objects (sun, clouds, etc.), and the majority of them focus on objects in their understanding of nature (Köşker, 2019; Yardımcı et al., 2010). When children's responses are analyzed within the scope of another study on the effects of environmental problems, the frequency of explanations about humans and animals stands out. These elements are followed by air, nature, soil, and water in terms of frequency (Ayvacı et al., 2021). In children's environmental drawings, sun, house, grass, human, cloud, tree, and animal images are the most commonly observed elements (Ahi, 2015; Özsoy & Ahi, 2014; Özsoy, 2012). Another striking point in the drawings is that they define the human being separately from the environment (Shepardson, 2005) and see the environment as a layered perception extending from the near environment to the far environment (Alerby, 2000; Keinath, 2004; Shepardson, et al., 2007). In addition, children's drawings also included the habitats of living things, which is consistent with the conclusions of other studies (Shepardson, 2005, Shepardson 2007). In summary, the analysis of children's drawings reveals a developmental progression in their perception of the environment, with younger children predominantly depicting basic elements such as houses, traffic, and nature, while older children incorporate additional elements such as schools and forests. Moreover, these findings align with existing literature highlighting the multifaceted nature of children's environmental understanding, wherein human presence, habitat depiction, and the hierarchical organisation of environmental elements emerge as recurring themes across studies.

Although the validity of Rousseau's (1969) argument for "No book but the world" for children is still confirmed by experts, there has been a regression in children's lives since the days of that great philosopher, with children being distanced from nature, and left with much fewer opportunities to establish close relationships with the nature, depriving them of valuable experience (Akyüz, 2019). As a result, the relationship between our children and nature has been damaged. For the new generation, nature has become an abstraction rather than reality (Louv, 2012). Looking at children's perceptions of the environment as reported in the literature, it is possible to say that similar elements such as trees, sky, and houses are generally included, and the child's immediate environment is surrounded by artificial elements such as parks, houses and traffic. Since being in touch with nature is an important stimulus for children and has an important place in the subsequent education and development of the individual (Tanner, 1980), one can forcefully argue that the findings of this piece of research reveal an important reality. In this context, the following recommendations are made for early childhood children's environmental education, new research, and curricula.

Recommendations

Recommendations for Early Childhood Environmental Education Research

This study was conducted to reveal the difference between age levels. This study can be carried forward and the mental models of primary school pupils, the next level of education, can be examined comparatively.

The meaning of environmental elements such as parks, traffic, sky, and living and non-living elements for children, which emerged most frequently in this study, can be examined through in-depth case studies.

In the word association test, different stimulus words (nature, sky, forest, etc.) can be used together with the stimulus word environment to examine children's more inclusive mental models of the subject.

The place of environmental education in the recently published preschool curriculum can be critically examined in comparison with the curricula of the past. Thus, the place of environmental education can be revealed through a developmental analysis.

The strongest emphasis in this new curriculum is on the theme of sustainability and children playing every day outdoors. In this context, environmental education can be handled with a sustainable perspective and new studies can be carried out in early childhood by associating it with current themes such as recycling, nature conservation, living diversity, and waste control. These sustainability themes can be used as stimulus words for WAT.

Recommendations for Educational Practices

In the literature, WAT and drawing, which are frequently used in conceptual change studies at different educational levels, can also be used for early childhood environmental education studies. The WAT and drawing can be used before and after the educational practices to be developed for different themes related to the environment (environmental sensitivity, ecological footprint, environmental problems, etc.).

These practices can take the form of environmental education in out-of-school learning environments, current sustainable environmental education interventions, training of environmental and nature education experts, etc.

Recommendations for Curriculum Developers

Considering the curriculum development studies, which are currently on the agenda in Turkey, drawing activities such as nature, environment, forest, etc. can be recommended as teaching and evaluation activities for the themes within the scope of environmental education for preschool curricula.

Courses on the use of these drawing activities in teaching and evaluation processes can be given in preschool teacher training undergraduate education. These trainings can also be carried out for preschool teachers in in-service processes.

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Enhancing prospective biology teachers' critical analysis skills: an evaluation of plant anatomy and development textbook effects

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ABSTRACT
Critical analysis (CA) skills are crucial in higher education and should be incorporated into the curriculum at that level. The unique characteristics of abstract biology materials and the involvement of prospective Biology teachers (PBTs) in scientific investigation activities make them highly relevant for teaching CA skills. Inquiry activities require teaching materials or textbooks that explicitly engage science teacher trainees in science process skills (SPS) activities. For effective inquiry-based learning (IBL), appropriate textbooks are essential. Therefore, in this study, a Plant Anatomy and Development textbook based on SPS was utilized as a tool to develop CA skills. The main objective of the study was to assess the impact of SPS-based PADT on PBTs' CA skills in the Plant Anatomy and Development (PAD) course. To achieve the research objectives, a quasi-experimental research design with a pretest-posttest control group was implemented. The research sample consisted of fifty-five prospective teachers who were selected through purposive sampling. They were divided into two groups: the experimental group (n=28) and the control group (n=27). To analyze the students' critical analysis skills, twelve valid and reliable essay items were utilized. The research findings indicated that the experimental group exhibited a significantly greater cognitive gain (>0.70) compared to the control group (0.30 < n-gain < 0.70) (p < 0.05).

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Introduction

The learning process in higher education places significant emphasis on the active transfer of information (Hamouda & Tarlochan, 2015; Hincapié Parra et al., 2018) and autonomous cognitive aspects (Guo & Wang, 2021; Mystakidis et al., 2019) in order to enhance the thinking skills of prospective teachers (Heijltjes et al., 2015). However, thinking skills cannot be acquired simultaneously, and they are typically viewed as a byproduct of learning in general (Davies, 2013). Consequently, specific learning activities targeting thinking skills are necessary (Halpern, 2014).

Additionally, there is still ongoing debate regarding the most effective approaches for teaching these skills (Davies & Barnett, 2015; Tiruneh et al., 2014). Critical analysis is considered one of the crucial thinking skills that need to be cultivated (Fitriani et al., 2019), alongside problem-solving, effective communication, collaboration, creativity, and innovation (Christian et al., 2021).

The primary objective of the present study is to investigate the efficacy of scientific-inquiry-oriented learning, specifically when accompanied by teaching materials that actively engage prospective teachers in scientific investigations (Kruit et al., 2018; Lazonder & Harmsen, 2016). Additionally, the study aims to address the imperative of enhancing critical thinking (CT) abilities, as previously discussed. While numerous studies have explored the utilization and effectiveness of inquiry-based learning (IBL) in fostering CT skills (Davenport Huyer et al., 2020; Pahrudin et al., 2021; Rusmansyah et al., 2019), there exists a gap in assessing the impact of the Plant Anatomy and Development Textbook (PADT) and its implementation in IBL for the enhancement of prospective biology teachers' (PBTs) CT skills.

A number of empirical studies have demonstrated the significance of acquiring critical analysis skills (Haerazi et al., 2021; Karantzas et al., 2013; Wale & Bishaw, 2020). Unfortunately, students tend to exhibit limited improvement in their thinking skills (Flores et al., 2012; Pascarella et al., 2011), particularly in critical analysis (CA) skills (Fitriani et al., 2019a) during their college and post-college years (McLaughlin et al., 2014). This situation leads to numerous instances of college graduates facing difficulties in employment due to their lack of thinking skills (Alsaleh, 2020; Arum et al., 2012), including CA skills. In today's digital era (Klimova, 2013), where the verification of information is crucial (Haug & Mork, 2021; Knight & Horsley, 2013; Pantò & Comas-Quinn, 2013; Spector & Ma, 2019), CA skills are indispensable. However, several authors argue that the teaching of CA skills is inconsistent (Sotiriadou & Hill, 2015) due to teachers' or lecturers' limited knowledge about the subject (Fitriani et al., 2019), the belief that conceptual knowledge alone guarantees success in employment (Wale & Bishaw, 2020), and the lack of teaching materials explicitly designed to enhance students' CA skills (Barsoum et al., 2013; Mena, 2019).

The SPS-based PADT utilized in this investigation has been demonstrated to possess validity and reliability (r=0.77) with regards to its content and construct (Fitriani et al., 2019a). Nevertheless, its effectiveness in relation to CA skills has not been previously examined. The PAD course possesses abstract characteristics and tends to be experimental, focusing on the structure and development of seed plants. The PADT, which was developed based on SPS, encompasses a variety of topics, including cell structure and development, tissues, and reproductive organs. The objective of this study is to evaluate the impact of SPS-based PADT on the CA skills of PBTs. In this study, CA skills are defined as the ability to break down information into smaller components in order to attain a more comprehensive understanding. This is measured through indicators such as organization, association, interpretation, evaluation, reflection, and decision-making. The two research questions guiding this study are: (1) What is the effectiveness of SPS-based PADT in enhancing the critical analysis skills of prospective Biology teachers? and (2) How does the implementation of SPS-based PADT influence the development of Critical Analysis (CA) skills among prospective Biology teachers?

Literature Review

Analyzing problems requires cognitive skills to break down information or knowledge into smaller parts in order to gain a comprehensive understanding (Anderson & Krathwohl, 2001; Muhali et al., 2021). Critical analysis is developed through cognitive strategies that aim to guide appropriate decision-making (Ennis, 2018). This is done by considering the strengths and weaknesses of different alternative strategies and the resulting needs (Facione, 2020; Muhali et al., 2019). Critical analysis involves organizing information, making connections between the different parts or variables in the information (association), interpreting data, reflecting on the evaluation process, and making decisions based on formulated concepts and problem-solving (Fitriani et al., 2019b).

Critical analysis is related to both critical thinking and problem-solving (Brookhart, 2010; Karantzas et al., 2013), which are essential for accurately interpreting information (Sotiriadou & Hill, 2015). The connection between critical analysis and the enhancement of cognitive skills and the facilitation of effective problem-solving is becoming increasingly clear, given the significant role that critical analysis plays in these areas. Therefore, it is crucial for individuals to actively engage in extensive educational pursuits that embrace the principles of critical analysis. This will enable them to acquire the necessary skills to effectively analyze information and make well-informed judgments (Eggen & Kauchak, 2012; Fisher, 2011; Fitriani et al., 2019b; Woolfolk Hoy et al., 2013).

Critical thinking and problem-solving abilities are essential skills that students must acquire during their higher education. These skills are crucial for future educators as they help them comprehend the connection between scientific theory and practical application (Thomas, 2011). Additionally, these skills equip educators to address novel and ambiguous problems (Caesar et al., 2016) and promote active communication and collaboration (Heritage et al., 2016; Morris et al., 2013).

While the theoretical foundations of critical thinking (CT), creative thinking (CA), and problem-solving may seem distinct (Fitriani et al., 2019a), these concepts are intricately intertwined (Karantzas et al., 2013). Critical thinking involves a range of skills, including interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2020). It is used to assess ideas and problem-solving strategies, leading to decision-making related to strategy selection, refinement, and practical application (Ennis, 2018; Ruggiero, 2015). The development of critical thinking requires procedural activities such as organizing, associating, interpreting data, evaluation, reflection, and decision-making (Fitriani et al., 2019a). These activities are also fundamental components of creative thinking and problem-solving.

A textbook holds significant importance as a tool for effective learning (Dancy et al., 2016). It has the potential to enhance learners' competence and effective communication when implementing learning models or strategies (Hidayatulloh et al., 2020; Knight, 2015). Textbooks play a crucial role as a source of learning for students (Barsoum et al., 2013; Mena, 2019), particularly in the field of Biology, where knowledge formation and the development of scientific attitudes are emphasized through experimental activities (Sormunen & Serdar, 2014). Textbooks that incorporate scientific process skills (SPS) serve as valuable learning resources and mentors for students, connecting procedural, factual, conceptual, and metacognitive knowledge (Madsen et al., 2016). SPS is a skill that students should acquire through active scientific investigation, by posing and answering questions (Asy'ari, Fitriani, et al., 2019; Lee, 2014). The Plant Anatomy and Development textbook, which is grounded in scientific process skills (SPS), provides comprehensive instructional materials and guidelines. It effectively integrates SPS to assist instructors in fostering students' scientific abilities and promoting interactive and student-centered learning experiences. Additionally, it aids students in comprehending complex concepts related to plant anatomy and development (Fitriani et al., 2019b).

The integration of SPS in the materials of the Plant Anatomy and Development textbook assists prospective teachers in conducting simple observations/experiments, discovery, problem analysis, problem-solving, and communication of new knowledge. Scientific activities are presented in the form of exploration worksheets, while questions help develop students' critical analysis skills. In line with this, Holmes et al. (2021) assert that textbooks should incorporate the principle of visible learning or evidence-based learning to address various aspects of students' learning, such as attention, memory, and executive control (planning and problem-solving), in order to foster their cognitive skills and engage in critical analysis.

Learning emphasising SPS is the best way to train thinking skills (Rönnebeck et al., 2016; Sambudi et al., 2023) because it involves prospective teachers directly in scientific reasoning, compiling experimental procedures, data interpretation, and critical thinking (Schallert et al., 2020; Wirzal, Halim, et al., 2022). SPS consists of two categories, i.e., basic SPS and integrated SPS (Aktamış & Yenice, 2010; Bulent, 2015). Basic skills including observation, classification, communication, measurement, prediction, and inference, while integrated skills including variable identification, data table preparation, graphing, describing relationships between variables, data acquisition and data processing, analytical investigations, hypothesis formulation and variable definition operational (Asy'ari, et al., 2019). The integrated SPS particularly is necessary to conduct an investigation to solve problems (Lazonder & Egberink, 2014). However, prospective teachers did not understand SPS clearly (Asy'ari et al., 2019; Durmaz & Mutlu, 2017) and so it has a low impact on their CA-skills (Fitriani et al., 2019b).

Methods

Research Design

A quasi-experimental research study was conducted to assess the impact of SPS-based PADT on the critical analysis skills of PBTs. The study utilized a pretest-posttest control group design, as described by Fraenkel et al. (2012). The posttest data from both the experimental and control groups were analyzed to achieve the objectives of the research. The sample underwent six meetings, during which pretest and posttest data were collected at the beginning and end of each meeting, respectively. The pretest data of the sample were employed as a covariate to account for any initial variations in the critical analysis skills of the PBTs who participated in the study. Table 1 provides an illustration of the research design.

Table 1

Research design

Group	Pretest	Treatment	Posttest
Experimental	CAS test	Inquiry-based with SPS based-PADT	CAS test
Control	CAS test	Conventional	CAS test

Research Sample

The participants in this study were selected from the biology education programme at Universitas Pendidikan Mandalika. Specifically, the sample consisted of prospective Biology teachers who were enrolled in the Plant Anatomy and Development course during the even semester of 2021/2022. The total number of participants was 55, divided into two groups: the experimental group (n= 28, male= 11, female= 17, age= 20) and the control group (n= 27, male= 12, female= 15, age= 20).

Instrument and Procedure

The critical analysis skills of BPT were evaluated through twelve essay items. The instrument demonstrated a content validity of 3.83 and a construct validity of 3.87. Moreover, it exhibited high reliability, with a content reliability of 0.97 and a construct reliability of 0.98 (Cronbach's Alpha: 0.78) (Fitriani et al., 2019a).

The instruments were utilized to evaluate the initial critical analysis skills of pre-service biology teachers (PBTs) through a pretest, as well as the impact of the treatment on the critical analysis skills of PBTs through a posttest. The experimental group received inquiry-based learning with SPS-based Problem Analysis and Decision-Making Technique (PADT) (refer to Appendix 1), while the control group received conventional learning in the form of group discussions. Both groups were taught the same instructional material for a duration of 2 x 45 minutes per session. The integrated skills, which encompassed variable identification, data table formulation, graph formulation, variable association, data collection and processing, analysis, hypothesis formulation, and operational definition of variables (Asy'ari, Fitriani, et al., 2019), were incorporated into PADT in this study by employing scientific activities in the form of exploration worksheets.

Data Analysis

Critical analysis skills were assessed in a descriptive and statistical manner. The improvement in these skills was reflected by the mean scores obtained by the students for each indicator. The total score was analyzed using the following formula: n-gain = (posttest score - pretest score) / (maximum score - pretest score). Subsequently, the scores were divided into three categories: low (score < 0.30), moderate (0.30 < score ≤ 0.70), and high (score > 0.70) (Hake, 1999). The responses of prospective teachers were analyzed using a critical analysis marking key, which assigned scores ranging from 1 to 4 (Fitriani et al., 2019b). The responses were then categorized based on Finken and Ennis's (1993) categories (Table 2).

Table 2

BPT critical analysis skills categories

Categories	Score
Not yet visible or still underdeveloped	1-2
Start developing or developing well	3-4

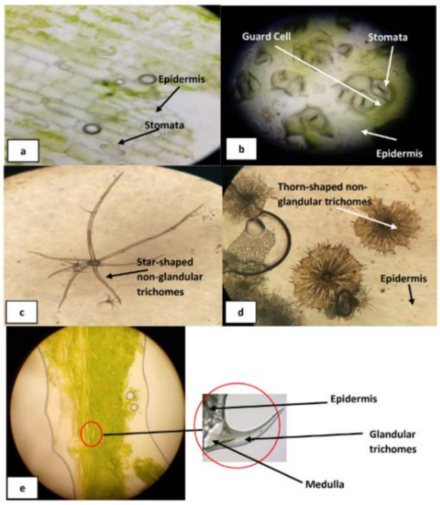
The impact of SPS-based PADT on PBTs' critical analysis skills was examined through the utilization of the analysis of covariance (ANCOVA) test, incorporating the pretest score as a covariate. Additionally, an independent-sample t-test was performed. Before conducting a parametric statistical test *(t-test)*, the normality and homogeneity of the research data were assessed using the one-sample Kolmogorov-Smirnov and Levene's tests. The research data was determined to exhibit normal distribution with homogenous variance at p > 0.05 (alpha level). The statistical analysis was conducted using IBM SPSS 23, with a significance level set at 0.05.

Findings

PBTs' CA-skills descriptively improved according to n-gain score obtained both in the experimental and control group (Table 3). However, the category of PBTs' CA-skills in the experimental group obtained better improvement (high category) than the control group (moderate category). These findings indicate that the SPS-based PADT used as a learning resource and media can improve PBTs' CA-skills. Inquiry learning using SPS-based PADT facilitates PBTs in conducting experiments through identifying problems, formulating hypotheses, collecting and analyzing data, evaluating hypotheses, and generalizing results. In contrast to the control class which was taught using conventional learning (exploratory learning) without the support of SPS-based PADT, PBTs are asked to make summaries from various reading sources to identify images or solve problems given without conducting experiments/inquiry activities.

Figure 1

PBTs practicum results in the experimental group



Plant anatomy is a branch of biology that focuses on the microscopic structure of plants. It involves examining plant structures through incisions and observing them under a microscope. Including practicum activities in plant anatomy can greatly enhance learning by allowing students to interact with materials and observe phenomena firsthand. One example of such materials is the epidermis, which is a protective tissue that prevents water loss, mechanical damage, temperature fluctuations, and nutrient depletion in plants. Epidermal cells and their derivatives are found throughout the outer parts of the plant body and form the skin tissue system, which includes the epidermis itself, stomata, trichomes, lithosis, fan cells, silica cells, and other components. By carefully observing these materials, students can analyze the different types of epidermal derivatives present. In the experimental group, the students used a 4x10 magnification to examine the following samples during the practicum: Corn leaf stomata (*Zea mays*) (Figure 1a), Peanut leaf stomata (*Arachis hypogea*) (Figure 1b), hibiscus leaf trichomes (*Hibiscus tiliaceus*) (Figure 1c), Durian leaf trichome (*Durio zibethinus*) (Figure 1d), and Nettle leaf trichome (*Fleurya interrupta*) (Figure 1e).

Table 3

Critical analysis skills improvement

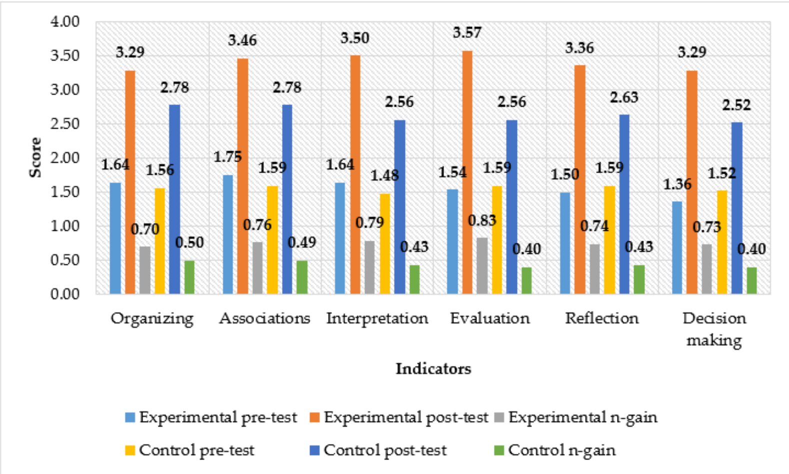
Group	Items	Indicators					
		O	A	I	E	R	DM
Experimental	Pretest	1.64	1.75	1.64	1.54	1.50	1.36
	Posttest	3.29	3.46	3.50	3.57	3.36	3.29
	n-gain	0.70	0.76	0.79	0.83	0.74	0.73
Control	Pretest	1.56	1.59	1.48	1.59	1.59	1.52
	Posttest	2.78	2.78	2.56	2.56	2.63	2.52
	n-gain	0.50	0.49	0.43	0.40	0.43	0.40

Note. O= Organizing, A= Associations, I= Interpretation, E= Evaluation, R= Reflection, DM= Decision making

The divergent treatments administered to the two groups yield disparate outcomes. The experimental group exhibited a superior enhancement of PBTs' CA skills, as evidenced by all the identified indicators in this study, when compared to the control group (Figure 2). These findings cannot be dissociated from the profound emphasis placed on PBTs in the experimental group, wherein they were instructed to procure practical resources to accomplish learning objectives aligned with the assigned topic, establish test protocols, interpret outcomes, engage in analytical activities, and make inferences.

Figure 2

The comparison of experimental and control group improvement



There was a notable disparity in the critical thinking abilities of the participants in the experimental group and the control group ($p < 0.05$; experimental mean = 3.4106; control mean = 2.6359). These results suggest that the SPS-based PADT, employed as instructional materials in the experimental group, substantially enhanced the participants' critical thinking abilities (Table 4).

Table 4

The comparison of SPS-based PADT impact on BPT critical analysis

Group	Item	N	Mean	Std. Dev	t	df	p
Experiment	Posttest	28	3.4106	.25850	12.014	53	.000
Control		27	2.6359	.21705			

The initial knowledge of prospective teachers can be assessed through pretest scores. To reinforce the assumption that the improvement in PBTs' CA-skills was due to the use of SPS-based instructions rather than other variables (pretest), an ANCOVA test was conducted, using the pretest score as a covariate (see Table 5). Although previous research has shown that students' prior knowledge plays a crucial role in the development of higher-order thinking skills (Martin et al., 2019; Piekny & Maehler, 2013), in the present study, students' prior knowledge (pretest) did not have a significant impact on PBTs' CA-skills ($p > .05$). These findings suggest that APDT based on SPS has a significant positive effect on enhancing PBTs' CA-skills.

