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Students' perceptions of information and communication technology (ICT)-based literacy learning needs in higher education

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ABSTRACT
This paper presents a needs analysis with regard to ICT-based literacy development. This needs analysis consists of three aspects: ICT readiness, target needs, and learning needs, which are related to literacy acquisition. This paper discusses how advanced student readiness in using ICT, target needs, and learning needs in higher education is using student teachers as subjects. Data were collected using a survey, which was administered to 140 students at the primary school teacher education programme of two universities of Pekanbaru in Indonesia. During the process of learning activities, students used the Indonesian language as their communicative language. Based on the result of the need analysis of the ICT, students need access to the internet facilitated by the campus. In addition, not only is the lecturer required to provide tasks that encourage the use of ICT as a learning resource frequently but students also need to develop their interests such as participating in training programs. In the target needs, it was found that literacy skill is needed by students as it is an essential competence, but in the learning implementation, they expect to use varied learning, learning media, and appropriate strategies to read comprehensively. In the learning needs, the result indicates that students need to determine the objective of increasing advanced literacy skills, the lecturer as a role model, and the lecturer as a learning resource so that the students can learn based on the instruction and teaching and learning contract.

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Introduction

Literacy learning and technology are interrelated in developing students' literacy acquisition, especially at the higher education levels. Hobbs et al stated that literacy development and technology are needed in education (Hobbs et al., 2022; Guo et al., 2022; Kamble et al., 2022; Afrilyasanti et al., 2023). Literacy is needed by all levels of all ages to deal with the change in the 21st century, which aids students in attaining their basic knowledge. (Safrizal et al., 2022). Literacy and technology often become important public issues to provide information so that it builds critical, logical, innovative,

and creative thinking skills and a globally competitive individual (Negoro et al., 2023; Sigit et al., 2023). Technological intensification and its use demand the need for digital education (Kurniaman et al., 2022). The dependability of technology produces a consideration for providing facilities that encourage students to use technology, interact with each other online, and increase digital literacy skills. (Reddy et al., 2023a). By having literacy skills, students can finish their digital-based tasks (Prabowo et al., 2023). Educational institutions play a role as facilitators in literacy development in order to increase students' advanced literacy skills. The utilization of a technology-facilitated, as such, can be one way to establish innovative learning for students.

According to Cavus et al. (2022), 21st-century education is delivered as technology-based learning, which guides the lectures integrating technology adequately for students. Razak et al. (2022) state that learning in the 21st century needs to encourage advances in ICT in Indonesian society. Kargin et al. (2023) stated that 21st-century learning is applied to society's development over time. It is recognised that society developed from a primitive society to an agrarian society to an industrial society and is now shifting towards an information society (Demirezer, & İlkörücüi, 2023) marked by advances in technology and digitalisation.

Technology influences a change in teaching and literacy learning from direct to online teaching and learning activities in the classroom by providing e-books access as references for learning (Shymansky, 1991). It means that technology changes the system from direct to online teaching and learning. Senge (1990) states that technological integration-related professional development in teaching must be focused on the students' learning increase. Technology literacy, which has been integrated into the university level, requires more than just focus on information and its communication technology. It is equally essential to focus on the available learning strategy about new technologies and make a decision strategy about what and how this technology can increase literacy learning for students (Taffe & Gwinn, 2007). It means that the teaching and learning activity using literacy and ICT is not only focused on its technology integration but is also on how the strategy can be applied and increase literacy learning for higher education students.

In terms of successful literacy development, learning target needs are required by students as a means to make them easily fulfil their needs in learning (Anwas et al., 2022; Nasution et al., 2023). Švajger (2022) noted that the role of the lecturer is to adjust the learning outcome based on the student's literacy acquisition skill in order to create a learning environment that encourages students' progress and success. According to Rigianti (2023), needs analysis in literacy learning for lecturers was to discern students with reference to the use of reading material