Table 5

The initial knowledge impact on BPT critical analysis

Source	Type III Sum of Squares	df	Mean Square	F	p
Corrected Model	8.462[a]	2	4.231	78.113	.000
Intercept	6.519	1	6.519	120.364	.000
Pretest	.213	1	.213	3.925	.053
Group	8.139	1	8.139	150.268	.000
Error	2.816	52	.054		
Total	516.331	55			
Corrected Total	11.278	54			

Discussion

This study investigates the impact of utilizing SPS-based PADT on the CA skills of PBTs. The results indicate that the experimental group, instructed with SPS-based PADT, exhibited a notable improvement in CA skills compared to the control group. Textbooks have a vital role in science education, especially in the field of biology (Hultén, 2016). They can enhance learning outcomes and facilitate effective communication of learning models and strategies (Fitriani et al., 2019a). However, biology materials, which encompass factual, conceptual, and procedural knowledge, necessitate a structured presentation rooted in scientific methods (Rofieq et al., 2021). In this context, SPS functions as the basis for constructing scientific knowledge (Asy'ari et al., 2019; Nur, 2011) and is crucial for delivering biology teaching materials without introducing bias into the learning process (Dancy et al., 2016).

The Science Process Skills (SPS)-based Problem Analysis and Design Tool (PADT) was developed to align with the key features of science as a body of knowledge, the exploration of nature, critical thinking abilities, and the interplay between nature, technology, and society. These features are in line with the fundamental principles of science as a process (Molefe & Stears, 2014), which are typically implemented through the inquiry-based learning model (Rönnebeck et al., 2016), particularly in the context of science education (Pedaste et al., 2015). Inquiry-based learning places emphasis on formulating scientific inquiries, developing evidence-based conclusions, and engaging in discussions about scientific concepts (Furtak et al., 2012). In this study, inquiry-based learning is implemented by guiding Problem-Based Tasks (PBTs) in (1) formulating experimental procedures, (2) analyzing and evaluating experimental results, and (3) discussing and communicating the findings (Figure 1). These learning activities promote the active involvement of PBTs in their learning process, which has been found to effectively enhance the component of critical thinking and analytical skills when using the SPS-based PADT. The positive impact of inquiry-based learning on the science learning outcomes of PBTs has been extensively demonstrated. The findings indicate that 77% of prospective science teachers provided positive feedback and believed that inquiry-based learning could improve understanding and academic skills (McLoughlin et al., 2014). In support of the results of this study, Sotiriou et al. (2020) emphasized that the experience of inquiry-based learning can contribute to a deeper understanding of scientific concepts.

Based on the perspective of meaningful learning, learners should be provided with continuous opportunities to develop scientific knowledge and skills (Mtshali & Msimango, 2023; Mystakidis, 2021; Wirzal, Nordin, et al., 2022) through inquiry-based learning. The process of inquiry-based learning not only enables students to generate scientific knowledge and develop an understanding of concepts related to the learning materials (Muhali et al., 2021), but also assists students in engaging in scientific practices (Alhendal et al., 2016) to cultivate critical thinking and analytical (CA) skills through activities such as observation, questioning, evaluation and management of information, data analysis, interpretation, explanation, and cognitive regulation (Asy'ari et al., 2019; Muhali et al., 2019). The enhancement of PBTs' CA skills in inquiry-based learning with the SPS-based PADT is further supported by practical activities that promote scientific behavior, application of prior knowledge, and construction of new knowledge. This is evidenced by the substantial increase in the n-gain score of PBTs' CA skills in the experimental group, which falls within the high category (n-gain > 0.70) for each indicator (Figure 3). In contrast, the CA skills of PBTs in the control group also exhibited improvement, but it was in the moderate category (0.30 < n-gain < 0.70). We need some indication as to why BOTH groups benefited. Although research findings suggest that hands-on activities may not always be effective in improving students' conceptual understanding (Pfaff & Weinberg, 2017; Septaria & Rismayanti, 2022), there are still many students who lack confidence, and the implementation of inquiry-based learning can assist them in achieving positive learning outcomes (Ebrahim, 2012). Moreover, the results of other empirical studies have also demonstrated similar findings to this study, where learning that incorporates hands-on activities increases students' scientific behavior (Kilic et al., 2011; Prokop & Fančovičová, 2017), performance, motivation, and participation in science learning (Erickson et al., 2020; McDonald et al., 2017). However, it is worth mentioning that these studies were conducted with primary and middle school students and did not explicitly focus on PBTs' CA skills, as was done in this study.

Inquiry-based learning using SPS-based PADT demonstrated a significant impact ($p < 0.05$) on the critical thinking (CA) skills of prospective biology teachers (PBTs) (Table 5). The experimental group exhibited a higher mean score for CA skills (mean = 3.4106) compared to the control group (mean = 2.6359). The results indicated that the CA skills of the experimental group were categorized as either starting to develop or developing well (score = 3-4), while those of the control group were categorized as not yet visible or still underdeveloped (score = 1-2). The effectiveness of SPS-based PADT was further supported by the ANCOVA test, where the PBTs' pretest scores were used as a covariate (Table 6). The results revealed that the PBTs' prior knowledge (pretest) did not have a significant effect ($p > 0.05$) on their CA skills. These findings suggest that SPS-based PADT in the experimental group was the primary factor contributing to the improvement of PBTs' CA skills. The integration of SPS features in experimental activities, thinking skills, and conceptual contextualization within SPS-based PADT, along with a conducive learning environment, enhanced PBTs' motivation to learn. Consequently, this had a positive impact on the improvement of their CA skills. Our findings align with the research of Ekmekci and Gulacar (2015), who found that learning through experimental activities resulted in increased student engagement, motivation, collaboration, and communication. Furthermore, other studies evaluating the impact of inquiry-based learning (Prayogi et al., 2018), collaborative learning, and problem-based learning (Karantzas et al., 2013) share theoretical features relevant to the SPS-based PADT employed in our study. Our study contributes to the body of knowledge by demonstrating a positive impact of the implemented treatment on the development of critical thinking skills and CA skills among prospective teachers.

On the other hand, previous studies have found that inquiry-based learning is not more effective in improving critical thinking dispositions (Arsal, 2017) and the construction of scientific explanations (Jantrasee, 2022) compared to learning in the control group. It has also been negatively correlated with learning outcomes (Cairns & Areepattamannil, 2019). Students taught using intensive or frequent investigation-based learning tend to have a negative impact on science learning outcomes (Teig et al., 2018). These results contradict another study that demonstrated a significant impact of inquiry-based learning on PBTs' CA-skills ($p< 0.05$) and showed better learning outcomes compared to conventional learning in the control group. These different results may be attributed to differences in the context and methodologies used (Kwan & Wong, 2015; Qing et al., 2010). In this study, IBL was supported by the use of SPS-based PADT to enhance PBTs' CA-skills. Consistent with the findings of this study, Sari et al. (2020) discovered that the IBL environment has a positive effect on the development of scientific process skills and STEM awareness. SPS in this study assists PBTs in organizing the process of investigation and knowledge construction in science learning (Kruit et al., 2018). Furthermore, PBTs' skills in interpreting, analyzing, evaluating (Asy'ari et al., 2019), and learning autonomy (Constantinou et al., 2018; Kaçar & Balim, 2021; Yıldız-Feyzioğlu & Demirci, 2021) can be improved.

Conclusion and Implications

The findings of this study suggest that inquiry-based learning (IBL) with Self-Regulated Learning (SRL) Problem Analysis and Decision Making (PADT)has a significant impact on the critical thinking (CT) skills of prospective teachers. The experimental group demonstrated a greater improvement in CT skills compared to the control group. The initial knowledge of the prospective teachers, which was found to be homogeneous, did not significantly affect the development of CT skills. This strengthens the conclusion that SRL-based PADT effectively enhances the CT skills of prospective teachers. The results indicate that SRL-based PADT is a valuable teaching tool for improving CT skills among prospective teachers. To achieve the desired learning outcomes in CT skills, educators should carefully consider and prepare for the integration of higher-order thinking skills (HOTS) and learning models that encourage active learner participation. While this study focused solely on CT skills, it is worth noting that these skills are closely linked to other thinking skills such as problem-solving, metacognition, and critical thinking. Therefore, future studies should explore the impact of learning models such as problem-based learning, cooperative learning, and cognitive conflict learning, which are believed to have the potential to enhance students' thinking skills. Furthermore, it is important to investigate the impact of SRL-based PADT on prospective teachers' CT skills using a wider range of teaching materials beyond those used in this study.

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Appendix 1

Sample of Lesson Plan Procedures
Stage 1: Introduction (10 minutes)
• Begin by discussing the importance of plants in our daily lives and their role in ecosystems. For example, presenting a phenomenon or problem like: "Imagine a world where our understanding of plant tissues and their derivatives holds the key to addressing critical global challenges. As prospective biology teachers, you are tasked with exploring the intricate world of plant anatomy and development, focusing on how plants produce tissues that serve as the building blocks for an array of essential products. From textiles like cotton to natural rubber, timber for construction, and even life-saving pharmaceuticals derived from plants, these tissues have a profound impact on our lives and the environment. But how do plants manufacture these valuable materials at the microscopic level, and what ecological and economic implications do these processes carry? To prepare you for your role in teaching the next generation, let's embark on an inquiry-based journey to understand how plant tissues give rise to these vital derivatives and the complex web of interactions that make it all possible." • Share the lesson objectives with the students. • Ask students what they already know about plant tissues and derivatives, and record their responses on the board.
Stage 2: Engage (15 minutes)
• Show images of different plant tissues on the projector. • Ask students to make observations and discuss what they see. • Prompt questions like: "What differences do you notice in the tissues?" and "Why do you think plants have different types of tissues?"
Stage 3: Explore (30 minutes)
• Distribute microscopes and prepared slides of plant tissues. • In small groups, students will examine the plant tissue slides. • Encourage them to record their observations and make sketches in their lab notebooks. • Students should try to identify the types of tissues they see (e.g., epidermal tissue, xylem, phloem, etc.)
Stage 4: Explain (20 minutes)
• Have a class discussion about the different types of plant tissues observed. • Use the diagrams provided in handouts to explain the functions and roles of various plant tissues. • Discuss how these tissues contribute to plant growth and development.
Stage 5: Elaborate (15 minutes)
• Show examples of plant derivatives (e.g., zea mays, Arachis hypogea, Hibiscus tiliaceus). • Discuss how these derivatives are obtained from different plant tissues. • Ask students to think about the ecological significance of these derivatives. • Encourage students to share any personal experiences or knowledge related to plant derivatives.
Stage 6: Evaluate (10 minutes)
• Assign a homework assignment: Have students research and write a short essay on the importance of plant tissues and derivatives in modern society. • Review the main concepts discussed in the lesson. • Answer any questions or concerns the students may have.
Stage 7: Reflection (5 minutes)
• Summarize the key takeaways from the lesson. • Emphasize the relevance of plant tissues and derivatives in biology education. • Encourage students to explore more about plants and their applications in their future teaching careers.

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Effect of think-pair-share and choral response assessment methods on academic achievement of prospective science teachers

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ABSTRACT

A number of assessment methods are used to improve teaching which accelerates students' achievement. This study investigates the effect of two assessment methods (Think – Pair – Share and Choral Response) on academic achievement of prospective science teachers in a public sector university in Lahore, Pakistan. It employed a quasi-experimental pretest-posttest control group design which was conducted on two already existing intact groups i.e. control group (n=51) and experimental group (n=36). The pre-test was administered to both the groups, and then the participants were exposed to the treatment after which the post-test was administered. The two tests, which had been devised based on Bloom's Taxonomy of Educational Objectives, were the same for both groups. The validity of the tests was ensured by five relevant experts; the reliability was established as 0.832 through a pilot study on 200 prospective teachers. Those items in the test were selected that had difficulty ratings of 0.2 – 0.8 and discrimination ratings of 0.2 – 0.6. The collected data were analysed using independent sample *t-test*. Results revealed that the students who were assessed through chosen methods of assessment showed better performance than those who were assessed traditionally. It was also found that students showed better performance while applying Think – Pair – Share than Choral Response. Hence, the study recommended to use these methods of assessment during teaching in order to improve students' achievement.

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Introduction

In the new millennium, the education system of Pakistan experienced a major shift and affecting the quality of education owing to the aims of policy makers to bring about reforms (Ahmad et al., 2014). In a global education context, assessment of learners, teachers and the system has become a major means to identify the flaws in an education system in order to improve its quality at both systemic and individual levels (Braun, & Singer, 2019). Towards this end, exploration, implementation and innovation are required at system level to improve the quality of teaching-learning. Major questions that arise are when to assess how to assess, and what kind of assessment is effective (Huber,

& Helm 2020). Assessment might be used to measure the quality of education and to ensure that standards are matched with what tertiary learners are learning i.e. learning outcomes (Kile, 2020; Redfield, 2001).

Recently, a paradigm shift has occurred from traditional assessment to standard based assessment system to improve the quality of education. Standards-referenced assessment refers to the achievement of pupils in relation to a particular set of standards. It provides a criterion on the basis of which one can decide whether progress has been taking place or not. It provides the opportunity to the pupils to improve their learning and plays a key role in mobilising educational reforms through assessment (Rind & Malik, 2019). Assessment aids teachers in selecting the content matter, teaching methodology, designing curriculum and evaluating pupil performance in order to achieve the targeted objectives/ outcomes as well as what kind of assessment method is suitable to assess the particular learning outcome. Assessment and learning outcomes both examine the alignment between components of effective teaching i.e. objectives, teaching material/content, effectiveness of methods used for teaching, and level of achievement attained on specific learning objectives. It also diagnoses the involvement of pupils in the classroom. Teachers can assist pupils in achieving their goals not only through instruction but also by using proper assessment methods (Kulasegaram & Rangachari, 2018). The improvement of learning does not only depend on the assessment method used but also how well it is aligned to the specific learning targets and the content that is to be used in achieving that targets. This is basically the umbrella under which standards/outcomes based education lies (Sharma, 2015).

Standards-based education is commonly followed in many countries where they focus on learning outcomes and choose the assessment that best suits that standard. At global level, government authorities set standards for achievement and clearly set standards and criteria for learners to attain particular knowledge or skill at different levels of education. The alignment of standards and curricula is the critical element of the assessment system (U.S. Department of Education, 2018, p. 9). The importance of standards-based education lies in matching of objectives to particular standards. If, in any case, the standards are not aligned or matched to the assessment then results have less value in diagnosing the learning needs of learners as well as determining how well a pupil is performing at some grade level. Researchers need to focus in exploring the strategies and tools to measure the standard based performance.

Standards-based assessments serve an important role in educational system because educators have to teach the content based on the learning standards and then conduct assessment accordingly. Alignment of assessment with standards is not a new concept in education system (Bloom, Maidus, Hastings, 1981; Impara, 2001; Tyler, 1949; Webb, 1999). It has been important tool to measure education outcomes and the validity of assessment methods. The present study has its roots in Webb's (1997, 2002) method of alignment to determine the match between the educational objectives and assessment methods used (Blank, 2002). The alignment model presented by Norman Webb (1997a; 1997b; 1999) has been one of the influential models in education (Ananda, 2003; Impara, 2001; La Marca et al., 2000). With the passage of time, people became more research and outcome oriented. They used the results of assessment in the evaluation of education systems and to take decisions based on that (Azeem & Gondal, 2011). Assessment methods are very much interrelated with that of learning standards as well as course contents. One cannot proceed in the process of effective assessment without considering the content and standards. However, in this study, the effect of two methods of assessment viz. Choral Response and Think – Pair – Share were ascertained on academic achievement of prospective science teachers to get an insight of the methods best suitable to improve their achievement.

Choral Response

Choral response is a recent data based procedure that is no longer being used. In choral response the teacher gives a flag or signal to the learner who have to respond in a unified way (Wolery et al., 1992). Using this quick paced strategy can get pupils' attention resulting in increased response and commitment. In direct instruction, choral response is additionally used as an informal method (Carnine et al., 2004). Pupils who need correction and the ones who gave correct answers might be distinguished by this procedure Teachers can correct the students immediately after getting the responses. This process relies on three criteria: learners must have the ability to give a concise answer; 1-3 word answers; and just a single perfect response. With these criteria, a teacher can easily monitor how the pupils react and then provide them a constructive feedback accordingly (Heward, 1994). In order to support all considered things and guarantee mindfulness, the exercise should be carried out at a lively pace (Kamps et al., 1994). Small groups improve the reliability of choral response. Using clear signal of when to respond, giving sufficient feedback, giving pupils a little break to think and calling individual pupils occasionally are some of the other aspects by which choral responding can be enhanced. With this method, teacher can easily assess whether pupils can understand the concepts and educational content being taught, or not (Blackwell & McLaughlin, 2005).

Think – Pair – Share

Another method to carry out assessment is Think – Pair – Share; it is a simple method of assessment in which teacher asks students to think in pair and then respond by either writing the vocabulary or concepts after instruction, reading out aloud the answers asked by the teaching, summarize main ideas of the concept, discussing muddy point from the lecture, choral responding and answering the questions asked while doing self/peer assessment. Frank Lyman was the first educationist who proposed this model in 1981. The fundamental component of this model is to improve achievement by means of discussion with fellows. The process is more effective with more discussion and learning outcomes are also improved (Kaddoura, 2013). This method is one of the active learning methods which prompts learners to work out solutions to problem (Nasr, 2003). Pupils are required to think about the answers and write them on a paper sheet in the given time. Then, they are required to pair up with their class fellows and share their views. After discussing their answers in pair, they are asked to share their answers with the whole class. The teacher may circulate throughout the class during this time, and provide guidance where appropriate. This method places pupils at the centre of learning (Dyer, 2012). If it is done properly, it gives a true reflection of knowledge sharing among individuals and groups resulting in a healthy classroom environment. Teachers can intervene to avoid useless classroom discussions that may not achieve the set objectives. This method asserts that students' in-class participation is an important precursor of their academic achievements. The short time between teachers' questions and calling on the first pupil, hand raising as the gateway to in-class participation which requires students to elaborate and formulate their ideas in a short time. TPS can be assumed to provide students with the opportunity to elaborate their ideas and gain more confidence from peer support by reducing anxiety and boost their confidence (Mundelsee, & Jurkowski, 2021).

Many researchers including Boston (2002), Deubel (2006), Kile (2020), and Stiggins (2018) have addressed the different dimensions of effective assessment particularly at higher education level. They found that students can get involved in learning and perform better while using multiple assessment methods such as think-pair-share, oral questioning, think aloud activities, exit ticket, self-responding, peer-responding, Muddiest Point. The study focuses on two of these assessment methods (Think – Pair – Share and Choral Response) and explored how these methods of assessment improve the achievement of trainee teachers in classroom.

Rationale of the Study

Researchers (Grisay, 1991; Harlan & Malcolm, 1996; Pinger, Rakoczy, Busser, & Klieme, 2018; Tomlinson & McTighe, 2006) found the overall effectiveness of assessment methods on students' achievement at different levels. At university level, no significant research has been found by the researcher to find the effect of TMAs on students' academic achievement. Teacher's assessing methodologies act as a bridge between his or her teaching and his/her students' academic achievement. It minimizes the learning gap and improves the quality of the teaching-learning process by increasing the learning proficiency of students (Bitchener & Knoch, 2008). In Pakistani education system, traditional assessment methods just measure the limited performance of the students instead of guiding them during the process of learning (Adegoke, 2010; Aftab, Qureshi, & William, 2014; Ahmad, Rehman, Ali, Khan, & Khan, 2014; Aworanti, 2011; Peterson, 2007; Rehmani, 2003). They lay more focus on the students' learning capacity rather than on their abilities to think systematically and how they comprehend and analyze the things. In view of this approach, the current study was designed to determine the effectiveness of assessment methods such as Choral Response and Think – Pair – Share on students' achievement.

Research Objectives

Following research objectives were formulated for this study.

1. To find out the effect of Think – Pair – Share and Choral Response as methods of assessment on prospective science teachers' academic achievement.
2. Identify the best method of assessment among Think – Pair – Share and Choral Response in regard to promoting prospective science teachers' academic achievement.

Methods

This study was experimental in nature using pretest and posttest with a control group to compare the effect of assessment methods Think – Pair – Share and Choral Response on the academic achievement of prospective science teachers. There were 238 prospective science teachers in the programme. For this purpose, those students were selected who were specialising in Science Education. Two intact groups were chosen for the study with a total of 87 prospective science teachers who were later named as experimental and control group. In this way, the number of participants in control group was 51 whereas in experimental group it was 36.

Instrumentation

Lesson plans, worksheets and an achievement test were used as instruments for collecting data for this research. The instruments were developed in accordance with the student learning outcomes and methods of assessment. The lesson plans were formulated by considering the learning objectives on four domains presented by Chappuis, Stiggins and Arter, (2012): knowledge, reasoning, process and product (Appendix-B). A brief description of each of these is given in the figure.

The achievement test (pre-test and post-test) was developed with reference to Bloom's Taxonomy of Educational Objectives 1956. For this, a two-way specification table was formed covering all levels of Bloom's Taxonomy. The final test consisted of 30 MCQs, one essay type question and two short open-ended questions (Appendix-A).

The instruments of the study were validated by five experts in the field of education and curriculum and finalised by implementing their suggestions. Two hundred students in their 5th semester were chosen for piloting of the achievement test. Some items were then revised following item analysis. The reliability of the final test was 0.832 and the items exhibited difficulty and discrimination ranges of 0.2 - 0.8 and 0.2 - 0.6 respectively. The final test after piloting was administered to the students before conducting the experiment. The post-test was conducted 16 weeks later.

Intervention Procedure

The intervention was carried out for 16 weeks. Both the groups were assessed and taught by the principal researcher to keep both groups on the same pace and to minimise the external threat of validity and researcher biasness during the study. Traditional method of assessment such as paper and pencil test at the end of the instruction was used to assess the control group while the experimental group was assessed through Think – Pair – Share and Choral Response on daily basis. For this purpose, worksheets and tests were used and the results were recorded daily.

Both these groups were assessed side by side on daily basis. Beside this, groups were pre-tested before the experiment to check their baseline performance. After pre-test, both groups were randomly assigned to treatment groups. Both the groups were taught by the same person and the content taught to the prospective teachers were the same as well. After intervention, both the groups were post-tested to get the cumulative achievement score on the basis of which groups are to be compared. The lessons were planned in such a way that every individual got an opportunity to participate in the study and assessed by both assessment methods. Same content was taught to both the treatment group and the comparison group. The study lasted for the whole semester (16 weeks). Separate portfolio of every student was organized in which their record was maintained. Students received the feedback promptly to excel. The experimental group was tested after applying every assessment method to measure the significant effect of that assessment method on students' achievement. After applying the treatment both the groups were tested (post-tested). The researcher compared the achievement of the both groups. The scores of pre-test and post-test of each group were also compared to check the effectiveness of the assessment methods.

Results

The results for the present study are given below;

Table 1

Independent sample t-test on pretest and posttest scores of control and experimental group

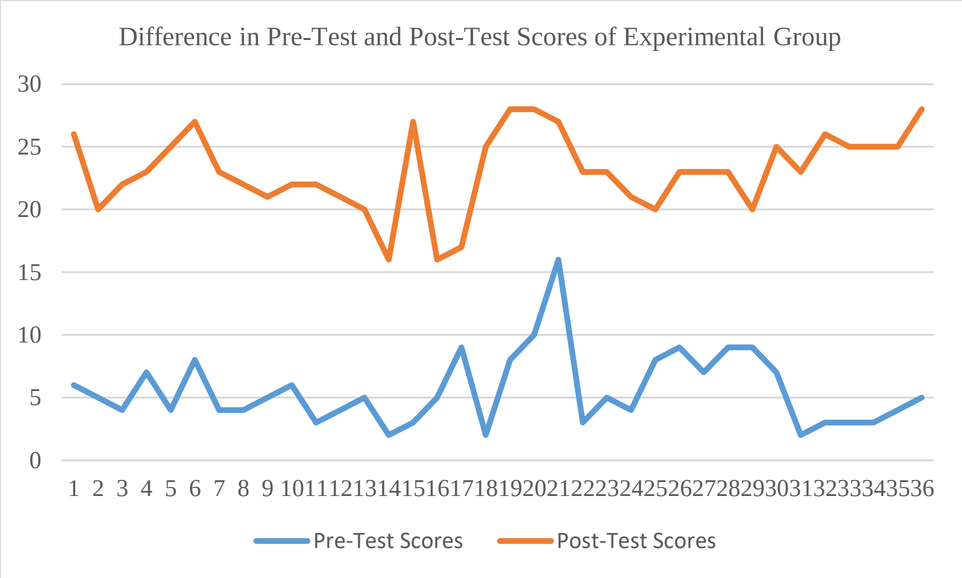
Test	Groups	N	Mean	SD	df	t-value	Sig. (2-tailed)
Pretest	Control	51	6.12	2.215	85	1.191	0.237
	Experimental	36	5.53	2.360			
Posttest	Control	51	14.25	2.869	85	16.82	.000
	Experimental	36	23.97	2.311			

Table 1 describes the difference in pre and post achievement scores of the control and experimental groups. Independent sample *t*-test was applied (Control M = 6.12, SD= 2.215; Experimental M = 5.53, SD= 2.360) at 0.05 level of significance, in order to compare the mean achievement scores of the prospective teachers in pretest. The t value was 1.191 with df (85) which is lower than the table value of t (1.290). In the same way, the p-value is 0.237 that is higher than 0.05 which reflected that the prospective teachers in both groups are not significantly different from one another.

The achievement scores of prospective teachers in posttest were (Control M= 14.25, SD= 2.869; Experimental M = 23.97, SD= 2.311) at 0.05 level of significance. The t value was 16.82 with df (85) which is higher than the table value of t (1.290) and the p-value is 0.000 that is less than 0.05 which reflected that prospective teachers in experimental group scored better in posttest when they were separately assessed by Think – Pair – Share and Choral Response than the prospective teachers of control group.

Figure 1

Graphical representation of pre-test & post-test score of the experimental group



The above figure shows the difference in pretest and posttest scores of prospective teachers from the treatment group. It can be clearly seen in the graph that the pretest scores of the experimental group are well below than the posttest scores of the group which shows the improvement in group during sixteen weeks of experiment. The lines of the graph clearly show that the assessment methods i.e. Choral Response and Think – Pair – Share played a clear role in improving the academic achievement of the students.

Table 2

Independent sample t-test of control and experimental group after using choral response

Groups	N	Mean	SD	df	t-value	Sig. (2-tailed)
Control	51	2.101	.534	85	25.220	.000
Experimental	36	5.026	.304			

The table describes the difference in achievement scores of control and experimental group. Independent sample t-test was applied (Control M= 2.101, SD= .534; Experimental M= 5.026, SD= .304) at 0.05 level of significance in order to compare the mean achievement scores of the students in both groups. The t-value was 25.220 with df (85), which is higher than the value of table t (1.290). In the same way, the p-value is 0.000 that is less than 0.05 which reflected that experimental group students scored better when they were assessed by Choral Response than the control group.

Table 3

Independent sample t-test of control and experimental group after using think-pair-share

Groups	N	Mean	SD	df	t-value	Sig. (2-tailed)
Control	51	2.849	.713	85	23.990	.000
Experimental	36	7.720	.540			

The table describes the difference in achievement scores of control and experimental group. Independent sample t-test was applied (Control M= 2.849, SD= .713; Experimental M= 7.720, SD= .540) at 0.05 level of significance in order to compare the mean achievement scores of the students in both groups. The t-value was 23.990 with df (85), which is higher than the value of table t (1.290). In the same way, the p-value is 0.000 that is less than 0.05 which reflected that experimental group students scored better when they were assessed by Think-Pair-Share than control group.

Table 4

Independent sample t-test to compare group after applying think – pair – share and choral response

Groups	N	Mean	SD	df	t-value	Sig. (2-tailed)
Think – Pair – Share	36	7.720	.540	34	19.731	.000
Choral Response	36	5.026	.304			

The table describes the difference in achievement scores of groups assessed through Think – Pair – Share and Choral Response. Independent sample t-test was applied (Think – Pair – Share M= 7.720, SD= .540; Choral Response M= 5.026, SD= .304) at 0.05 level of significance in order to compare the mean achievement scores of the students in both groups. The t-value was 19.731 with df (34), which is higher than the value of table t (1.290). In the same way, the p-value is 0.000 that is less than 0.05 which reflected that the students scored better when they were assessed by Think – Pair – Share as compared to Choral Response.

Discussion

The results of the study are evident that treatment group exhibited better performance as compared to control group which means that assessment methods (Think – Pair – Share and Choral Response) put a positive effect on the academic achievement of the students and they showed interest in the methods of assessment used. Abejehu (2016) conducted a study in which he explored the effect of assessment methods on students' academic achievement and the results supports the finding of this study that assessment methods increase the performance of the students. Likewise, another study revealed that assessment methods were supportive to promote the students' performance and achievement (James & Folorunso, 2012). The results of the current study also aligned with the research studies conducted by (Gibbs & Simpson, 2004, 2005; Louden, 2005; Matters, 2006; Nicol & MacFarlane 2004) which revealed the positive effect of assessment methods on students' achievement.

Some other studies discovered that pupils responded more to teacher questions when they were required to chorally respond in the classroom instead of using traditional questioning like raising their hand and volunteering to respond individually (Godfrey, Grisham-Brown, Schuster, & Hemmeter, 2003; Haydon et al., 2013; Kamps, Dugan, Leonard, & Daoust, 1994). Results also showed that during choral responding individuals' learning improves and they were motivated to learn (Haydon et al., 2013). Another study reported that the pupil respond actively during choral responding and their achievement increased as compared to individual response mode (Hughes & Coplan, 2010; Umbreit et al., 2007). Akhtar & Saeed (2020) also confirms that choral responding improves the students' academic achievement and have significant effect on students and can be used in the classrooms at higher education.

Another method of assessment used in this study is Think – Pair – Share that was also very helpful for teachers and students to improve the learning. Yusuf, Owede, and Bello, (2018) conducted an experimental study following quasi experimental design to investigate the effect of think – pair – share on students' academic achievement in Bayelsa State compared to the traditional (lecture) method of teaching frequently used by classroom teachers. This present finding also confirms the findings of Bataineh (2015) and Bamiro (2015) reported in their separate studies that students who were taught with the use of Think-Pair-Share strategy obtained higher scores compared to those taught with traditional method. This finding corresponds with the findings of Jumanta (2014), Sejani (2016) and Shadrina (2013) that had worked on the effect of the use of think-pair-share on students' academic performance in mathematics and found it to be effective at improving students' academic performance. The result of the study revealed that both male and female students benefited from the use of think-pair-share as a teaching strategy. Cooper and Robinson (2000) were also of the view that Think – Pair – Share may be used as a valuable form of assessment that may be helpful in increasing the performance of the students. The results correspondingly explored that this method improve the understanding and performance of the students. Heward (1994) results also justify the findings of the present research study in a way that Think – Pair – Share not only improved the understanding and performance of the students but it also creates a sense of cooperative and sharing among students that ultimately leads them towards constructive learning and they perform better. They explored that this method is also helpful for the students to understand the content matter inn a better way. Vineeta Persaud and Rita Persaud (2019) also explored in their study that Think – Pair – Share increased the students' achievement as well as students' interaction in the large classes even. Pradana, Sujadi, and Pramudya (2017) were also of the view that if Think – Pair – Share was used as formative assessment method it can improve students' learning and they pose the reason against this learning increase that this method made students active and they take more interest that may helpful to them in increasing their learning.

Conclusion

From results of the study it can be concluded that methods of assessment (Think – Pair - Share) improve the academic achievement of prospective science teachers. These methods have significant effect on students and can be used in the classrooms at higher education. Although when it comes to the comparison of these methods, the students produce significantly high mean scores across Think – Pair - Share than Choral Responding. It reflects that Think – Pair - Share is the more effective methods of assessment, but these two methods are significantly good in regard to promoting pupil's achievement. It is practicable in the classroom easily at a time and even separately. These methods of assessment may be used with different teaching strategies or other assessment methods in order to get better results. The teachers at other levels may also use these methods to explore them at other levels in intentions to improve students' learning.

Recommendations

In the light of the aforementioned findings and conclusions of the study, the following recommendations have been put forward for consideration:

The university teachers may be recommended to use different assessment methods to assess their students in different subjects. By using TMAs of assessing the students who showed relatively greater interest in class as compared to the students who were assessed by using traditional methods of assessment. In this way, the assessment methods used might leave long-lasting effect on students and consequently, their performance may improve in the relevant subject. This study may be replicated by using other TMAs with specific duration of time to assess the students' learning that may add the body of literature on the actual efficacy of assessment methods, especially of those that are flaunted as especially effective methods of assessment.

Implications for Future Research

The present study was conducted to find out the effect of TMAs on academic achievement of students in university classrooms. The results of the study suggested that TMAs has positive effect on students' achievement. While considering the research findings, following implications are drawn from the study for future researchers. Some other TMAs may be used at same level like Agree/Disagree Circles, Exit Ticket, Frayer Model, Muddiest Point, etc. to find out the effectiveness of those methods. These methods may be used while altering the combination of TMAs used to see if still they are this much effective or not. The future researchers may use more than two groups to check out the effectiveness of TMA separately in spite of doing it on single group. The researchers may adopt any other research design e.g. True Experimental design or Solomon four group design instead of quasi experimental design to find out the effectiveness of TMAs on students' achievement. The policy makers or curriculum developers might conduct this kind of research at large scale level as some project in more than one university before indulging it in curriculum or making it the part of university curriculum. They should promote such assessment systems that measure progress of students and the education system over time.

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Appendix

Test

Student Number: __________	Student Name ___________	Time: 1- hour
Course: Curriculum Development	Program BSEd. (Hons.)	Marks: 40

Part I – MCQs

Read each statement and all of the alternatives carefully. Encircle the alternative that best answers the question or completes the statement. Overwriting and cutting leads to deduction of marks.

1. Who defines curriculum as the written document that systematically describes goals planned, objectives, content, learning activities, evaluation procedure and so forth? (KNOWLEDGE)
   a. Pratt
   b. Cronbleth
   c. Tyler
   d. Tanner
2. The creative principle of curriculum deals with the objective of education which means: (COMPREHENSION)
   a. Create new things while considering students' needs
   b. Discover and develop special interests, tastes and aptitudes of students
   c. Develop curricular activities to promote teaching
   d. Investigate different learning gaps and create interest of students.
3. The outline of the content to be studied by a student at a specific level of education is called: (COMPREHENSION)
   a. Course
   b. Subject
   c. Syllabus
   d. Content
4. Principle of maturity deals with the type of curriculum at different stages. According to this principle the best sequence for the activities to be included in the curriculum is: (ANALYSIS)
   a. Activity related to wonder, practical curriculum, generalization
   b. Practical Activities, generalization, theory development
   c. Activities related to interest, generalization, theory development
   d. Activity related to wonder, practical activities, generalization,
5. In your computer subject, you allow your class to chat as a part of your motivation before discussing them the roles of computer as a tool. Chat is used in this context as a/an: (APPLICATION)
   a. Informative
   b. Communicative
   c. Application
   d. Situating
6. When students learn lessons such as the importance of winning, the pain of losing, or how competition can turn friends into enemies, they are most likely learning the: (APPLICATION)
   a. Null curriculum
   b. Hidden curriculum
   c. Curriculum-in-use
   d. Rhetorical curriculum
7. When confronted with a learning situation, the learner: analyzes the problem, discriminates between essential and nonessential data, and perceives relationships: (APPLICATION)
   a. Gestalt theory
   b. Psychosocial theory
   c. Piaget theory
   d. Theory of curriculum development

8. Determining the value orientation of the curriculum involves consideration of the following components EXCEPT: (ANALYSIS)
    a. Availability of facilities and equipment
    b. The students for whom the curriculum is being developed
    c. The subject matter to be learned
    d. The society that has established the schools
9. Which is an example of spiral curriculum? (ANALYSIS)
    a. Teachers work together to integrate several subject areas into their lessons to give students a more holistic learning experience
    b. A student is required to use skills he acquired in math the previous grade to understand new information about a math topic in his current class
    c. A teacher organizes her class around several key questions that students will work to answer throughout the year
    d. None of above
10. During her first year as a teacher, Sara was visited on several occasions by colleagues and administrators who observed her teaching. Following each observation, she met with those who observed her so that they could help her identify her strengths and areas for improvement. These observers were engaged in: (ANALYSIS)
    a. Collaborative action research
    b. Evaluative reviews
    c. Diagnostic reviews
    d. Learning reviews
11. In demonstration method, teacher acts as a: (COMPREHENSION)
    a. Facilitator
    b. Helper
    c. Showman
    d. Leader
12. Special needs of the child should be considered while developing the curriculum follows the principle of: (COMPREHENSION)
    a. Integrity
    b. Individual differences
    c. Learning
    d. Flexibility
13. Curriculum trends according to progressivism are: (COMPREHENSION)
    a. Humanistic approach, societal education, cultural experiences
    b. Cultural experiences, school development, ideological principles
    c. Schools reforms, cultural reforms, societal reforms
    d. School reforms, relevant and contextualized curriculum, humanistic education
14. The trend which is catching the attention of policy makers is: (KNOWLEDGE)
    a. CAI
    b. ICT
    c. IRT
    d. CTT
15. Professor Ali is thinking of an online learning approach by which content provides links to information at other locations and serves as a focal point for a distance education experience. Which of the following should he use? (APPLICATION)
    a. Computer-aided Instruction
    b. Web-based Instruction
    c. Self-paced Program
    d. Teleconferencing

16. Which is NOT a basic consideration in selecting and evaluating the content of an educational technology tool? (ANALYSIS)
    a. Will it motivate and maintain interest?
    b. Is there evidence of its effectiveness?
    c. Can it be easily dismantled?
    d. Does it match the content?
17. Technology, computers, and the Internet have been used for many classroom and educational purposes. Which of the following is NOT a reason offered for computer use? (ANALYSIS)
    a. Drill and practice on specific skills, often the same skills required in state assessment tests
    b. Promote higher order thinking through simulations and collaborative action research
    c. Reduce disruptive behavior by refocusing students on individual computer tasks and assignments rather than on each other
    d. Modernize the school culture by reshaping American education for the twenty-first century
18. The process in which philosophy provides the starting point and will be used for the succeeding decisions is known as: (APPLICATION)
    a. Problem solving
    b. Decision making
    c. Inductive approach
    d. Deductive approach
19. When a teacher comes in a class and say, "Today we shall try to know about the proportion of oxygen and nitrogen in the air". He/she follows which step of lesson plan: (APPLICATION)
    a. Introduction
    b. Students' learning outcome
    c. Announcement of aim
    d. Generalization
20. The curriculum that is perceived and experienced by the students referred to as: (COMPREHENSION)
    a. Experiential
    b. Instructional
    c. Institutional
    d. Societal
21. Kainat and Maliha want to answer this question, but they have just answered two questions. "Let's give Sidra a chance to answer and then you both can tell the class whether you agree with her or not". What method of teaching is being used by the teacher? (APPLICATION)
    a. Discussion
    b. Lecture
    c. Project
    d. Problem solving
22. A student has difficulty staying focused and on task. Which one of the following teacher responses would be a consequence, rather than a punishment? (ANALYSIS)
    a. Calling the parents to notify them of the student's behavior
    b. Deducting points from the student's final grade
    c. Having the student move closer to the teacher's desk
    d. Having the student stay in detention to make up the work missed due to being off task
23. The non-verbal barrier to communication in the classroom may be: (COMPREHENSION)
    a. Informal dress style
    b. Walking too quickly up to someone
    c. Repeating the words again and again
    d. Speaking too loudly in the classroom

24. The kind of curriculum that is BEST to learn the social roles is: (KNOWLEDGE)
    a. Total
    b. Hidden
    c. Societal
    d. Managerial
25. Steps of Glover Plan are: (KNOWLEDGE)
    a. Questioning, Discussion, Investigation, Expression
    b. Introduction, Explanation, Discussion, Questioning
    c. Introduction, Expression, Questioning, Investigation
    d. Expression, Investigation, Questioning, Discussion
26. Heuristic is derived from the Greek word, which means to: (KNOWLEDGE)
    a. Discover
    b. Learn
    c. Demonstrate
    d. Act
27. A new element was introduced into curriculum process of cyclical models, called: (KNOWLEDGE)
    a. Content analysis
    b. Product analysis
    c. Situational analysis
    d. Curriculum analysis
28. The principal proponents of rational model are: (KNOWLEDGE)
    a. Ralph Tyler and Hilda Taba
    b. Skill beck and Hilda Taba
    c. Oliva and Tyler
    d. Tyler and Wheeler
29. Hilda Taba defined that the curriculum should be designed by the: (KNOWLEDGE)
    a. Curriculum wing
    b. High authority
    c. Teachers
    d. School
30. According to the needs and differences of the child; the curriculum should not be rigid and adopted follows the principle of: (COMPREHENSION)
    a. Integrated
    b. Individual differences
    c. Phantom
    d. Societal

Part II – Subjective Type

Attempt all Questions.

1. Consult the book of Biology-II and identify while developing this book which principles of curriculum development were considered. (5) (EVALUATION)
2. While considering the models of curriculum development create a model of your own choice. The model must possess all those characteristics which you think should be implemented in Pakistan. (5) (SYNTHESIS)
3. Develop a lesson plan that you consider is a best fit approach on any topic of your choice while considering different models and approaches of lesson plan. (5) (ANALYSIS)

Appendix-B

Model – Lesson Plan

Course Curriculum Development **Topic**: Concept of Curriculum
Level BSEd. (Hons.) **Time** 90 minutes

Objectives

1. Comprehend the concept of curriculum by different practitioners.
2. Understand difference between curriculum, syllabus and textbook.
3. Know about the difference between different levels of curriculum and recognise the characteristics features of each.

Teaching Aids

Multimedia, White Board, Board Marker, Worksheets, etc.

Recapitulation 10 minutes

Students' previous knowledge about the topic being taught is checked by asking various questions about it.

Different statements will be asked about syllabus, subject, course and curriculum from students. They will be required to give answer of the statement.

Explanation of the Content 30 minutes

After collecting the responses from the students discuss these statements with students to build up their concepts at the beginning. The terms curriculum, subject, course and syllabus will be discussed with the students by quoting different examples. The concepts of the students will be built on the basis of different definitions given by different practitioners.

Assessment Methods

1. Think – Pair – Share 15 minutes

After explaining the terms, students will be asked to separate curriculum, content, syllabus, outline, and course from a book individually. After this, they will be required to discuss it with their pair and then in the class for discussion and clarification of concepts.

After this activity, different levels of curriculum will be explained to the students.

Explanation of the Content 20 minutes

After collecting the responses(written) from the students, some definitions of curriculum from different practitioners will be discussed with them according to the context. The definition in different country context and the Latin and Greek meanings of the term "curriculum" will also be discussed with them. Students will be then required to think about their previous educational experiences and find a difference between curricular, extra-curricular and co-curricular activities by relating it with the concepts discussed.

Ending 10 minutes

At the end of the lesson it will be asked from the students to tell on which point they feel difficulty during the lesson. An exit slip will be provided to all students and their responses will be collect on individual basis by asking them to paste the slip on the board while exiting.

Task Outcome 5 minutes

Chose a definition of curriculum of your choice and discuss what you like about that definition that make it unique from all others. Also, write what is content and syllabus from a book of your choice.

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Research trends in blended learning in chemistry: A bibliometric analysis of scopus indexed publications (2012–2022)

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ABSTRACT
Applying bibliometric techniques to blended learning research is still relatively uncommon. This study employs bibliometric analysis, employing data from the Scopus database and VOSviewer to show papers published between 2012 and 2022. The study's sample is made up of publications on blended learning in science that have been indexed by Scopus and were published between 2012–2022, amounting to 194 articles. Through Scopus filters, 85 irrelevant works, including editorials, comments, and book reviews, were excluded. Subsequently, 109 articles relevant to the research objectives were extracted. Citation patterns, publication trends, frequently cited articles, and author keyword analysis were examined, shedding light on the growth of research in blended learning chemistry. As a result, research in blended learning chemistry has grown steadily from year to year in publications in journals with a Scopus index. Analysis and online learning are two terms rarely used concerning blended learning in chemical education. The most often used terms were "e-learning," "online learning," "collaborative learning," and "reverse classroom." Most blended learning research is carried out in the United States and the United Kingdom. For all of the papers examined, bibliometric analysis was utilised to determine goals and key areas of chemical content. The findings contribute to a deeper understanding of the evolution and current state of blended learning in chemistry education, providing insights for future research directions and educational practices.

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Introduction

An educational strategy called blended learning combines in-person and online instruction. Traditional classroom lectures can be combined with online lectures in a setting where technology is used to provide learning materials (Arifiani & Irwanto, 2024). There is plenty of evidence that a blended learning strategy that includes in-person and online learning resources is significantly more successful in raising achievement than employing only in-person education techniques (Ramadhan et al., 2023). However, to be successful, blended learning resources must be created and delivered in a row with sound pedagogical principles (Van, 2016).

Because it integrates conventional classroom methods with online learning models, blended learning is both intriguing and realistic. Learning using a blended learning approach gives students a productive and successful educational experience, expanding their access to the curriculum, improving their learning results, and enabling them to follow teacher instructions (Dziuban et al., 2004). Educators should bear in mind that the adoption of blended learning technology should not aim to replace instructors or professors. As emphasized by Singh and Reed (2001), students' learning does not stem directly from the technology itself, but rather from the effective strategies employed by teachers to communicate using technology. For over a decade, blended learning has been employed in educational settings. However, Chew et al. (2010) suggest that it remains in a developmental phase. The progression has been notably influenced by highly interactive technologies like games and simulations (Dede, 2005; Irwanto et al., 2022). The central topic under debate pertains to whether blended learning proves more effective than alternative learning approaches. Over the past few decades, the educational landscape has witnessed significant transformations propelled by rapid technological advancements (Irwanto et al., 2023a). Traditional education, until recently, stood as the predominant classroom model (Schaber et al., 2010). It typically involves the physical presence of both instructors and students in a classroom setting where teaching and learning activities take place (Nortvig et al., 2018). The emergence of online learning took place in the 1990s (Schaber et al., 2010), presenting a departure from traditional methods. Online learning involves fully virtual courses devoid of physical class meetings, allowing for asynchronous participation of professors and students (Irwanto et al., 2023b; Nortvig et al., 2018). Research has extensively explored the effectiveness of three teaching modes: traditional face-to-face, blended, and online instruction. Dziuban et al. (2004), employing blended learning approaches, found that students utilising blended learning systems outperformed those in fully online environments and, in some cases, even traditional face-to-face instruction. In a recent study, learning was delivered through all three modalities, revealing that an online learning environment outperformed blended and face-to-face methods (Reason et al., 2005). As conventional and online learning paradigms continue to evolve, a third instructional approach has emerged—blended learning—resulting from the integration of traditional and online learning practices. Blended learning serves as a method that harnesses the strengths of various theories, technologies, and applications (Haijian et al., 2011).

With technology, learning may take place anytime, anywhere, without regard to location or time, with the potential for student involvement support. Other learning activities can also boost engagement and assist students in achieving higher achievement (Bliuc et al., 2007). Additionally, students develop their social and academic self-projection skills in online research groups. Importantly, support students in mastering some technologies, and digital learning skills becoming crucial for lifelong learners (Cleveland & Wilton 2018; Sahara et al., 2021; Jebraeily et al., 2020).

Bibliometrics involves the quantitative and descriptive statistical analysis of various types of publications, including journal articles, conference proceedings papers, and book chapters (Ding et al., 2016; Zuccala & Leeuwen, 2011). Bibliographic information can be retrieved by searching databases such as Web of Science (WoS) and Scopus using keywords, authors, journals, and specified time periods. Over the past two decades, the quantitative analysis of publications and citation data has become widely utilised in educational contexts to evaluate top authors and conceptual frameworks (Aria & Cuccurullo, 2017). Two key aspects of bibliometric mapping include the creation of distance-based maps and their visual representation. In bibliometric literature, there is more emphasis on map creation than on graphical representations of these maps (Van Eck & Waltman, 2010). While computer programmes like SPSS and Pajek can generate simple visual depictions of bibliometric literature, they are typically suitable for smaller maps containing fewer than 100 entries (Chen, 2003; Skupin, 2004). Consequently, new software programmes capable of producing larger maps have been developed (Van & Waltman, 2020).

Using bibliometric metrics such as the h-index and impact factor, bibliometrics is frequently used to assess the significance of scientific research. By measuring the number of other publications that reference a specific work, bibliometric indicators can determine the impact of that paper. Many researchers employed Harzing's Publish or Perish program to determine citation metrics such as the *h*-index and *g*-index (Harzing, 2020). The conceptual framework of this research is that the authors use bibliometric analysis literature, especially for journals published in the last ten years.

Advanced analytical techniques are now readily available to ensure the accuracy of bibliometric analysis and to cover a wide range of publications spanning a significant period of time. Popular databases such as WoS, Google Scholar, and Scopus are commonly utilised (Li et al., 2010). However, as of February 2, 2020, searches using keywords like "blended learning," "achievement," "engagement," "perception," "higher learning," and "bibliometric analysis" yielded no results in the Scopus database. Nonetheless, other articles have explored the relationship between students' perceptions of blended learning courses and their academic performance in higher education (Owston et al., 2013).

Given the persistent disparity between blended learning and perceptions, achievements, and engagement in higher education, the present investigation was undertaken. The research findings identified three factors contributing to educational disparities in Indonesia: limited access to schools, declining school facilities, and inadequate teacher interest and quality. For this study, the authors formulated three research questions: (1) *How have publications on blended learning evolved over the past decade?*, (2) *Which blended learning study in chemistry education has garnered the most citations?*, and (3) *What are the most commonly used search terms for blended learning studies in chemistry education?*

Methodology

The population for this research consisted of chemistry education blended learning articles published up to June 10, 2021, from the Scopus database. From 2012 to 2022, 109 research papers were selected from a total of 194 papers. Data about integrated learning in chemistry education were gathered, processed, and analysed using bibliometric analysis techniques. Data gathering was conducted using VOSviewer data visualization with the Scopus database accessed via www.scopus.com. The search was limited by typing "blended learning" in the search menu, setting the publication date range from "2012" to "2022," selecting the document type "journal," and clicking "search" to retrieve the information. The data from the search results were saved in RIS format for handling using VOSviewer and Microsoft Excel (Irwanto et al., 2023).

The data collected was stored in RIS format. Both descriptive quantitative and qualitative data analysis methods were performed in the present study. Microsoft Excel 2010 was utilised to evaluate data obtained from scientific publications on blended learning in chemistry by year, author, title, and subject. Articles on blended learning in chemistry were analysed using the VOSviewer program. Data processing output took the form of graphs in Excel and network maps based on authors and keywords in VOSviewer. Subsequently, VOSviewer was used to visualize the findings of the analysis, as illustrated in Figure 1 (Moher et al., 2009).

The inclusion and exclusion criteria applied during the study are outlined in Table 1.

Table 1

Inclusion and exclusion criteria

No	Inclusion Criteria		Exclusion Criteria
1.	Limited to documents related to blended learning published in the 2012-2022 period in the Scopus database	1.	Documents concerning blended learning that were published outside the timeframe of 2012 to 2022 within the Scopus database
2.	All documents written in English	2.	All articles written not in English
3.	All documents in the form of journal articles	3.	All documents other than journal articles (e.g., conference papers, books, book chapters, etc.)

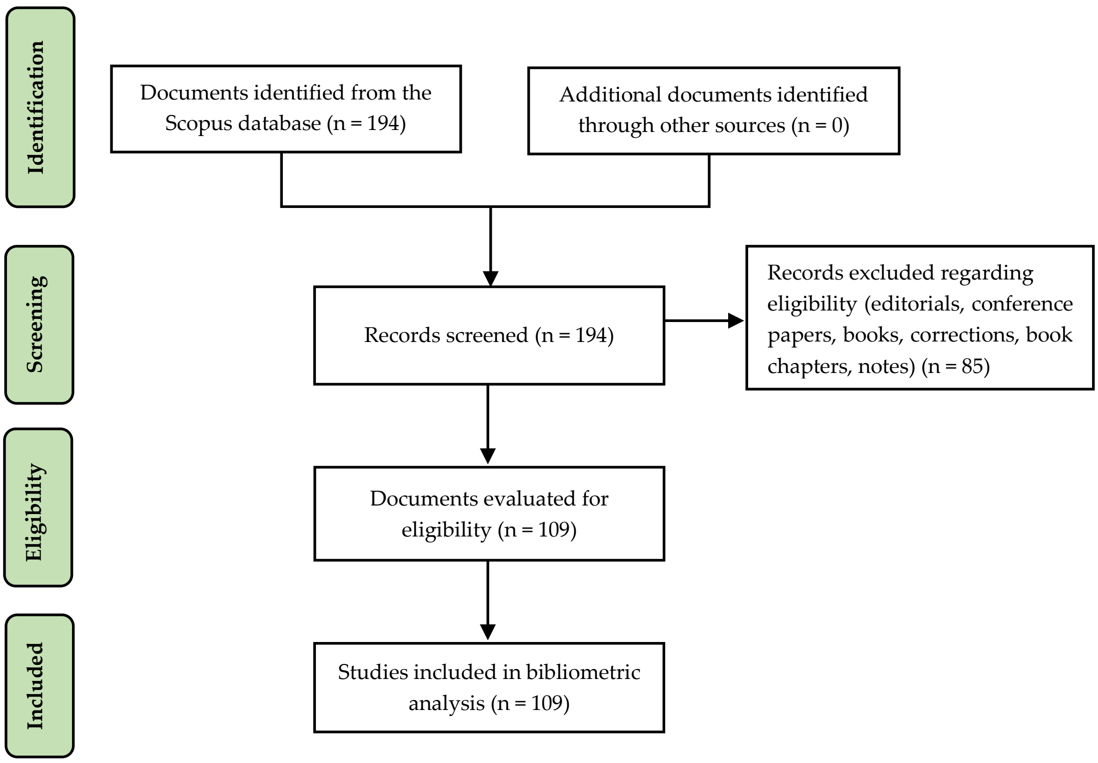
Data Analysis

A computer tool named VOS (Visualization of Similarities) viewer, developed by Van Eck and Waltman (2010), is designed to generate and exhibit bibliometric maps. While other tools like Histcite, SPSS, and Pajek can also be utilised for bibliometric mapping (Chen, 2003; Skupin, 2004), VOSviewer places a stronger emphasis on graphical representation. For instance, it is capable of constructing maps of authors or journals based on keywords, co-citations, and co-occurrence data. One notable advantage of VOSviewer is its ability to handle large datasets, accommodating over 100 items. It exhibits excellent performance in viewing and creating maps using VOS mapping techniques, which are seamlessly integrated into the VOSviewer software. The three forms of visualization that can be displayed are network, overlay, and density visualization.

Figure 1 provides a detailed breakdown of the data collection process utilised by researchers, employing the PRISMA flow diagram.

Figure 1

PRISMA flow diagram



The following details the study's data search process as shown in the prism flow diagram, which was created up until the 2020 revision shown in Figure 1. Figure 1 shows that there are four phases, namely identification, screening, eligibility, and included:

Identification

Identification involved conducting literature searches in the Scopus database, and refining the search to include keywords, abstracts, and research question titles. This stage yielded a total of 194 documents.

Screening

During the screening or selection phase, literature sources that aligned with the study's objective, subject, or research question were identified. Criteria for inclusion and exclusion had been previously established. Any literature sources that did not meet the inclusion criteria (n=85) were disregarded.

Eligibility

At this stage of the process, it was important to further investigate any material that matched the title and keywords. As a result, 109 articles that met the requirements were identified.

Included

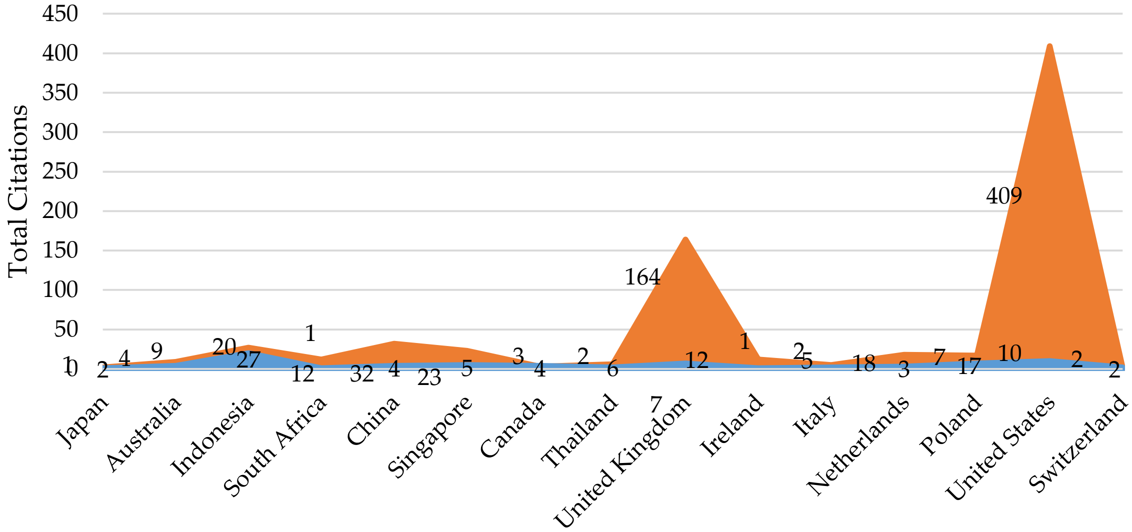
All literature sources that passed the screening or selection stage were then subjected to further analysis.

Findings

Figure 2 displays the findings regarding countries and the number of publications and citations in the field of chemistry education. It illustrates the growth of documents, citations, and research on blended learning from various countries. The publication of works on blended learning in chemistry is becoming increasingly common in various nations. Research on blended learning in chemistry, as published in Scopus-indexed journals, has shown steady growth over the years. The United States emerges as the country with the highest number of citations for blended learning publications, totaling 409 citations.

Figure 2

Number of publications and citations by country



Frequently Cited Articles

The most frequently cited article on blended learning was written by "Baepler P., Walker J.D., Driessen M." with 394 citations, and 10th place was written by "Ping G.L.Y., Lok C., Wei Yeat T., Cherynn T.J.Y., Tan E.S.Q." with 14 citations. In their paper published in *Computers & Education*, Baepler et al. (2014) compared the learning outcomes of traditional classes with active learning classes. They reported that student contact with lecturers in active learning classes could be reduced by two-thirds and students achieved better learning outcomes compared to learning outcomes in traditional classes and student perceptions of active learning classes were more favorable. In addition, Ping et al. (2018) evaluated three mobile applications that are freely available on the Apple App Store and Google Play Store. They found that apps were most effective when used in a blended learning environment and that higher frequency of app use also supported improved student performance. The top 10 most frequently cited articles can be seen in Table 2.

Table 2

10 most frequently cited articles

Authors	Title	Cites
Baepler P., Walker J.D., Driessen M. (2014)	It's not about seat time: Blending, flipping, and efficiency in active learning classrooms	394
Lapitan L.D., Jr., Tiangco C.E., Sumalinog D.A.G., Sabarillo N.S., Diaz J.M. (2021)	An effective blended online teaching and learning strategy during the COVID-19 pandemic	83
Williams N.A., Bland W., Christie G. (2008)	Improving student achievement and satisfaction by adopting a blended learning approach to inorganic chemistry	37
Bortnik B., Stozhko N., Pervukhina I., Tchernysheva A., Belysheva G. (2017)	Effect of virtual analytical chemistry laboratory on enhancing student research skills and practices	24
Heilesen S.B., Josephsen J. (2008)	E-learning: Between augmentation and disruption?	24
Yang L., Sun T., Liu Y. (2017)	A bibliometric investigation of flipped classroom research during 2000-2015	22
Campbell C.D., Challen B., Turner K.L., Stewart M.I. (2020)	#Drylabs20: A new global collaborative network to consider and address the challenges of laboratory teaching with the challenges of Covid-19	18
Hurst G.A. (2020)	Systems thinking approaches for international green chemistry education	18
Bernard P., Broś P., Migdał-Mikuli A. (2017)	Influence of blended learning on outcomes of students attending a general chemistry course: Summary of a five-year-long study	15
Ping G.L.Y., Lok C., Wei Yeat T., Cherynn T.J.Y., Tan E.S.Q. (2018)	"Are chemistry educational apps useful?" - A quantitative study with three in-house apps	14

In this bibliometric analysis, we also present the 10 most recently published articles in the field of blended learning. The most recent article on blended learning was written by Al Mamun M.A., Lawrie G., and Wright T.; their article was published in *Computers and Education* in 2022. Al Mamun et al. (2022) investigated the nature of students' interactions with learning content in guided inquiry-based and online independent learning environments. As a result, the researchers found that previous online experience influenced students' behavioral efforts and previous subject knowledge influenced students' cognitive efforts. The 10th article was written by Kuroki N. and Mori H.; their article was published in the *Journal of Chemical Education* in 2021. In their study, Kuroki and Mori (2021) designed a physical chemistry laboratory course to help undergraduate chemistry students maintain their knowledge of physical chemistry. The researchers found that students were excited about the new course that comprehensively covered experiments, computing, and data science. Table 3 lists the 10 most recently published articles related to blended learning in chemistry.

Table 3

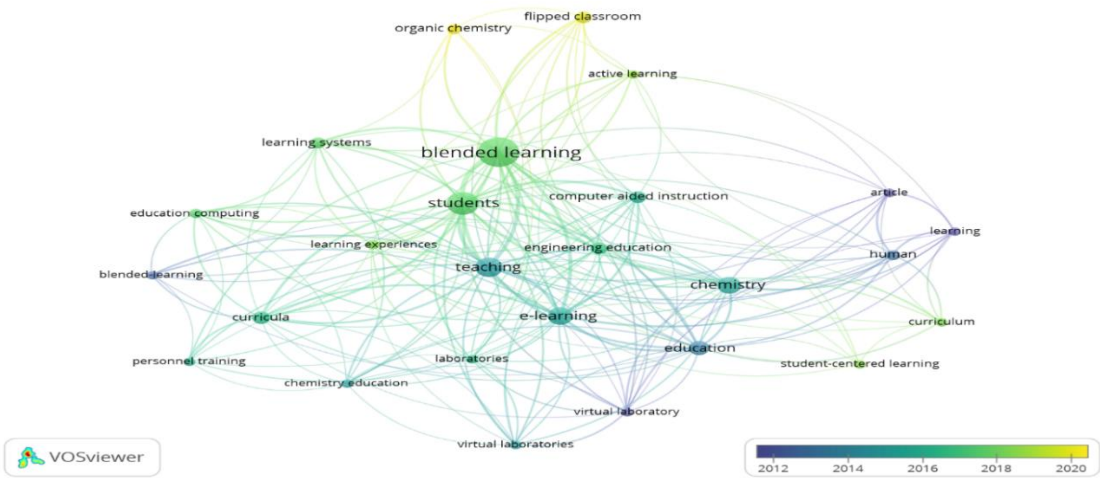
10 most recently published articles

Authors	Title	Year
Al Mamun M.A., Lawrie G., Wright T.	Exploration of learner-content interactions and learning approaches: The role of guided inquiry in the self-directed online environments	2022
Aidoo B., Macdonald M.A., Vesterinen V.-M., Pétursdóttir S., Gísladóttir B.	Transforming teaching with ICT using the flipped classroom approach: Dealing with COVID-19 pandemic	2022
Ang J.W.J., Ng Y.N.	Effect of research-based blended learning with scrum methodology on learners' perception and motivation in a laboratory course	2022
Kędzierski W., Wawrzykowski J., Jamioł M., Kankofer M.	Effects of tutoring in teaching basic subjects to veterinary students	2022
Reyes C.T., Kyne S.H., Lawrie G.A., Thompson C.D.	Implementing blended first-year chemistry in a developing country using online resources	2022
Yin B., Yuan C.-H.	Detecting latent topics and trends in blended learning using LDA topic modeling	2022
Lapitan L.D., Jr., Tiangco C.E., Sumalinog D.A.G., Sabarillo N.S., Diaz J.M.	An effective blended online teaching and learning strategy during the COVID-19 pandemic	2021
Fonseca C.S.C., Zacarias M., Figueiredo M.	MILAGE LEARN+: A mobile learning app to aid the students in the study of organic chemistry	2021
Dai N.V., Trung V.Q., Tiem C.V., Hao K.P., Anh D.T.V.	Project-based teaching in organic chemistry through blended learning model to develop self-study capacity of high school students in Vietnam	2021
Kuroki N., Mori H.	Comprehensive physical chemistry learning based on blended learning: A new laboratory course	2021

Figure 3 illustrates how the analysis of blended learning writing keywords using VOSviewer reveals the appearance of various relevant articles, including "student," "education," "teaching," "engineering education," "chemistry," "e-learning," and others.

Figure 3

Network visualisation map of author keywords



This mapping aims to identify the information that has been utilised by multiple researchers over the past decade. Through a keyword analysis of blended learning publications related to chemistry education, it was found that terms such as “blended learning,” “chemistry,” and “online learning” are the most commonly used. Cluster 1, highlighted in green, represents the primary research trend in this field. The four keyword clusters’ specifics, as determined by VOSviewer’s analytical findings, are as follows:

1. Eight keywords comprise the first cluster (green): blended learning, curriculum, chemical education, e-learning, education computers, learning systems, personnel training, and teaching. The term “teaching” appears frequently.
2. Seven keywords make up the second cluster (purple), including “article,” “chemical,” “curriculum,” “education,” “human,” “learning,” and “student-centre-learning.” Human is a term that frequently arises.
3. Six keywords make up the third cluster (light green): computer-aided teaching, flipped classroom, active learning, organic chemistry, and student. Keywords such as blended learning are frequently used.
4. Five keywords are grouped in the fourth cluster (dark green colour): engineering education, labs, learning experiences, virtual laboratories, and virtual laboratory. Teaching is a term that frequently emerges.

Discussion

The utilisation of bibliometric methods in researching blended learning remains relatively uncommon. Consequently, this study employs bibliometric analysis, utilising data from Scopus and VOSviewer databases to examine papers published between 2012 and 2022. The research focuses on scientific publications concerning blended learning in science indexed by Scopus and appearing in journals. Over the preceding decade, from 2012 to 2022, there were 194 such publications. Through Scopus filters, 85 irrelevant works were excluded to ensure the quality and relevance of the data. These criteria align with previous findings by Halverson (2012) and Yang et al. (2017), which highlight journal articles as the primary document type in blended learning research. Following the exclusion of irrelevant works, a total of 109 articles were identified. Examination of research output reveals a rapid increase in articles and research attention between 2016 and 2018, consistent with findings from Cheng et al. (2014) and Güzer and Caner (2014). This underscores the importance of further exploring how educators and administrators can cultivate effective blended learning environments. Additionally, the study finds that English predominates as the language of scientific publications in the Scopus database during the study period, echoing previous research by Sweileh et al. (2017) and Ferguson et al. (2011). Given that blended learning intersects with the social sciences, it is unsurprising that over half of the papers analysed belong to this disciplinary category.

The present study indicates a noticeable upward trend in the number of documents pertaining to blended learning research over the past decade. This pattern undoubtedly provides practical and theoretical contributions for researchers and educators. Recent studies underscore the numerous benefits of blended learning. By leveraging technology, learners can engage in flexible learning experiences anytime and anywhere, transcending the constraints of time and location. Moreover, blended learning fosters stronger connections between students and teachers, enhances engagement, and promotes higher academic achievement. Additionally, it cultivates students' digital literacy skills (Cahyana et al., 2023; Dewi et al., 2022), preparing them to navigate online learning communities effectively as lifelong learners. The evolution of competencies and the integration of technological advancements in education have propelled blended learning to the forefront as a fundamental pedagogical approach. Its ability to facilitate meaningful interactions amidst a digital landscape underscores its importance in contemporary learning environments. The increasing research interest in blended learning is reflected in its growing citation impact, indicating its significance in technology-mediated education. Several studies in this field have demonstrated a substantial influence on citation counts, suggesting a growing recognition of blended learning's relevance and efficacy (Omar et al., 2021). These may be possible reasons for the increasing number of publications in the area of blended learning over the years.

Citation patterns, publication trends, and author keywords are thoroughly examined. The findings indicate a continuous growth in research concerning blended learning in chemistry, reflected in the increasing number of publications indexed in Scopus journals. In 2020, there were 109 citations related to blended learning in chemistry education. The articles frequently cited as references play a pivotal role in shaping scientific advancements and research directions positively. Interestingly, terms such as "analysis" and "online learning" are infrequently utilised in the context of blended learning in chemistry education. Instead, terms like "e-learning," "online learning," "collaborative learning," and "reverse classroom" dominate the discourse. Moreover, the majority of blended learning research in this domain originates from the United States and the United Kingdom.

The author's keyword analysis and network visualization of shared events reveal the most popular keywords. However, certain research papers delve into aspects such as perception, involvement, and achievement. Further exploration of blended learning trends concerning student engagement, perception, and academic performance warrants additional research. Yang et al.'s (2017) study supports the notion that the United States leads in the number of publications in this field.

The outcomes of bibliometric analyses may vary depending on the database used (such as WoS or Google Scholar) and the inclusion of additional search terms (e.g., e-learning). Consequently, the study exclusively examines papers with author keywords, which can be utilised to display keyword networking. Moreover, to identify highly cited works produced between 2012 and 2022, with the majority published between 2021 and 2022, a citation criterion of fewer than 200 citations was established. Given these constraints, all analyses, discussions, and findings presented in this paper should be interpreted within this framework (Raman, 2021).

While Scopus encompasses numerous journals, it primarily provides access to more recent articles with potentially lower impact (Chadegani et al., 2013). Consequently, it is recommended to explore other scientific databases, such as the WoS, to access a broader range of peer-reviewed articles that can enhance the scalability of the approach further. Experimenting with different keyword combinations can also augment exposure and retrieve the most recent quotations related to blended learning. Additionally, for a comprehensive examination of the literature, it is advisable to conduct bibliometric analysis concurrently with a systematic literature review. This combined approach ensures a more thorough investigation of the body of literature on blended learning.

Reviewing the bibliometric analysis of articles conducted by previous researchers over the past decade provides valuable reference material indicating that blended learning can effectively enhance student learning outcomes while facilitating teachers' proficiency in utilising increasingly sophisticated technology. We anticipate that research on blended learning will continue to progress, especially in countries where information technology is rapidly advancing. Ultimately, these nations are expected to enhance their educational policies to integrate technological advancements, thereby paving the way for the widespread adoption of blended learning strategies (Raman, 2021).

Conclusions and Suggestions

Research articles on blended learning in chemistry education have shown a consistent increase in publications indexed by Scopus over the years. The United States leads with the highest number of articles, totaling 409 citations. The COVID-19 pandemic accelerated interest in blended learning as an alternative to remote learning, particularly in chemistry education, with 2020 seeing the most significant references to blended learning-related literature, totaling 109 citations. A notable article by Baepler P., Walker J.D., and Driessen M., published in 2014, received the most citations and significantly influenced the advancement of knowledge and research opportunities in chemistry education with blended learning.

This study employs bibliometric analysis, utilising data from the Scopus database to examine papers published between 2012 and 2022. Out of 194 initially identified papers, 109 were selected after excluding irrelevant works through Scopus filters, providing a foundation for further research. Keyword analysis reveals that terms like "online analysis" and "learning" are seldom used in blended learning in chemistry, suggesting potential areas for future exploration. However, terms such as "online learning," "e-learning," "collaborative learning," and "reverse classroom" are frequently employed. Furthermore, blended learning research in chemistry education is predominantly conducted in the United States and the United Kingdom. Overall, the most cited articles contribute positively to scientific developments and research prospects, underscoring the ongoing growth and significance of blended learning in this field.

Indeed, utilising keywords like "online analysis" and "learning" can serve as a valuable guide for further research. Alternatively, the scarcity of studies on online learning could be argued, highlighting numerous opportunities for investigation in this area. This underscores the vast scope available for studying this subject. To achieve a more comprehensive knowledge mapping, the authors suggest conducting additional studies employing alternative techniques and data sources, such as Google Scholar or others. Expanding the research scope beyond Scopus and utilising different methodologies could provide a more nuanced understanding of the topic and uncover previously unexplored insights.

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Students' independent work in genetics in a multilingual education setting

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ABSTRACT
The study examines the role of independent work in enhancing the genetic knowledge of third-year biology students within a multilingual education setting. Conducted at Abai Kazakh National Pedagogical University, the research involved 164 biology teacher candidates. A quasi-experimental design with pre-test and post-test measures was employed to compare the effectiveness of various independent work methods in control and experimental groups. The findings reveal that independent work significantly improves students' understanding of genetics, particularly when supplemented with technology and project-based learning. However, students faced challenges due to limited resources in their native languages. The study concludes that independent work, guided by appropriate pedagogical strategies, is essential for developing genetic knowledge in a multilingual context. The implications for educators include the need for tailored resources and enhanced lecturer guidance in independent work.

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Introduction

Independent student work is essential to the learning process, as it forms professional competence on a subject matter and maintains motivation for further self-development. During independent work, students acquire cognitive techniques, develop their interest in creative work, improve logical and critical thinking skills, and gain the ability to solve scientific problems (Abilkhamitkyzy et al., 2014; Azamjonovich et al., 2023; Musakhonovna & Uchkurova, 2023). In this study, we adopt Abilkhamitkyzy's (2014) definition of student independent work as forming the necessary level of knowledge, skills, and abilities to solve cognitive tasks in isolation and showing progression from ignorance to knowledge. Investigations of undergraduate students undertaking biology in general, and specifically genetics, reveal that these students tend to have difficulties forming independent-study behaviours (Abilkhamitkyzy et al., 2014; Buma and Nyamupangedengu, 2020; Peacock & Cowan, 2018). These challenges could be attributed to the complicated language of genetics, differences in the presentation of genetic materials, and complex genetics laws. Intensive and abstract vocabulary is a factor that causes students at all levels to struggle with learning biology (Kıryak et al., 2024). For example, terms such as mitosis, meiosis, genetic engineering, genes and chromosomes, require a teacher to expound upon (Tekkaya et al., 2001). Buma and Nyamupangedengu (2020), Singer, and Smith's (2013) studies revealed that undergraduate students reported minimal independent work findings as they focused on teacher-based study approaches. However, Tazhbayeva et al. (2014) highlighted that there were academic reforms in Kazakhstan advocating individualism and pragmatism (Tazhbayeva et al., 2014) and the prevalence of online learning during the current unprecedented times (e.g., coronavirus, Mertens et al., 2020) and have prompted students to pursue independent work in sciences (e.g., biology). The students' need to adapt to the reformed socioeconomic environment requires the promotion of independent work among Kazakhstan undergraduate students. Lecturers are expected to initiate, sustain and stimulate meaningful discourse for active participation so that the students achieve meaningful learning outcomes (Anderson et al., 2001; Garrison and Akyol, 2013;).They should lead students in accordance with their abilities and competencies and inspire self-confidence in them. Students in an independent work are not only expected to fulfill the tasks assigned to them but should also be able to identify and work on the necessary tasks depending on own needs, interests and abilities (Kurbanova, 2023). Previous research has shown that students show significant improvement in their collaboration and independent work schedules (Çepni & Şahin, 2010; Peacock & Cowan, 2018) when it is lecturer-led. In this current study, we posit that lecturers play a critical role in creating and sustaining an independent student study.

Genetics course lecturers must prepare students for independent work (Peacock & Cowan, 2018). This requires lecturers to reallocate responsibilities (e.g., laboratory work, data collection, or analysis) from the lecturer to the student. Lecturers must create a programme structure that fulfills the expectations of independent student work. Furthermore, there must be an avenue for collaboration and community-based interactions (e.g., access to instructional resources and assessment schedules). All of these tasks should be undertaken before implementing independent work programmes; otherwise, the student behaviours might not produce desirable outcomes (Peacock & Cowan, 2018; Vlachopoulos and Cowan, 2010). Once the lecturers evaulate the tasks and provide feedback, so they can nurture the higher-level cognitive and interpersonal abilities that demand student engagement. Although the lecturers are involved, they do not interfere with or offer leads that outline how specific genetics-related tasks are executed (Peacock & Cowan, 2018; Vlachopoulos & Cowan, 2010).

Independent student study programmes follow the learning-centred approach, which is grounded in the community of inquiry framework. Its central tenets include a focus on how individuals collaborate to criticise discourse, construct personal meanings, and establish mutual understanding (Garrison, 2011). Garrison (2011, p. 21) states that the purpose of the community of inquiry framework is "the development of an appropriate, quality, generic educational experience in which learners engage in collaborative educational conversations and activities including discourse, and reflection". Garrison's (2011) community of inquiry framework is constructed by observing an independent student working in an online setting. Biology courses, such as genetics, are rarely studied online as they require face-to-face interactions and hands-on experiments (Buma & Nyamupangedengu, 2020). Therefore, implementing the community of inquiry framework (Garrison, 2011) poses a significant challenge. However, with the attention given to online communities (e.g., Peacock & Cowan, 2018), exploring how to balance an offline and online study environment for students undertaking genetics is worthwhile. There are studies proving the benefits of community inquiry (Cheung et al., 2020) and learning genetics with online contexts (Ristanto et al., 2022) in learning science courses. Although community inquiry shows promising results for students undertaking science subjects, such as genetics, studies applying this pedagogy in the genetics classroom are lacking. This course involves students with an incredibly diverse prior knowledge and interest in science (Cheung et al., 2020) Therefore, this study's first contribution is that it builds on previous research (e.g., Peacock & Cowan, 2018) and adapts this framework to facilitating an independent student work.

Howe and Abedin's (2013) review consisted of one-hundred and fifty-eight studies. Although their findings were conclusive, they cannot be generalised for English-speaking students learning science, technology, engineering and mathematics (STEM) courses in languages other than English. Researchers (e.g., Boyle et al., 2020) have highlighted cross-cultural variations in learning styles. Although their findings have been significant, there have been few studies (Baikulova et al., 2017; Tazhbayeva et al., 2014) addressing the effects of cultural experiences in STEM education. According to Tazhbayeva and colleagues (2014), current Kazakh students have experienced market reforms and changing social relationships, which could be reflected in their value orientations. Therefore, students espouse individualism, pragmatism, and a desire to dominate their environment (Tazhbayeva et al., 2014). Since they desire to grow academically and professionally, these students pursue self-development opportunities (e.g. scientific and cultural information and computerization), which encourages independent work (Baikulova et al., 2017; Tazhbayeva et al., 2014).

Few recent studies have examined the role of independent study in science courses (Jones & Smith, 2022; Patel et al. 2021; Zhang & Liu, 2023). These studies examined independent work elements, such as training (Jones and Smith, 2022), time management (Patel et al. 2021), and self-assessment (Zhang & Liu, 2023), in isolation. The current study examines these three elements simultaneously in the context of biology students undertaking a genetics course. We argue that students must observe all independent work elements to achieve the desired learning outcomes. By examining the individual needs of students in genetics class, this study can help proving that science-based students can benefit from the skills proposed by Cowan (1978) and Watson and Gallagher (2005) such as planning, monitoring, and self-assessment.

Literature Review

A. Student Independent Work

Independent work is standard in practice but its conceptualisation varies across countries and disciplines (Abilkhamitkyzy et al., 2014; Hayes, 1999; Herppich et al., 2018; Ivanova and Logvinova, 2017). According to Herppich and colleagues (2018), independent work is an educational activity where students solve academic problems in isolation. Ivanova and Logvinova (2017) emphasise the process of independent knowledge acquisition through the independent study of educational material. Abilkhamitkyzy's (2014) definition focuses on forming the necessary volume of knowledge, skills and abilities to solve cognitive tasks at various complexity levels. The definition of Andreeva and colleagues (2020) stresses the benefits of independent study, i.e., it provides students an advantage over other students and extends the frontiers of their experience. Independent study fosters students in qualities such as their abilities, interests, tendencies, and needs (Richardson, 2005) that would be relevant in their professions (Balçıkanlı, 2010). In addition, independent study improves student autonomy (Cotterall, 2000), self-organisation and self-management (Abilkhamitkyzy et al., 2014), and research competence (Cao et al., 2017). Hayes (1999) determined that independent work was a source of vitality and considered it a life priority in some level. Various terms have been used to emphasise different aspects of independent studies such as indirect (isolated) learning (Balfakih, 2003), silent work (Serin, 2018), individual work (Hockings et al., 2018), and self-education (Fidyk, 2017).

Independent work gained prominence when Peters (1970) called for educators to offer their students learning autonomy. According to Peters (1970), individuals are intrinsically motivated to self-understand, alter their self-concept, and eventually direct their own behaviour. This motivation can be utilised when individuals are placed in a favourable environment that better facilitates psychological attitudes (Peters, 1970), such as independent work. Boud (1988) reiterated Eters' (1970) observations and extensively examined the benefits of student autonomy in learning. Subsequently, researchers and practitioners (e.g., Anon, 1981; Candy, 2012; Dfes, 2004; Miliband, 2004) endorsed independent work principles. They argued that education should follow active learning methods when dealing with academic or industrial problems (Anon, 1981). This endorsement led to personalisation in education and promoted learner autonomy and life skills for lifelong learning (e.g., independent learning, decision-making, and planning (Anon, 1981; Candy, 2012; Dfes, 2004; Miliband, 2004)).

Students are considered partners in the learning process through independent work, while teachers are considered as peers (López-Pérez et al., 2011; Peacock & Cowan, 2018). Therefore, students are not only agents of change but also co-creators of the learning process (Debowski, 2007; Peacock & Cowan, 2018). Independent work is relevant in the current socioeconomic environment that is experiencing turbulences such as rapid technological change, diverse ideological convictions, (Peacock & Cowan, 2018). These shifts call for collaboration among all education stakeholders including parents, students and lecturers. Desired benefits of independent study significantly depend on relevant abilities such as analysing, evaluating, valuing, planning and managing (Debowski, 2007) in all areas of expertise such as biology and genetics.

Generally, students have diverse preferences, styles, approaches, abilities, and independent study skills (Candy, 2012; Ülger, 2021). As it is a self-directed initiative, students must collaborate with their lecturers to highlight suitable features and request support. A productive, independent work programme depends on the pace, the study method, and personalised tutorial support (Peacock & Cowan, 2018) of students. Recent research indicates that comprehensive independent study programmes can significantly enhance student outcomes in STEM fields. Johnson et al. (2023) demonstrated that structured training programmes improve students' ability to engage in self-directed learning. Similarly, Patel et al. (2022) found that effective time management strategies are crucial for independent worksuccess, while Wang and Liu (2023) highlighted the importance of self-assessment in fostering student autonomy and improving performance.

The effectiveness of independent work depends on the modern technologies offered by the teacher and various types of activities, such as projects, abstract presentation of material, and annotation (Gordeeva et al. 2024). In the works of Gulbahor and Umida (2022) depending on the goals, independent work can be divided into the following: - educational, education, correction, repetitive, developing, creative, control.

Synthesizing all these articles reviewed, it is clear that an integrated approach, combining training, time management, and self-assessment is essential for maximising the benefits of independent work. This study builds on these insights by examining these elements in unison, focusing on genetics students.

B. Cultural Influence on Independent Work

Culture arises from integrating human values, beliefs, and behaviour with the capacity of individuals to transmit this knowledge to subsequent generations (Fernandez et al., 2010). According to Klassen et al. (2013) traditions, language and the native tongue of the student and belief systems shape individual attitudes and motivation toward academic learning. Several studies have included culture as an explanatory variable (e.g., Bonneville-Roussy et al., 2019; Boyle et al., 2020). Culturally-shaped variables such as academic volitional strategies (e.g., Schlüter et al., 2018), moderate academic motivation and performance. Academic volitional strategies determine the degree to which students set, monitor, and manage their learning behaviours (Schlüter et al., 2018). In their study, Boyle and colleagues (2020) found that Thai university students were expected to listen carefully and respectfully without directly challenging the lecturer's authority. Thai students were required to uncritically memorise material, whereas Australian university students adopted a more critical analytical style and closely evaluated the statements and assertions of lecturers (Boyle et al., 2020). Dennehy (2015) compared learning approaches between two heritages (Confucian vs. Western) and found that Asian students preferred surface learning (students reproduced facts through rote learning rather than understanding underlying principles). In contrast, Western students tended to adopt deep learning (where they mastered the learning material).

Recent studies have expanded on these concepts, emphasising the importance of individualised learning paths in higher education. For example, Roberts et al. (2022) found that personalised learning trajectories significantly enhance student engagement and performance in university-level STEM courses. Similarly, they demonstrated that incorporating flexible learning modules allows students to better integrate their interests with academic requirements, fostering deeper learning and self-motivation. Mwangi, Kitainge and Nyabuto (2023) studied the relationship between self-esteem and student maturity. The study found that there is a positive relationship between self-esteem motivation and the grade level of students. Cronin-Golomb and Bauer (2023) discussed the role of personal motivators such as self-efficacy beliefs and personality traits in self-motivated and directed lifelong learning. They then examined the role of cognitive processes that contribute to the expansion of the knowledge base of students of all ages, particularly executive functions. Krapivina (2022) developed and practiced independent work schedules for students under the new conditions of a hybrid system in higher educational institutions on the basis of foreign experience and in accordance with the methodological requirements and approaches to optimising educational activities. He cites the special role of the teacher in organizing independent work, personalising the language material, stimulating the skills of critical understanding. All the proposed organizational and pedagogical strategies have shown their effectiveness.

We argue that students must master all independent work elements to achieve the desired learning outcomes. By examining the individual needs of students in a genetics class, this study aims to demonstrate that science-based students can benefit from the same skills proposed by Cowan (1978) and Watson and Gallagher (2005) as planning, monitoring, and self-assessment. In this study, we investigated motivations for independent study among Kazakhstan students and high light the role of cultural nuances contributing to academic performance. We sought to determine the effectiveness of the process of developing the genetics knowledge of future biology teachers by organising independent work on the subjects of genetics in a multilingual learning environment.

Research Questions

To resolve challenges faced by students during independent work, the authors developed two research questions:

1. What types of independent work in genetics are most effective for students in the context of multilingual education?

2. What is the impact of the regular use of independent work on genetics in the educational process on the level of achievement?

Methods

The multilingual educational programme has been running since 2015 at Abai University in specialised courses including "5B011300 Biology". The most important requirement for the composition of the educational content of the course under consideration is the requirement that all components of the content comply with the needs of the society. An important area of development of state programmes is the "Roadmap for the development of trilingual education for 2015-2020"(https://online.zakon.kz/document/), which requires the development of teaching aids for integrated teaching of the subject and language. Multilingualism in the educational environment is one of the main aspects of the work of all educational institutions in Kazakhstan.

The study employed a quasi-experimental design with pre-test and post-test measures for both experimental and control groups. The participants were 3rd-year biology students enrolled in a genetics course at Abai Kazakh National Pedagogical University. The purpose of the course is theoretical justification and development of methodological foundations for the development of genetics knowledge of students - future biology teachers, whose methodological training is based on independent work with educational information in the conditions of multilingual education, and experimental testing of the main conceptual provisions in the conditions of educational practice.

The first stage of experimental work was the detection. At the stage of the detection experiment, an analysis of independent work performed in Kazakh and multilingual educational groups of biology specialties was carried out in order to determine the level of the actual state of the problem under study. In the course of the detection, various methods were used: pedagogical, methodological works and scientific and methodological works related to the research topic were analysed, best practices in teaching biology were studied. Thus, in order to determine the actual state of the educational process and the initial level of training at the stage of the detection experiment, a solution to the following tasks were sought. In the training of future biologists in the conditions of multilingual education in higher educational institutions;

1. Determining the quality of the organisation of independent work,
2. Determining the degree of knowledge as a result of the organisation of independent work,
3. Determination of the effectiveness of the modified application of independent work on genetics,
4. Preparation of educational and methodological materials necessary for methodological support of the application of independent work in the discipline "Genetics" in the context of multilingual education.

In the process of solving these problems, a questionnaire (survey) was developed, and tested by researchers were used for data collection The items in the questionary were taken from the intendent literature. The survey conducted at the stage of the detection experiment was the basis for planning the orientation work for conducting the experiment based on the thoughts of students. At the stage of the formative experiment the effectiveness of the methodology for the development of genetic knowledge by organising independent work of future biologists in the conditions of multilingual training was monitored Students in the control groups used such types of independent work as preparing abstracts, essays, presentations, report while in experimental groups - "Quiz", "Matching", "Find the terminology", "True or False", "Semantic map", "Black Box" Activities & Games, "Number Talks", "Brainstorming", "Complete the gaps with the words below"," Active vocabulary", "Try to guess the odd one out" along with these methods, project also were given to the sample.

Model of Organisation of Professionally Oriented Independent Work of Students on the Development of Genetics Knowledge in the Context of Multilingual Education

We sought to determine the effectiveness of the process of developing the genetics knowledge of future biology teachers by organizing independent work on the subjects of genetics in a multilingual learning environment. A sample lesson plan and its implementation about independent work on the subjects of genetics in a multilingual learning environment is presented in Appendix 1. The purpose of the experimental training was to test the effectiveness of the methodology for the development of genetic knowledge based on independent work with educational information in a multilingual teaching environment at a pedagogical university.

At the beginning of the experiment a questionnaire to identify learning problems of students were developed by researchers. In order to develop the questionary (Table 1), an expert group consisting of a professor, 2 doctors of pedagogical sciences, 1 doctor of biological sciences and 2 candidates of pedagogical sciences were studied together All experts have been engaged in scientific and pedagogical activities in their specialty for more than 20 years. The expert group assessed the compliance of each issue with the conceptual structure. The formulation of the questions was based on the clarity and accessibility of the respondents' perception, with the exception of the use of specific medical terminology and abbreviation. The questionnaire was compiled using single word and multiple choice answers. To measure the reliability of the content, relevance, clarity, simplicity and ambiguity were evaluated on a scale from 1 to 4 points. The calculation of the content reliability index (IDS) was used to assess the relevance, clarity and simplicity of the elements and the overall reliability of the questionnaire content.

For pilot testing, the survey was conducted anonymously, manually on paper. The informed consent of the respondent was attached to each questionnaire, indicating the purpose and procedures of the questionnaire, the benefits of the respondent's participation, anonymity and voluntary participation. The determination of the internal consistency of the questionnaire was based on the splitting method and the calculation of a Cronbach value (Tenkebayeva A. Z., and others, 2019). The questionnaire is considered reliable with an acceptable value of Cronbach's a (>0.6).

Data Analysis

Descriptive statistics were used to analyse demographic findings, as well as for individual questionnaire elements. The reliability of the questionnaires was assessed by analyzing internal consistency. The content and criteria validity were assessed at the questionnaire development stage. The constructive validity was carried out using factor analysis.

Classes with the control group followed a sequence of traditional methods, and in the experimental group a methodological system of teaching genetics was introduced using independent work during one term (see sample lesson plan in Appendix 1)

Data Collection

To determine the readiness of students for independent work and the conditions in the educational process, the survey was conducted including 164 students (see Appendix 2). The survey aimed to assess their study methods and attitudes towards learning genetics.

Data Analysis

To ensure the analysis directly addresses the research questions, we will clearly outline the process and findings. The research questions focused on the effectiveness of the independent study methodology and the specific challenges faced by students in a multilingual learning environment.

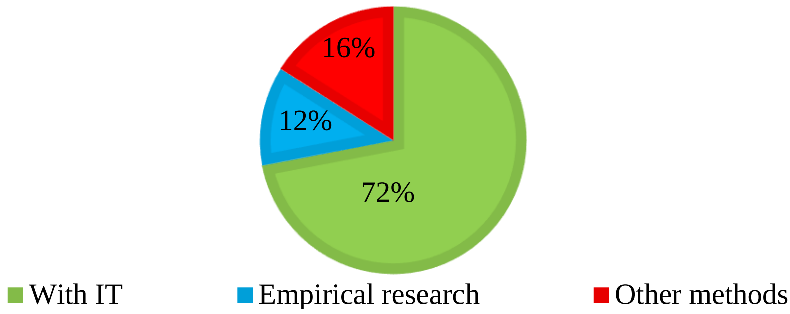
Results

The study was conducted among students majoring in Biology of the 3rd year. The questionnaire sought answers to 12 questions, including questions on the development of genetics knowledge through independent work in a multilingual environment. Table 1 (Appendix 2) shows that 53.6%) of students were familiar with independent study methods. Most of these students (72%, Figure 1) used technologies in their independent studies, while others preferred practical research when resolving their problems. As shown in Figure 2, 39.6% of students stated that they creatively used computer study while the rest relied on verbal guidance from the teacher or laboratory-based practice. Generally, students thought that independent study was the best learning method (48.7 %, Figure 3), contributed to their understanding of theoretical aspects within the genetics field and helped them form habits that would be useful in the future. When asked about the challenges they encountered, 54.8% noted insufficient literature in their native language while others did not have adequate time. To resolve these challenges, 39% of students proposed that lecturers should outline the purposes and tasks of the independent work before starting the program. Other students requested training in software application and organisation skills.

Figure 1 shows the methods used in independent work.

Figure 1

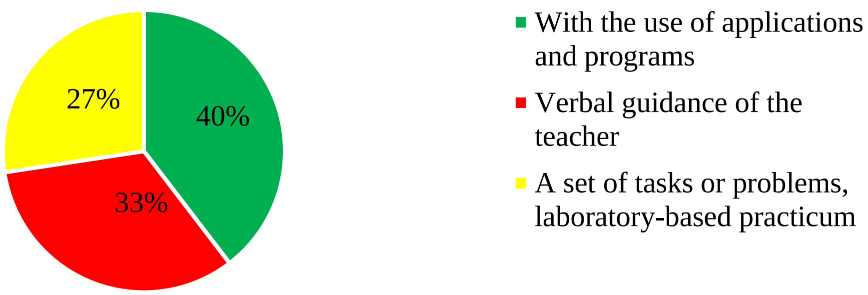
Representation of methods used in independent work



A total of 72% of students used IT, 12% used empirical research, and 16% used other methods.

Figure 2

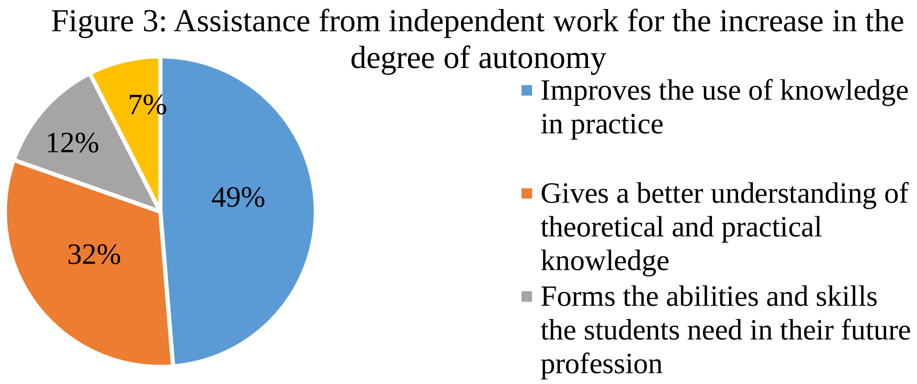
Independent work preparation methods



A total of 39.6% of the students worked with applications and programmes, which allowed them to perform an independent study on computers, 33% used verbal guidance from the teacher, and 27.4% preferred laboratory-based tasks.

Figure 3

Autonomy in knowledge development



A total of 48.7% of students believe that practice is the best way to help them learn, 31.7% believe that it contributes to a deeper understanding of theoretical and practical knowledge of genetics, 12.1% believe that it forms abilities and skills they need in their future profession, while7% chose other.

Research Question 1: What Types of Independent Work in Genetics Are Most Effective for Students in the Context of Multilingual Education?

Based on answers to this question, we learned the general direction of independent work in studying genetics. We considered a rating of 50.1% and above as the majority opinion. However, in cases where the opinion on a particular question was lower than 50% but higher than the percentage of the other answers within that question, we defined this situation as a comparative majority opinion. Based on the results, we found a majority opinion for questions one, two, three, and five. In question one, 91% of the participants preferred attending physical genetics classes, 53.6% viewed independent work as a useful study method, and 72% used information technology for independent study. In addition, 54.8% had challenges finding literature in the Kazakh language.

However, there was a comparative majority opinion from questions six to twelve. For example, 39.6% prefer to use programmes for independent study (see Figure2),39% consider it essential to clearly define the tasks,39% support the idea of methodological guidance for students within the scope of independent study,48.7% think that practice is the best option in education (see Figure3), 42.6% proposed a change in the study content,33.5% chose project-based study as a pedagogical technology, and 46.9% chose the brief assignment method (five to seven minutes) as an independent work control method.

In summary, following the questionnaire data, 33% of the questions revealed a majority opinion and 58% revealed a comparative majority opinion. Therefore, there is a common opinion toward independent study in genetics classes.

Research Question 2: What Is The Impact of The Regular Use of Independent Work on Genetics in the Educational Process on the Level of Education?

The third question in the survey established whether there were questions without a majority opinion. This includes questions to which the researchers did not receive responses. In the study, there were no responses to the fourth question. Consequently, only 1 of 12 questions (0.083%) lacked an opinion. In the course of the study, we compared the learning outcomes of the experimental group with the learning outcomes of the control groups.

To determine the levels of assimilation of genetic knowledge at various stages of the experiment, three cross-sectional control work and a delayed knowledge test were conducted to identify an indicator of the strength of knowledge. The first cut-off was carried out before the start of the experiment in order to identify the current level of knowledge acquisition, the second - after 3 months of experimental training, when students had hopefully mastered the necessary knowledge and skills base, the third - immediately after the completion of the experiment.

An important requirement for the structure of the educational content in the conditions of multilingual teaching of biology students at a pedagogical university is the requirement to observe the logical connection of its components. Therefore, the course "Genetics" is designed in such a way that at the first stage of teaching genetics, the patterns of heredity are studied, which provide important knowledge and practical skills. At the second stage, information on variability, molecular genetics, population genetics, human genetics, and the breeding foundations of genetics is studied.

As an educational content structured in accordance with the idea of multilingual education for students at a pedagogical university, consider the discipline "Genetics". The content of the genetics course for students of the English group of the specialty 5B011300–Biology "Cytological basis of sexual and asexual reproduction", "Regulations of heredity", "Gene interactions", "Sex-linked inheritance", "Linked genes and crossing over", "Classification of variability", "Molecular genetics", "Population genetics", "Human and medical genetics", "Genetic basis of selection". The following methods were used in organising independent work for students based on these topics: "Quiz", "Matching", "Find the terminology", «True or False», «Semantic map», «Black Box» Activities & Games, «Number Talks», «Brainstorming» «Complete the gaps with the words below» «Active vocabulary», «Try to guess the odd one out» and etc. In independent work, the results of research related to methods that are effectively used in foreign and domestic methods are used. These methods allow you to develop genetic knowledge. The results of systematically organized independent work will help to get a quality education in genetics. The organization of independent work of students, diverse in purpose and content in the course of the development of genetic knowledge, contributes to increasing their subject knowledge.

Research work on the development of genetic knowledge through the organization of independent work in the context of multilingual education for students showed that they are interested in performing independent work in the direction of digital education in the course of conducting questionnaires. In this regard, the following platforms were used for independent work in the process of genetic education: crossword - https://childdevelop.info using the site, rebus generator rebus1.com, test generator online test pad (https://onlinetestpad.com/ru)
cross puzzle generator (http://cross.highcat.org/ru),Interactive whiteboard: okulyk.com " performs tasks, padlet board https://ru.padlet.com/.

All topics can be presented by preparing and presenting various independent works. Only students made their own choice and completed the tasks at their discretion. Also, when performing tasks, new programs (google slides, prezi, zoho show, powtoon, canva, wordwall, xmaind) used timeline, etc.

To determine the level of development of genetic knowledge among students, we developed control sections of knowledge at the ascertaining stage on the topic "Laws of Heredity", and upon completion of the "Genetics" course at the formative stage of the experiment - on the topic "Selection Fundamentals of Genetics". Processing of the obtained results was carried out on the basis of quantitative and qualitative analysis of the data obtained. To quantitatively assess the development of genetic knowledge in multilingual student conditions, we used the coefficient of knowledge assimilation, and for a qualitative assessment we determined the properties of genetic knowledge, its completeness, strength, quality and consistency. To identify the development of the student's genetic knowledge, we compared the research results at the initial and final stages of the experiment.

In diagnostics, we will apply three levels of knowledge acquisition: algorithmic, heuristic and creative.

Level I - "algorithmic" is the solution of tests based on the knowledge available to students - a reproductive algorithmic action to solve a problem based on the application of a previously learned action, rule or algorithm to solve it.

Level II - "heuristic" is a productive action performed not according to a ready-made algorithm or rule, but during the independent transformation of a known basis of previously learned actions. In the process of completing a task, the student discovers subjectively new information and applies it to solve an atypical task. For example, tasks for analysis, for comparison

Level III - "creative" is a productive activity of a creative type, in which a suitable situation and actions are searched for to create objectively new, previously unknown information on the basis of learned information, leading to the achievement of a goal. If the task is, for example, to violate the splitting formula.

As a means of determining the quality of assimilation, Bespalko suggests using specially designed tests. The test consists of a task for the activity of this level and a standard, i.e. a sample of the complete and correct execution of the action. According to the standard, the number of significant operations (p) leading to the solution of test tasks is determined.

Comparing the student's response with the standard in terms of the number of correctly performed operations (a) of test tasks makes it possible to determine the coefficient of assimilation (Ka). The determination of Ka is an operation to measure the quality of assimilation. The coefficient of assimilation is amenable to normalisation ($0<Ka<1$) and is compared with any rating scale. According to the coefficient of assimilation, the completeness of the learning process is judged: at $Ka > 0.7$, the learning process can be considered completed, since in subsequent activities the student is able to improve his knowledge during self-study. If the coefficient of assimilation does not reach the level of 0.7, then the student makes systematic mistakes in subsequent activities and is not able to correct them.

Based on the methodology for determining the levels of assimilation of concepts according to Bespalko, we have developed criteria for evaluating students' knowledge, which include the following levels:

The first level is the answers of students in which there are inaccuracies. The presence of specific correct examples combined with the absence of any explanations. The second level is answers in which students reproduce some single aspects of concepts, but do not transfer essential facts to other objects. The third level consists of answers in which students correctly formulate concepts, but do not provide examples and explanations. The fourth level consists of answers in which students competently apply concepts and terms, give various examples, mark and characterize the essential aspects of objects and phenomena.

Knowledge qualities:

• completeness - the amount of knowledge acquired in accordance with the program about the studied object, phenomenon or process,

• depth - the number of learned connections between related knowledge, components of a particular system, and their functions,

• variability - the ability to apply knowledge in different situations,

• flexibility - the ability to apply knowledge in a changing environment,

• concreteness and generality, convolution and unfoldment - the ability to use plans, theses, diagrams, linguistic methodological apparatus of textbooks and teaching aids,

• consistency, strength, awareness, reflexivity - understanding the nature, ways of obtaining and assimilating knowledge, the connections between them, the value of knowledge and the ability to prove their truth from the standpoint of science,

• a value-oriented and motivationally based attitude to education, i.e. the motivation for obtaining knowledge with an internal orientation towards the value of knowing reality - the laws of nature and society,

• intellectual orientation towards the processes of adaptation to the conditions of nature and society,

• humanism and humanitarianism,

• orientation in the information paradigm of science, culture, etc.

The results of the pedagogical experiment confirmed the effectiveness of the proposed methodology based on the consistent development of knowledge in the course of genetics in a multilingual learning environment and showed the following: at the initial stage of the development of concepts, their assimilation was at a relatively low level. This is due to the fact that at the initial stage of knowledge development, students were required to acquire knowledge in secondary education. As an example, we present the results of mastering knowledge at the initial stage (Table 2).

Table 2

Students' genetics knowledge based on the results of testing at the initial stage

Groups	Number of students	Results				
		61-69%	70-85%	86-89%	90-94%	95-100%
Control group	84	24	27	20	8	5
Experimental group	80	7	12	21	26	14

Current state of students in the discipline" genetics" criterion-based assessment of training results high, at k = 91 to 100%; sufficient, at k = 71 to 90%; medium, at k = 51 to 70%; weak, at k = up to 50%. During the pedagogical experiment, it turned out that acknowledge develops, its scope expands, and its content deepens, the quality of learning about the patterns of inheritance of the experimental groups becomes higher than in the control groups.

A significantly larger number of students in experimental groups than in control groups established the interrelationships of concepts, assimilated the most complex genetic concepts related to the disclosure of the mechanism of processes and phenomena (Table 3).

Table 3

Students' genetics knowledge based on the results of the final test

Groups	Number of students	Results				
		61-69%	70-85%	86-89%	90-94%	95-100%
Controlgroup	84	22	24	25	5	8
Experimental group	80	4	15	24	20	17

As a result of the study, it can be said that the increase in the level of knowledge of students in the experimental group compared to the control group is the result of their better mastery of the subject of genetics in the context of multilingual education. The problem of the development of genetic knowledge, which we are considering, is one of the most important disciplines for students studying in the specialty biology. From the point of view of mastering the same discipline in multiple languages, it expands access to additional information for students at a Pedagogical University, develops linguistic and didactic practice, and also has a great place for independent work, which contributes to the development of knowledge in genetics and the formation of an educated specialist. For the development of genetic education, it is necessary to master and apply in our own practice active methods of the content of domestic and foreign education in the context of multilingual education.

Discussion, Conclusion and Recommendation

This study investigated the impact of independent work methodology on genetics students at Abai Kazakh National Pedagogical University, within a multilingual educational context. The findings provide valuable insights into promoting independent learning among students in a multilingual environment.

Key Findings and Their Implications: Formulating Personalized Learning Paths: The study demonstrated that students could effectively formulate their own learning strategies within the framework of the "reference community" model (Harrison, 2011). This model supports collaborative learning and allows students to engage with peers and instructors both online and offline. The findings align with previous research, which emphasized the benefits of independent learning and personalized educational trajectories (Abulkhamitovna et al., 2014; Abishova et al., 2020; Andreeva et al., 2020; Argode et al., 2017; Azimov & Shchukin, 2009; Fidik, 2017; Hawk, 2011; Hayes, 1999; Lou & Lin, 2018).

Students highlighted the importance of having autonomy in their learning processes while also recognizing the value of teacher-led research guidance. This dual approach can enhance the depth and quality of independent work by providing a structured yet flexible learning environment.

Challenges in Multilingual Education: One of the significant challenges identified was the difficulty students faced in accessing and comprehending materials in English. Despite the multilingual setting, the scarcity of English-language resources on genetics posed a considerable hurdle. This challenge underscores the necessity for a robust database of educational materials and technical terms in multiple languages, particularly English, to support independent study effectively.

Recommendations for Practice

Development of Multilingual Resources: Create and maintain a comprehensive database of genetics literature and technical terms in English and other relevant languages. Develop textbooks and teaching aids in English to bridge the resource gap and facilitate independent learning. Encourage teachers to incorporate independent study modules into their teaching practices, offering guidance while promoting student autonomy.

The results of this study showed that the use of independent work in a multilingual environment significantly improved achievements in the study of the subject of genetics compared to students who studied these topics in genetics using traditional teaching methods. The study showed that students' academic performance after the intervention was significantly higher than before it. Most of the students of the experimental group answered correctly on the final test than from the control group. This result confirms the results of the study. This confirms the conclusions that the effectiveness of learning using traditional learning styles is minimal. It was found that most students easily use different digital methods in independent work.

Limitations and Future Directions

Our goal was to create awareness of independent working undergraduate students undertaking biology and genetics courses. Independent work is beneficial to students as it provides an advantage over other students and extends their knowledge beyond their academic scope (Abishova et al., 2020; Andreeva et al., 2020). Therefore, promoting independent study among undergraduate students in Kazakhstan is beneficial to students, lecturers, and practitioners. However, this study had limitations that could be explored in the future. For instance, the study had only 164 participants. The results from other studies may be influenced by their research design (longitudinal study or experiment). However, these study findings lay a foundation forthe needs of students, and future studies may use these opinions to enhance the generalizability. Most studies exploring this phenomenon have either been teacher-focused (Buma & Nyamupangedengu, 2020; Singer & Smith, 2013) or student-focused (Al-Otaibi, 2019; Briede & Popova, 2020; Burns et al., 2020; Cowan, 2020). However, the community inquiry framework (Garrison, 2011) advocates for a teacher-led independent study. Overall, students are considered partners in the learning process through independent study, which emphasizes that teachers are peers (López-Pérez et al., 2011; Peacock & Cowan, 2018).

Therefore, a survey from a single source (students) eliminates the contribution of the lecturer. Future research should simultaneously engage lecturers and students to enhance the accuracy of the phenomena under study.

Answers to some questions of the questionnaire are missing. The lack of answers can be explained by the ambiguity of the question. Research shows that the researcher's task is to ask non-deductible and relevant questions with sufficient information to ensure that participants provide appropriate answers (Legaspi & Henwood, 2017). Therefore, future research should explore other ways to adequately ask this question in order to get an answer. Finally, these results provide the basis for the development of constructs and variables that can be scientifically proven. Although the study includes a series of questions that reflect the three elements of independent research, planning, observation, and self-esteem, future research should clarify variables for convenient replication in other studies.

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Appendix 1

Lesson Plan: "Human Genetics and Research Methods"

Lesson topic: Human genetics and research methods.
The purpose of the lesson: to consider the inheritance of human genetics traits
The content of lesson: "Human genetics".
Slide 1: "Human chromosome set",
Slide 2: "The pedigree of the Victoria family"
Slide 3: Classification of hereditary diseases
Teaching methods and techniques:
Verbal (story), visual (working with pictures), working with a textbook.
Equipment: interactive whiteboard, multimedia presentation, printouts of tasks on genetics
Taching steps:
1. Problem statement;
2. Table analysis "Methods of human genetics research";
3. Analysis of the Human Chromosome Set table;
4. Consideration of the inheritance of traits in humans
5. Consideration of chromosomal abnormalities and their causes;
6. Tasks for the compilation and analysis of pedigrees; twin methods
7. Online Shezhire (genealogy-in English) analysis or Pedigree in "digital". Mobilaser.kz
8. Solving problems of inheritance of pathological genes;
9. Independent work of students;
10. Reflection

The teaching process of the lesson:
I part of the lessons: Teacher's conversation with students:
• poses specific questions (for generalization, justification, concretization, logic of reasoning);
II part of the lessons: Explanation of the teacher with new materials for the student (Updating knowledge):
III part of the lessons: Solving the problem of students' independent work
Preparation of reports on the topic "Methods of studying human heredity":
• genealogical;
• twin;
• cytogenetic;
• Biochemical;
• immunogenetic.

Independent compilation of genetic tasks: Introspection
Reproductive:
• reproduction of the material covered;
• solving problems according to the algorithm.

Reconstructive
• with a diagram on the board (comparison, generalization);
• solving the problem of applying knowledge in an unfamiliar situation (creating family trees with different platforms).

Productive activities:
• Preparing messages;
• compilation of genetic tasks (homework);

IV part of the lessons: Reflection and homework.
activity reflection sheets are used
- I remember the most about the lessons...
- I was surprised that...
- I would also like to know...
- I can use the knowledge gained in classes in...
- I worked best in classes...

Appendix 2

Table 1: Findings of the Survey on Independent Study in Genetics

Question	Response (%)
1. Do you like genetics as a science and academic subject?	
2. How effective is the independent educational work of students as a tool for the development of expertise in genetics?	
3. What is your favorite type of independent study?	
4. Where did you conduct the independent study?	
5. What prevents you from doing the independent study? -Lack of literature	
-Lack of time	
6. What are your favorite methods for self-preparation within the independent study? -Application programs	
-Verbal guidance	
-Laboratory-based experiments	
7. What conditions can help increase the degree of independence during genetics classes? -Purpose and task have to be clear	
-Learning how to use software	
-Organization skills and self-motivation	
8. What is the best method for organizing an independent study? -Methodological guidance	
-Computer equipment	
-Class and out ofclass study	
9. What is the role of multilingual education (education in different languages) in a pedagogical university within genetics classes? -Learning methods	
-Theoretical and practical expertise	
-Formation of ability and skills	
10. How possible do you think it is to improve genetics classes taught in a foreign language? -Change content	
-Design classes in a foreign language	
-Use of technology and simultaneous interpretation	
-Strengthen teacher control	
11. Choose the pedagogical technologies that you think are the most effective for organizing multilingual independent studies in genetics. -Project-based learning	
-Problem-based learning	
-Reflexive learning	
-Development of critical thinking methods	
-Research work organization	
-Group discussions	
-Case technology	
-Game-based technology	
12. What is the best type of control for an independent study? -Brief assignment method with test cards	
-Present independent study in the form of multimedia presentations	
-Check test and exam results	
-A control system including all control types in the discipline	
N=164	

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A new perspective on STEM education: The possible contributions of architectural education

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ABSTRACT
Considering the structural similarities between STEM education and architectural education, it is thought that architectural education, which has a deep-rooted history, may be useful for improving STEM education. This research was planned to gain useful inferences for STEM education by trying to get to know architectural education. In this study, ethnographic field research method was used. During the four-week observations, students made presentations with projects, models and plan drawings. In this process, teachers' criticisms and students' defenses were analyzed through the data table. By discussing the identified elements of architectural education, at least six innovations and/or meaningful results were revealed in the context of STEM education. These are: i-Students should be given the opportunity to solve open-ended problems on their own and should be encouraged to learn through trial and error in this process. ii-Students should be highly motivated when dealing with open-ended problems, for example, STEM project courses should be turned into graduation qualifications. iii-The importance of real-life context in STEM education should be emphasized and problems should be a part of life; In this context, sustainability and economic value dimensions should be highlighted. iv- At secondary and primary school levels, children should be encouraged to learn by experiencing and manipulating materials in the context of problems. v- Courses that will improve technical drawing skills should be added to STEM education programs. vi- In STEM disciplines, teachers should ensure theory/practice balance at the undergraduate level, and evaluations in applied projects should be made by a jury system.

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Introduction

The prominence of STEM education as one of the most frequently discussed concepts in science education literature highlights its continued relevance in ongoing research (Tosun, 2024). Beyond the direct research conducted within the disciplines of science and mathematics education, theoretical and practical knowledge from other fields can also contribute significantly to STEM education. To enhance the practical aspects of STEM education, it may be beneficial to draw from architectural project education, which has a long-standing tradition as an alternative source of knowledge. The rich body of literature specific to architectural education can offer valuable insights. Researchers focusing on STEM education may derive useful conclusions from this deep-rooted knowledge in architectural education, potentially leading to further development opportunities for STEM education.

In this context, the research aims to draw on the valuable experiences from architectural education to identify ways to enhance STEM education. Before justifying this purpose and stating the research questions, the basic concepts of STEM education and architectural education were defined, and the results of a literature review on studies exploring the connections between these two fields were presented.

Conceptual Framework

Under this heading, STEM Education, Project-Based Learning approach, as well as some concepts that are thought to enable educators to understand project design education in architecture to some extent, are explained based on the relevant literature.

STEM Education

STEM education, aimed at cultivating human resources capable of problem-solving and technological development in a competitive global environment, has been a focus of educational discourse (MEB, 2018; Çepni, 2023; MEB, 2018; MEB, 2019; Yıldırım, 2018). Known for fostering 21st-century skills like collaboration, communication, critical thinking, and creativity (Rahmawati et al., 2021; Bayraktar, 2015;Karataş, 2017), STEM emerged in the USA during the 1990s, emphasizing the importance of science, technology, engineering, and mathematics in technological competition. Over time, the inclusion of art led to the evolution of STEM into STEAM, addressing gaps in creativity and innovation (Özkan, 2020; Chung, 2014). Among various pedagogical approaches in STEM, project-based learning (PBL) is particularly effective, aligning closely with STEM's emphasis on real-life problem contexts, creativity, and iterative design processes, though it does not explicitly integrate all STEM disciplines (Wieselmann et al., 2022; Norazla et al., 2016; Habók & Nagy, 2016).

Project-Based Learning

The Project-Based Learning (PBL) approach, developed on the basis of Dewey, Kilpatrick and Bruner's ideas on learning, arises from the constructivist learning theory (Bayraktar, 2015). PBL is described as an educational approach in which learners question real-life problems, conduct research, study in pursuit of knowledge, collect and analyse data, create opportunities to create products, and structure knowledge through experience. In PBL processes, students learn self-confidence through goal setting, planning, and organization; they improve their collaboration skills through social learning and provide motivation through their own choice opportunities (Kokotsaki et al. 2016). Learning is context-specific; learners actively build their understanding by participating in real-world problems that are meaningful and achieve their goals through social interactions and sharing of knowledge and understanding. In other words, PBL is a learner-centered, teacher-supported educational approach that transcends the boundaries of curriculum subjects and relates learning to the real world (Haatainen & Aksela, 2021; Baran, et al., 2021). It is known that PBL has many difficulties at school level with respect to teachers, pupils, and school conditions. The successful implementation of PBL in the classroom depends largely on the skill of the teacher (Haatainen & Aksela, 2021; Wieselmann et al., 2022; Morrison et al., 2021; Ladachart, et al., 2022).

Next Generation Science and Engineering Standards, NOS and STEM Education

Philosophical debates on STEM education continue, emphasizing the need for ongoing research and discussions for epistemological development (Revilla, Bravo & Greca, 2020). Despite the lack of a clear framework for defining the nature of science (NOS), the concept of "family resemblance" explains the strong similarities among sub-disciplines, which can be applied to STEM (Park & Erduran, 2020). The NGSS, developed in the U.S., aim to integrate engineering practices with STEM disciplines to provide students with scientific and technological literacy, guiding them towards STEM careers (Christian, Kelly & Bugallo, 2021). These standards are structured around three dimensions: science and engineering practices, cross-cutting concepts, and core disciplinary ideas (TeachEngineering, 2024).

Design

Design refers to the decision-making process of an individual tasked with solving problems within an economic context. The design process begins with a verbal or written expression of the person about the problem solution (Bayramoğlu et al. 2019; Kapkın, 2010). Creativity in the design process can be expressed as a leap from the problem situation to the solution area. There is no specified method of creativity, and not every design process results in creativity (Demirkan & Afacan, 2012; Yurt et al., 2020). It can be said that the creativity process in design manifests itself through the stages of preparation-incubation-enlightenment-testing. Design is not a linear process, but a feedback-driven cyclical development process. The expectation of "the single best solution" in design represents the master-apprentice relationship. For the apprentice, the master represents perfection. However, real life progresses with satisfactory solutions (Ciravoğlu, 2001).

Architectural Education (Design Studio)

Schooling in architectural education started with the Academy of Architecture in France in 1671. Designs on paper were first implemented in this school. The educational methods used by this school were very close to the studio education seen in architecture faculties. Students are given design problems, their work is criticized by juries, and supported by competitions. This educational tradition was developed at the beginning of the 20th century with the Bauhaus school, partly by emphasizing individual creativity (Ciravoğlu, 2001; Akyıldız, 2020). Today, the design studio is the center of the educational life of architecture students (Pasin, 2017). Criticising the students' design ideas by the instructors in the architectural design course (studio) is seen as the basic pedagogy of architectural education. The studio is not like the classroom layout in undergraduate education of other disciplines, but rather like a workshop where students spend a lot of time (Oh et al., 2013; Aykaç, 2021). Students can receive criticism from their teachers several days a week about the solutions they produce to design problems, and also benefit from other students' works and criticisms made on them. The system aims to develop students' spatial thinking and problem-solving abilities by confronting them with real design problems, providing them with critical thinking skills, to acquire professional knowledge, and to provide them with the ability to solve concrete problems through abstract thinking.

In this education process, the ability of hand and mind to work together develops, as in art education (Yurt et al., 2020; Yüksel et al., 2021; Hettithanthri & Hansen, 2022; Yılmaz & Ulusoy, 2016). The design studio is based on learning by doing. Architecture candidates have to learn the design process, which they do not yet know, on their own through a project (Ciravoğlu, 2001). Design can only be learned by doing it oneself. The concepts of knowing in action and reflecting in action come into play. It is an important challenge in the first year of design education for students coming from the traditional teacher-centered education system to give up these habits and develop their abstract thinking abilities and creativity. (Akyıldız, 2020; Yurt et al., 2020). Instructors' critiques are named according to the environment; such as table criticism, group criticism, intermediate jury criticism, and final jury criticism.

The method of teaching lessons in the studio is basically a teacher-student dialogue that takes place at the drawing table, where the teacher criticizes the student's thoughts. Due to the one-way flow of professional information in this communication and the inability to discuss the teacher's views, the teacher-student relationship is likened to the master-apprentice relationship (Ciravoğlu, 2001). However, it should not be overlooked that criticizing student's work is a developmental process that results in the students first defending themselves and then correcting their work.

Technical Drawing and Visual Communication

Drawing Techniques have a fundamental place in expressing architectural project ideas. Such skills of students are developed with "Design Geometry and Technical Drawing" and "Perspective" courses. Technical drawing is a narrative language through lines and is the main communication tool in presenting ideas in technology education. Being able to draw physical entities to scale is related to the individual's spatial thinking skills. The lack of courses aimed at developing such thinking skills in undergraduate education results in students who come to study architecture experiencing great difficulties in their first years (Bilgiç & Konak, 2016). Graphics, which has an important place in effectively conveying architectural ideas, is a more encompassing concept. Graphics are the meaningful development of an entity by isolating its photographic form from its details, in the context of the idea to be conveyed. Symbols, icons, emblems, logos, etc. can be given as examples (Ersan, 2022).

Theoretical Framework

A study based at Tufts University examined how hands-on educational activities can promote engaging learning. The aim of the study is to understand how all stakeholders in the learning process learn from the identification of a problem to its solution. Within the scope of the project, a technique combining novel and engineering practices was used. In this technique, students read a book, use their engineering skills to find solutions to the challenges faced by the heroes in the book, and are asked to see themselves as engineers. Thus, students face processes such as problem solving, gaining new skills and sharing experiences. Tufts University academics state that by using this method for two years, they have developed a powerful educational tool that combines different fields such as social sciences, CEIT, STEM and maker education. Research provides experiences and guiding principles that make engineering engaging (Brian et al. 2018).

You, Chacko and Kapila's (2021) study addresses a professional development (PD) programme designed to support secondary school teachers to integrate robotics into science and mathematics lessons. Teachers participated in this PD programme for three weeks (15 sessions, 8 hours each) at the NYU Tandon School of Engineering. The programme has been structured by experts in engineering and science education with course materials, robotic sample lessons and robot activities to ensure the active participation of teachers. Findings indicate that the programme was effective in increasing participants' robotics knowledge, confidence, and ability to integrate robotics into teaching practices. Teacher reflections and follow-up interviews provide guidelines for the development of technology-supported science and mathematics teaching.

In their study on Professional Development (PD) for Educational Robotics (ER)-based STEM education, Çepni et al. (2024a) investigated the effect of the ER STEM PD course based on a modified P3 task taxonomy on teachers' STEM knowledge. Twenty in-service teachers attended a 24-hour PD program using Arduino kits, creating lesson plans, and completing tasks. Pre- and post-tests showed significant improvements in robotics (2.08), science (1.49), and mathematics (0.92) knowledge. The results suggest the P3 task taxonomy is an effective approach for PD in ER settings, surpassing traditional methods like the 5E model and project-based learning.

Çepni et al. (2024b) conducted a qualitative on the premise that educational robots (ER) provide a problem-solving environment for prospective teachers that requires content knowledge and practical skills. In the study, the problem-solving strategies used by nine science teacher candidates who were assigned to build a methane gas detector in the online robotics integrated earthquake PD course were examined. Data obtained from, observations and interviews were analysed. The results showed that participants mostly used trial and error, expert opinion, and case-based reasoning, but rarely resorted to heuristics and intuition. The study also developed a comprehensive framework for understanding problem solving in ER contexts.

Chance et al. (2013) discussed the reflection of architectural education background, which they describe as project-based learning pedagogy, to engineering education. According to them, engineering programs similar to design studio education that force students to think outside the box are becoming widespread in the USA. They pointed out that similar techniques are used in medical and art education. They went further and argued that this model is "one of the best learning and professional development systems that can be designed" for all higher education majors. In their proposed approach, students are asked to work in groups of three to six people. Groups are confronted with problems in which they must go beyond their current knowledge. They are expected to discover the problem situation. Groups are expected to complete a cyclical process of brainstorming, self-learning, and reporting.

Ylirisku and Filz (2018) examined the differences between engineering and design education. In their research, they benefited greatly from Donald Schön's books "The Reflective Practitioner: How Professionals Think in Action" (1983) and "Educating the Reflective Practitioner" (1987). According to the authors, Schön expressed professional practices in two ways, namely t*echnical rationality* and r*eflection in action*. The idea of Technical Rationality was reflected in school curricula in the 1970s. Accordingly, the scientific essence must first be learned and then applied. Thus, theory is hierarchically superior to practice. The authors similarly demonstrated such problematic separation between theory and practice through their study of an engineering school curriculum. According to the authors, *reflection in action* emphasizes the epistemology of practice, which implies creative solutions that practitioners bring to situations of uncertainty, instability, uniqueness, and value conflict. Architecture studios have been considered to teach reflective practice. In the article, the authors include their observations on engineering projects and then list the characteristics of design education. Engineering students find open-ended real-life projects very disturbing and troublesome. Students are kept safe in an educational environment where they can learn basic skills and where the answer to every question is clear. Students solve problems with ready-made tools and techniques. This is indeed in line with the perspective of Technical Rationality stated by Schön. The authors gave the characteristics of design education as a framework for reflection in action. Finally, in the research, the necessity of constantly reviewing the problem situation, the fact that design is a learning process, and the necessity of destroying existing judgments that hinder creative design are presented as remarkable dimensions to understand the unique nature of design.

Tovar et al. (2018) examined how art pedagogy can be used in engineering education. In their paper, the authors developed the multidisciplinary engineering, technology and arts (ETA) education model for mechanical engineering education. The relevant elements of the education model, are that it includes hands-on learning, multidisciplinary design projects, and interaction of engineering students with art students. The expected goal of this model is to advance aesthetically technical innovation in engineering students. The proposed ETA model has been implemented in graduate courses. These courses include practical learning techniques with a problem-based, studio approach and a balanced mix of pedagogical methods consisting of engineering, technology and art.

Schnittka et al. (2012) examined the motivation created by the studio model in out-of-school engineering education experience. The authors stated that STEM education is becoming more visible in out-of-school environments such as summer camps and club organisations. Additionally, they pointed out that the majority of Nobel Prize winners in science first gained their passion for science in out-of-school environments. In the summer camp organised within the scope of the research, young people are given the role of engineers and asked to design better insulating building materials that can reduce energy consumption in the fight against global warming. In the created studio STEM design environment, participants were given the opportunity to experience and learn the thermal properties of various building materials, from paper to polyester, before the design and testing phase. After they were introduced to the concepts of heat transfer, conduction, convection and radiation, the design process began. As a result of the research, it was revealed that the studio STEM environment supports students' learning, makes them feel successful, increases their interest in engineering, science and computer science, and provides interest and motivation.

Based on the effectiveness of the Arida (2011) design studio in creative thinking, it was possible to implement a similar programme in a private high school in Boston. This programme, called NuVu (New Vision), educates students by focusing on multidisciplinary studio projects instead of traditional teaching methods. The programme aims to prepare students to solve today's complex problems and to raise a more creative generation. The programme operates on an 11-week trimester system and focuses on different themes each semester. As a result, students are involved in a creative process in which many ideas are generated, tested, modified, and tested again. The official launch of the program after the pilot implementation and the voluntary work of students on the projects show that the program was successful. This example shows that the principles of architectural education can also be used in STEM education (Arida, 2011; Gavra, 2015).

Idawati et al. (2018) argued that the STEAM approach in science education should start at a very early age to attract children's attention to science, technology, engineering and mathematics. One way to develop future interests in STEM is by using architecture in science classrooms. Many kinds of architectural shapes, sizes, and spaces have been experienced, prompting them to question what architectural design is. For this reason, the world's most well-known mega structures such as Borobuyor in Indonesia, the Taj Mahal in India, the Great Wall of China, the Twin Towers in Malaysia and other monumental structures of the world are also introduced. When children have basic knowledge about architectural structures, they can first imitate them and then design their unique structures using their digital skills. In this way, they can develop positive attitudes towards STEAM professions such as Architecture.

Aim of the Research and Research Question

Educational spaces called studios in architectural education are quite different from the traditional classroom environment. While the classroom environment is designed to transfer knowledge to young minds in the most efficient way, the design studio is like a workshop where knowledge is gained by doing. Project activities in STEM education differ from classical lessons in the classroom. It can even be said that the classrooms resemble studios during project activities. In STEM education, students are expected to encounter real-life context experiences. STEM skills are inherent in life learning. Because we use STEM skills such as critical thinking, interdisciplinary perspective and knowledge acquisition while coping with daily challenges (Jorgensen, 2017). Architectural education also exhibits an approach based on real life context. Therefore, it can easily be said that the basic qualities of STEM education and architectural education are similar to each other. In this context, knowledge embedded in architectural education can be transferred to STEM education with logical inferences. The basic assumption of this study is that the stated analogical inferences can transfer knowledge to STEM education. There are no studies in the literature on the effect of architectural education on STEM education. In this sense, it can be said that the article will fill a gap in the literature and raise awareness about the relationship between two disciplines that have not been associated until now, namely architectural education and STEM education.

The purpose of this article is to obtain new and/or meaningful results about STEM education by a science education researcher, by making observations in architectural education classes, to obtain knowledge and develop judgments about architectural education, and then to make analogical inferences with the findings obtained together with other researchers.

Research Question: *What are the prominent elements of the architectural design education method applied in the first year at BUU Faculty of Architecture?*

Methods

Scientific method was used to obtain information suitable for the purpose of this study. Ethnographic research method was preferred to find an answer to the research question. In the discussions based on the findings obtained from the ethnographic field study, elements of architectural design learning were evaluated comprehensively and information about STEM education was obtained through analogical inferences.

At this point, we point out that the data collected from an area of architectural education by ethnographic method is not evaluated for the purpose of a new invention in architectural education. Whether the findings bring an innovation to the architectural literature is a separate matter of debate. In this study, the findings obtained through a scientific method were used to produce new and/or meaningful information in the field of STEM education through logical inference, which is also an integral part of the scientific method.

Ethnographic Research Plan

Ethnographic research method, one of the qualitative research methods, was used in order to reveal how students learned to design. In ethnographic research, the researcher collects information by entering into that community and acting as a member of that community (participant observation) in order to obtain in-depth information about the community of interest (Çepni, 2021). The classroom environment of Architectural Design Courses at BUU Faculty of Architecture was chosen as the research community for the purpose of this study. This course aims to give basic information about the architecture and design process and to provide students with analytical thinking, analysis and problem solving skills. In addition, it is aimed to provide students with key concepts such as proportion, scale, aesthetics, form and function relationship. The architectural education classroom environment is different from the formal education tradition. Architectural Design is taught in a studio environment. In order to become architects, students receive studio project design training as a high-credit course (8-10 hours per week) for 8 semesters. The first author, a researcher in the field of science education, directly attended architectural design classes and made in-class (studio) observations. Thus, students' presentations of their designs and how teachers criticised them were observed in the studio environment. Later, interviews with students were also used for data verification. Considering the data obtained through observations of how prospective architects acquire architectural design/project skills, the information was compiled through content analysis and transformed into findings.

The researcher was introduced to the students as a person who wanted to get to know architectural education closely because he was considering becoming an architect. In this way, the students, who were the main observation focus of the observer, were prevented to some extent from feeling like they were being observed, and the naturalness of the environment was tried to be ensured. The course was followed for a semester and observation notes were taken for 4 weeks. The class size consists of 30 students. The research data was obtained from the notes taken by the observer in her notebook about the attitudes of the students who received criticism from their teachers during the lesson, how they defended themselves, and how their teachers criticized them. In order not to affect the environment and not to miss any details that could be gained, the observer did not participate in the in-class dialogues, did not ask questions, and maintained his passive position.

The first semester of the first-year students of the faculty of architecture was preferred, considering that it would provide more appropriate information for the research. The first semester is the most appropriate semester to observe how one adapts to the transition from high school education focused on solving multiple-choice tests to an education system where a problem does not have a single answer and has more than one solution. Choosing a period in which the students' knowledge of subjects such as architectural concepts, architectural design problems, and different design approaches has just begun to form, they do not yet have sufficient experience in solving design problems and they do not have prejudices, was preferred considering the purpose of the study.

Data Collection Tools

Considering the research purposes and the fact that the observer was not an architectural education expert, unstructured observation technique was used as the main data collection tool. In other words, a structured form was not used, but notes were taken effectively throughout the observation period. After the lesson, the notes were transcribed without delay and the observations were converted into report format. The teachers of the course, who are experienced professors of the faculty of architecture, are also the 4. and 5. authors of this research. The notes taken by the observer were shared with the course instructors because they included concepts related to the field of architecture expertise. Thus, misconceptions were checked and the validity of the data was tried to be ensured. At the end of the semester, 8 randomly selected students, all volunteers, were interviewed. Although the interview data was used for a different research purpose, the validity of the research was strengthened by comparing it with observation data. The interviews aim to reveal students' perceptions of the architectural design course rather than directly answering the research question. Since a limited amount of interview data was used in this article, there was no need to explain the data collection tool in detail.

Validity and Consistency

The analyzed texts of the observation reports and interviews were arranged in a file and the data obtained was systematically analyzed. The texts were read carefully and their extracts were coded by marking them with different colors. Thus, categories were determined from the codes. Then, inferential themes were reached through the analysis of the categories. The validity and consistency of the codes, categories, and themes created by the first author were mainly ensured by the controls of other authors. On the other hand, the Theoretical Triangulation Method was introduced to ensure the validity and consistency of the research. There are opinions in the literature that Theoretical Triangulation, comparing the findings obtained by researchers with known theories, will increase the scientificity of the article (Çepni, 2021). From this perspective, the research topic is "What is the process of students learning to design in the Architectural Design Course?" The question is a subject that has been widely discussed in the architectural education literature. When the findings were completed, it was evaluated that they did not contradict the information in the literature. Students' verification of interview texts and the use of more than one data collection tool are factors that contribute to ensuring validity. On the other hand, the fact that the third researcher is one of the rare experts in his field in terms of method and application knowledge of science education research guided the theoretical framework of the research to the method and findings. Again, the knowledge and experience of the fourth and fifth authors in architectural education were effective in analyzing the data and providing theoretical triangulation

On the other hand, the theoretical triangulation method was introduced in order to strengthen the consistency of the research. There are opinions in the literature that theoretical triangulation, which compares the findings obtained by researchers with known theories, will increase the scientific nature of the article (Çepni, 2021). From this perspective, the factors that determine the validity and reliability of the article are summarized below; i- There is information in the literature about how architectural design is learned. It has been observed that the findings obtained in this research do not contradict the information in the literature. ii- It was also determined that the findings of the interviews with the students were compatible with the observation data. iii- The fact that the second researcher is an expert in the field of science education research in terms of method and application knowledge strengthened the theoretical framework of the research. iv- The knowledge and experience of the fourth and fifth authors in architectural education supported the accuracy of the data and the consistency in the evaluations. v- The first three authors, who are science education researchers, contributed to the creation of the conceptual and theoretical framework and the analysis of the data. vi- When the findings of similar studies given in the literature section are tabulated in a document analysis, it is shown that they do not contradict the research findings. Information on how document analysis is performed is given below.

Document analysis can be expressed as synthesizing the thematic framework of the research conducted on a subject with a purpose-oriented critical approach (Çepni 2021; Sak et al. 2021). The content summaries of the research shared in the literature section were subjected to document analysis and compared with the themes obtained as a result of the content analysis of ethnographer field research data. Below is the document analysis result matrix created by five studies (Table 1).

Table 1

Categorical classification of similar research (Document Analysis)

	i- Confronting open-ended problems	**ii-**Deepening understanding of the problem situation	**iii-** Gain experience in presentation techniques	**iv-** Meeting the Culture of Criticism
Chance et al. (2013)	Self learning Reflection in Action (open-ended problems)	self learning Reflection in Action (open-ended problems)	Reporting processes	Thinking outside the box
Ylirisku AND Filz (2018)	Reflection in Action (open-ended problems)	Constantly reviewing the problem situation		Designing is a learning process Breaking existing judgments
Tovar and et all (2018)	Multidisciplinary design problems			
Schnittka and et all. (2012)	Building material design	Experiencing the properties of materials		
Arida (2011)	Multidisciplinary studio projects		Exhibition of projects	Generating ideas, testing, changing and retesting

When Table 1 is examined, it seems that it makes sense to bring together concepts such as self-learning and reflection in action, multi-disciplinary design problems and practices such as building material design, and expressions such as studio projects, under the title of Confronting Open-Ended Problems. Under the title of Deepening Understanding of the Problem Situation, it seems that bringing together the expressions of experiencing the properties of materials along with steps such as discovering the problem situation and constantly reviewing it provides meaningful integrity. It can be stated that similar combinations are meaningful for other headings as well.

Results

Findings from Observations

Students who are given a design problem in the architectural design course, just like an architect, research the solution to the problem and prepare drawings throughout the week, present them to their teachers in the studio and receive criticism from them. The students of the observed course were shown 5 plots of land in the city center to make designs. Since the class size is 30 students, there are 6 students per plot of land. Students have the opportunity to receive critiques from their teachers twice each week. Students are always asked to express their ideas through visual means; plan sketches, photos, storyboards, etc. This process continues for weeks so that the projects submitted by students mature to meet the design problem. The first observation was made on 01.12.2022, the second observation was made on 8.12.2022, the third observation was made on 15.12.2022 and the fourth observation was made on 22.12.2022. Although there were 30 students in the first observation, only six students explained the project concept themes. In the second observation, model presentations were made, and in the third week, presentations were made with models and plan drawings. In the fourth week, students were seen hanging storyboards, concept sheets, sketches, and plans on a board in front of the jury, this time using all presentation techniques. They made a presentation with 1/50 and 1/200 models with them. Project evaluations were carried out with the participation of an architect in addition to the course instructors on the jury. Reports were created regarding observations made in the studio environment for 4 consecutive weeks. Most of the texts consist of students' presentations and teachers' critiques of them. As a result of the analysis, the data is presented in Table 2 in the form of categories, and themes and enriched with typical quotations.

Table 2

Observation findings on architectural design course learning methods

Themes	Categories	References from observation notes (Codes)
Facing with the open ended problems,	Student Motivation	He finds the circular design interesting, but explains that for a good evaluation 1/50 architectural sketch plans are needed. She said that it is actually important to include the deaf wall on the neighboring parcel of the building in the design and to hang the spaces in a gridal system and that this is a brave approach...
	Thinking out of the boxes	The teacher breaks the student's model and forces them to go out of the mold. The lecturer tries to reorganize the model by dividing it with his hand... The lecturer explains to the student that what is being done is trying to generate ideas based on personal experiences. ... Another student explains that he lives in Balıkesir and that there is a youth center there and that he was inspired by it... When he tries to generate ideas based on personal experiences, the teacher shows personal stereotypes and raises awareness about stereotypical perspectives and states that it is necessary to go beyond the stereotype.
Deep thinking on understanding the problem	Suggestions on finding various solutions on the problem	It was suggested to think about more contemporary digital games instead of the game activities that the student wants to put in his/her needs program. Video mapping artist Refik Anadolu gave an example. He stated that the artist's exhibition is still going on in Beyoğlu, Alkazar in Istanbul, he stated that he should examine the works of Muse VR and think about games such as HADO... The lecturer stated that in order to

		design, the experiences of previous architects are important and that reading should definitely be done. He repeatedly emphasizes the importance of preliminary studies, reading and watching similar works. The lecturer asked to read Rasmussen's book "Living Architecture".
	Emphasizing making in depth research	He stated that no mother would leave her child in such a social center unless she was very sure that it was safe. The lecturer asked the design student to research the design criteria and safety aspects of children's playgrounds.... The lecturer told another student that Ebru and oil paintings on canvas can be done in the space he designed. However, while designing this, he asks if you ever thought that the materials produced for these processes would have heavy odors... He talks about the importance of concepts in knowledge areas such as physics, mechanics, vectors for rationalization, giving an example of the relationship between cantilevering and moment in the structure. He explains the necessity of designing by considering even the ease of manufacturing by the master...The lecturer stated that it is not possible to design without considering the costs and difficulties of the skylights created, and that the benefits behind them must be expressed strongly...
	Strong arguments for design ideas	How would you convince employers to make this design that you are thinking of realizing, would you be convinced by your own explanations, seeing yourself as an employer? You have to weigh this yourself.
	Students need to Make field research	In their presentations, the students emphasized the need to go to the land to explore the physical and cultural characteristics of the land they will design on and to conduct research on the needs of the neighborhood by meeting with the mukhtar or neighborhood residents. In response to this, the students said that the mukhtar stated that the biggest problem of the neighborhood is the lack of parking... In addition, regarding the issue of researching the demographic structure of the neighborhood, Veledi stated that there is a nursing home opposite the Mosque.
Gaining Experience in Presentation Techniques.	Portfolio File Preparation	The lecturer explained the need to prepare a portfolio file, starting from the first day, all the work in the form of sketches, photographs in the form of design stages in the best way to reflect the need for a filing. The importance of including all the works during the semester in this portfolio in terms of monitoring the student's development was conveyed....
	Presentation technics	Students reflected the work behind their ideas by showing that they used techniques such as synthesis sheet, storyboard, bubble diagram while explaining their ideas.
Meeting the Culture of Criticism	Demonstrating Spatial Errors in the Design Idea (Teacher Statements)	Considering the building dimensions, it seems that the designed bowling alley cannot be accommodated. When the teacher examined the model in detail, he noticed that the floor height in some places was almost 1.5 m. It was emphasized to the student that the floor height in residential and similar areas should be at least 2.60 m, and that the floor height should increase as the

		width and length of the area increases…the teacher asks how to get to the kitchen part., it seems that there is a very narrow area left for the passage due to the stairs, and the head of the passerby will be hit... The teacher explains that the door movements of the WC cabins are not considered and if the door is opened, it hits the toilet bowl... Considering the elevations, it is seen that there will be a retaining wall at the bottom of the building, approximately 4 m long. he stated.
	Questioning the Design Idea and Highlighting Its Deficiencies	He states that the necessary evaluation was not made, for example, he asks what functions were considered in the interior spaces, is there a need for 4 floors? The teacher now asked how many centimeters away he could bend down and work. He questioned that it was difficult to work even one meter away and even if he did, how many minutes could he work in such a tilted position... After examining the plans and models, the teacher questioned why this was built as a blind wall since there was no adjacent wall on which the building was based... The teacher needed to pay attention to the greenhouse effect of such large glass spaces. He stated that it would create completely different difficulties in terms of comfort… The teacher explains that it is very difficult to make a door leaf wider than 120 cm and that the hinge systems do not support them… ..he stated that the hobby area reserved for the elderly on the ground floor is very small, it is an area where two people can hardly fit.
	Emphasis on Professional Knowledge and Skills	He said that spaces should have a hierarchy, and you should take these into consideration in your designs such as reception areas, changing rooms, play areas, etc... He explains his relationship with the world... He stated that people have physical dimensions and psychological dimensions.

Table 2 shows the findings obtained as a result of the content analysis of the texts of student presentations and observation notes regarding the criticisms teachers gave to students. Accordingly, 4 themes were determined with possible groupings of categories. It is thought that these determined themes will reveal the general framework of learning in the Architectural Design course. To better understand the categories specified in the table, quotations of the trainers' criticisms have been specifically reproduced.

Interview Findings

What do you think is the purpose of the Architectural Design Course? There is a category of findings from the answers given to the question that the purpose of the course is to increase conceptual thinking skills. Student expressions representing this category are shared below:
O2....is making abstraction
O4....encourages us to make more original, modern structures by dealing with abstract concepts
O5....allows us to look at life in an abstract sense
O6...abstract thinking
O8....we see something in another lesson and apply it here, the basis of architecture

Two questions were asked to reveal students' perceptions of the difficulties of the course, and the difficulty categories revealed as a result of the analysis of their data are listed in Table 2.1 below.

Quotations from student expressions regarding the "difficulty of the invention process" are shared below in Table 2.2.

Table 2.1

Challenges perceived by students

a-	Difficulty in Model making	Ö1, Ö7,Ö8
b-	Expectation of perfection	Ö1,
c-	lack of time,	Ö1, Ö5,Ö7
d-	lack of motivation,	Ö1,
e-	difficulty in hand drawing,	Ö3, Ö4, Ö5
f-	Difficulty in making presentations,	Ö3,
g-	Difficulty in the invention process	Ö2, Ö3, Ö6,Ö7,Ö8
h-	Difficulty in carrying the model	Ö8

Table 2.2

*Student statements on the difficulty of the invention process (Codes***)**

O2.... I make a mistake and then I think of a better design. Then I think of something better again and it still doesn't work, so I keep redrawing it. Design from the beginning and make a model. O3....we have to do research all the time because it is something we do not know. O6....to be honest, we have to make our professors like us, because there is no concrete truth, we have to change all the time. O7....we designed something called an experiential space. I misunderstood it at first, there was a misunderstanding, I know I didn't leave for two days, I know I cried from stress, O8....thinking about something you would do in one day, you think about it for three days, four days, this process is a bit tiring, there can be a lot of things in your head, sometimes nothing at all. But on the bus, at home, you know, it's like that, I realized that especially after this last homework, your life becomes like this, you think about it on the bus, you go home, you think about it, you eat, you think about it. After you've found it, you feel a bit more relaxed, but until then it's always in your head.

Discussion

What are the prominent elements of the architectural design education method applied in the first year at BUU Faculty of Architecture? The answer to the research question has been revealed with the themes obtained from the content analysis of the data obtained as a result of the ethnographic field study (Table-2). Discussing these themes in terms of their possible contributions to the architectural education literature is not the subject of this article. In line with the purpose of the research, the findings will be evaluated and possible contributions to STEM education will be revealed through analogical inference.

Analogical inference is a type of logical thinking based on an analogy. It is widely accepted that analogies play a role in intuitive discoveries. An analogical inference is formulated as follows: If a system or part of it is similar to another system or part of it in certain aspects, the features discovered in the first system are also present in the second system, or these features are said to be similar (Bartha, 2024). The rules for the reliable use of analogical arguments are as follows: As the similarities between two fields increase, the analogy becomes stronger, and as the differences increase, it becomes weaker. As knowledge of the field decreases, the analogy becomes weaker. Analogies involving causal relationships are more plausible, and structural analogies are stronger than superficial ones. In addition, the suitability of similarities and differences to the conclusion is important, and multiple analogies supporting the same conclusion strengthen the argument (Bartha, 2024).

The discussion will be carried out by addressing four main themes one by one regarding how architectural design education is carried out. Each theme will first be interpreted by establishing a relationship with the literature, and then discussed in detail to draw conclusions about STEM education.

Self-Learning

Facing open-ended problems, (Radical Change in Learning Habits): In architectural education, students face real architectural design demands starting from the first semester with design courses. This method is compatible with the historical background of architectural education (Pasin, 2017). Students are expected to solve open-ended problems that they have not encountered before. This requires a radical change in learning habits in the first year of architecture school (Öksüz & Demir, 2018). Students have to solve these ambiguous and challenging problems on their own, and this process pushes them to creativity and intuitive solutions (Ciravoğlu, 2001; Ylirisku & Filz, 2018). Similarly, in STEM education, students are expected to deal with real-life problems and produce solutions.

Solving a problem encountered for the first time emphasizes problem-solving ability, which is a sought-after competence in the business world (Rahmawati & al., 2021; Bayraktar, 2015). In architectural education, students are expected to solve problems on their own; This process is challenging. Architectural education is like a simulation method that reflects real life; Students are allowed to make mistakes and are expected to learn from those mistakes. The first conclusion that can be drawn in this context is that in STEM education, students should be given long-term opportunities to solve the problem on their own from beginning to end.

Design education difficulties of architecture students are frequently mentioned in the literature (Akyıldız, 2020; Yurt & al., 2020). Students have two main supports in dealing with these challenges: professional motivation and the dedication of faculty members. In-class observations reveal the patient efforts of instructors to correct students' mistakes (Table-2). Giving students choice opportunities in STEM activities can provide motivation (Kokotsaki et al., 2016), but it is difficult to say that this is sufficient. It can be said that the low share of high value-added goods in our exports (Gökmen, Bulut, & Tunç, 2023; TEPAV, 2024; TİM, 2024) shows that we cannot provide successful STEM education. Therefore, radical innovations are needed in STEM education. As a radical suggestion, one might consider denying a high school diploma to students who cannot complete an applied project. Arida's (2011) NuVu experience can provide evidence of the project capability of students at the high school level.

However, it does not seem meaningful to tie graduation to a project at the K4 and K8 levels. At these levels, activities focusing on the problem situation rather than STEM projects may be more appropriate. A second conclusion that can be drawn under this heading is the suggestion to radically enhance the value of STEM projects in real-life contexts at K16 and K12 grade levels to ensure higher motivation, and to revise programs accordingly. At K8 and K4 grade levels, however, STEM activities that focus on problem situations appear to be more meaningful.

Deepening Understanding of the Problem Situation

Deepening understanding of the problem situation: Students are given the task of designing a building that will meet the needs of the district on a plot of land in the city. It is emphasized by faculty members that the design must have strong arguments. Identifying the problem requires research; Students determine needs by both examining local characteristics and interviewing local people.

Lecturers often state that students should benefit from the experiences of previous architects and not make presentations without sufficient research. The fact that students solve design problems in this way shows that architectural education overlaps with the problem-based learning approach.

In architectural design education, one of the issues that faculty members criticize is how deeply the problem is examined. This approach overlaps with Problem Based Learning (PBL). In PBL, expressing the problem strongly contributes to the development of scientific process skills and science literacy (Söyleyen, 2018). However, PBL keeps the student at a cognitive level and does not direct them to a product (Semerci, 2005). In architectural education, investigating the problem situation starts with going directly to the field (Table-2). At K4 and K8 levels, two inferences can be drawn from the architectural education background: It is the student's identification of the problem related to his/her life *(i)* and physical contact with the nature of the problem *(ii)*.

i- Authenticity of the Problem (Benefit Principle): In the architectural design course, students are assigned with a real project directly in the field. A real problem like this should be addressed in STEM education. Although there are statements in the science education literature that the problem should have a real-life context, this is generally not achieved in practice. The problem should be part of the student's life. There's a difference between an unowned problem and a real problem. The real problem includes the dimension of sustainability and value, this principle is also included in the definition of design (Kapkın, 2010). A century ago, John Dewey applied pragmatism to education, advocating being in production and learning by doing (Bender, 2005). İ.Hakkı Baltacıoğlu called this the principle of benefit (Özkan, 2012). However, this principle is almost absent in today's school practice. When the secondary school project subjects applied to TÜBİTAK are examined, it can be seen how far the projects produced by our education system are from the principle of benefit. For example, "Should Sunflower Oil or Corn Oil Be Used for Fries?" A project like this seems like a problem for the teacher or parent rather than a problem that a middle school student can grasp. Such unowned problems remain only at the cognitive level and do not develop real problem-solving ability, which is the goal of STEM education. There are many examples of such attached problems in TÜBİTAK projects (TÜBİTAK 2022). The problem the student chooses must have an aspect that belongs to his reality and leads to a value. In this sense, focusing the student on his problem carries us to high-level scientific process skills SCI education (Aydoğdu et al. 2012). This alone can be said to be one of the benefits of STEM education. Raw problem ideas that the student can capture, that is, real problems, should be the focus of STEM education for lower grade levels such as K4 and K8. The problem in architectural education is very simple: responding to people's functional building/space needs. However, when a secondary school student is asked to determine a project problem for himself, he falls into a very broad field. At this point, STEM activities should be planned to focus on the problem situation under the guidance of the teacher. The teacher's role here is to criticize students' opinions using similar methods as in architectural education. In Table 2, the criticisms given by the faculty members in the category of emphasizing the questioning deficiencies of the Design idea and the need for in-depth research reflect exactly this. Instructors should draw the student to the desired problem situation with questions that can be beneficial. In the end, even if the student poses a genuine problem of his own, he will probably not be able to progress to a product at his grade level. Ensuring the authenticity of the problem is the third recommendation that can be derived from architectural education.

ii-Contacting the physical dimension of the problem: In the architectural design course, students go directly to the field and conduct investigations to analyze their problem situation. Similarly, in STEM education, physical contact should be established with the object of the problem. The fact that a product cannot be produced in STEM education at K4 and K8 grade levels does not mean that the student cannot physically interact with the problem situation. Otherwise, as in the problem-based learning approach, this will require students to keep their studies at a cognitive level (Semerci 2005). However, as reflected in the ancient achievements of architectural design, learning in action can be implemented within these grade levels (K16) (Akyıldız, 2020). Therefore, depending on the topic of the problem, students need to transcend the cognitive domain and be carried away by the physical nature of the problem by touching related objects. For example, let's assume that a student has adopted the "Solar Panel that Follows the

Sun" project and wants to do it. In reality, it seems difficult for secondary school students to complete such a project with the principle of benefit. Even in this case, students should come into contact with the solar panel within the scope of their projects, experience how the electricity it produces changes according to the inclination of the panel surface to the sun, be able to change the angle of the panel on their own, observe the results, and be able to see and measure what changes occur. So, the fourth conclusion that can be drawn from the accumulation of architectural education is that children in K4 and K8 classes get to know the materials and tools related to their projects by experiencing them firsthand.

Technical Drawing and Graphic Communication

Gaining experience in presentation techniques: In the architectural design course, students have to present their work to the lecturers and this is used as a basic communication tool in the studio. At the beginning, students express their ideas with visual tools such as scale-free synthesis sheets, concept maps and storyboards, and as they progress, they use techniques such as scale models, plans, sections and perspective. Graphic communication is more effective than written language, especially in conveying three-dimensional ideas. However, inadequate teaching of spatial thinking skills in pre-graduate education makes it difficult to learn visualization techniques in the first years of architectural education. This situation is also reflected in the students' perception of difficulty in Table 2.1 (Bilgiç & Konak, 2016).

In architectural education, ideas are mainly presented through drawings. This is an issue that has been extensively covered in the literature and is reflected in the findings of the research (Table 2). It can be said that drawing techniques are, to some extent, a skill that should be acquired by students before undergraduate studies. The need to present ideas through visual communication can be encountered in many areas of life. On the other hand, gaining skills in technical drawing also means advancing spatial thinking skills, which have an important place in competencies in STEM disciplines (Cole et al., 2018). Although the pre-undergraduate visual arts course touches on visual communication to some extent, it is not sufficient. In the context of STEM education, students are expected to be able to convey their design ideas through technical drawings or graphic drawings. It can be easily stated that technical drawing and graphics education should be provided at least at the high school level, including students other than technical high schools. The recommendation to add courses that will improve technical drawing skills to high school programs may be the fifth conclusion that can be drawn from architectural education.

Adapting the Culture of Criticism

Meeting the culture of criticism: Criticism in architectural education is a challenging but essential learning tool for students. In the design studio, students are exposed to criticism from instructors during their presentations. Criticism enables students to develop their critical thinking skills and professional knowledge in architectural education (Yurt & al., 2020; Yüksel & al., 2021; Hettithanthri & Hansen, 2022; Yılmaz & Ulusoy, 2016; Pasin, 2017). In a sense, instructors represent physical realities and cultural values in front of students. It is emphasized that criticism sometimes improves students by breaking their prejudices, and that this process has an important place in architectural education but is a challenging process (Oh & Ark., 2013; Aykaç, 2021).

In the discussions above, it was mentioned that the instructors represented physical and cultural reality in their table critiques in the architectural design course. From the observation statements in Table 2 and readings of the relevant literature, it can be said that teachers' representations of reality are the essence of architectural education. Field specialization training is mainly provided at the undergraduate (K16) level. In this context, it can be said that the conditions for using the desk critique method in project work are available. Students can be given project topics with a real-life context. Since teachers are field experts, they must have the knowledge and skills to represent real life. Therefore, they can represent the physical and cultural reality of that professional field. However, it is not seen that similar topics are covered in the literature. When it comes to STEM education at the K16 level, the literature mostly investigates disadvantaged representation problems such as gender, skin color, disability, and the reasons for dropping out of school in the first years of undergraduate education (Li et al., 2020). It is known that graduation projects are compulsory courses in engineering departments in our country, even though their credits are not high. However, compulsory graduation papers (project courses) in engineering departments are overshadowed by the success concerns of theoretical courses and are not given as much importance as in the faculty of architecture. As mentioned in the literature section, two dimensions of technical education are mentioned: *Technical rationality* and *reflection in action*. After the 1970s, priority was given to *technical rationality* in engineering education. Thus, in a sense, it can be said that theory is hierarchically superior to practice (Ylirisku & Filz 2018).

Despite this, graduation papers should be structured based on the design studio approach (criticism culture) in architectural education and implemented as a compulsory course and should be a graduation qualification course with high credits. Supporting this prioritization, Chance et al. (2013) have argued that the design studio approach is "one of the best learning and professional development systems considered" for all of higher education, but also that it is becoming widespread at the K16 level. So, as the sixth inference in the context of architectural education; It can be said that in addition to the paradigm change in theory/practice (technical rationality and reflection in action) that faculty members should experience at the undergraduate level, radical institutional preparations such as assessment and evaluation with the jury system should also be made. For grade levels K12 and below, the fact that teachers do not have industry-related professional expertise limits students' possibilities of determining a project topic, and the teacher can't represent reality on the selected project. Therefore, with the high school level being an exception, the cognitive and psychomotor competencies of students at the K4 and K8 grade levels eliminate the possibility of product-oriented, project-based STEM education. Instead, as discussed above in the Reality in Problem Situation subheading, it seems possible to adapt STEM activities at K8 and K4 grade levels to include physical experiences within the design studio approach, starting with identifying a real problem.

To summarize, at the end of this discussion, six conclusions were drawn in the context of reflecting the knowledge of architectural education into STEM education:

1- In STEM education, students at all grade levels should be given the opportunity to solve the problem on their own from beginning to end. In other words, when faced with an open-ended problem, the student should develop his own solution method by trial and error and by learning from his mistakes. Although this is not an unknown issue for STEM education, it is recommended to place more emphasis on dealing with uncertainties on the way to solution and to increase the time and program weight.

2- It is very important to provide students with high motivation in tackling open-ended problems. For this purpose, STEM project courses should be converted into graduation qualifications. Provided that motivation is provided, a successful project-based STEM education can be targeted at undergraduate (K16) and high school (K12) grade levels. On the other hand, when students' knowledge and skill levels are taken into account, an approach that places STEM education, which focuses on problem situations, as the basis of programs at secondary school (K8) and primary school (K4) grade levels, may be meaningful.

3- The problem themes of the Architectural Design course focus directly on real life. In STEM education, this corresponds to the principle known as real-life context. However, a standard has not been established in establishing the context in STEM education. In this sense, the concept of authenticity of the problem has been defined in order to emphasize the importance of the real-life context and to set a measure. What is meant by the real problem statement is the sustainability and economic value dimension. Problems of questionable authenticity should be avoided.

4- Although children at the secondary school (K8) and primary school (K4) grade levels will not aim to obtain a concrete product in the context of a real problem, STEM education focused on deepening the problem situation can be provided. However, for these grade levels, children should be able to familiarize themselves with the materials, tools and equipment in the context of the problem by experiencing them firsthand.

5- It can be said that drawing and graphic skills, which have a big place in architectural education, are necessary in almost every aspect of life today. Therefore, in order to provide project narratives in STEM education activities, it is recommended to add courses that will improve technical drawing skills to the programs, including non-technical high schools.

6- In addition to the theory/practice (technical rationality and reflection in action) paradigm change that faculty members need to experience for real success in project courses/final papers in STEM disciplines at the undergraduate level, it is also recommended to make radical institutional transformation preparations such as measurement and evaluation with a jury system.

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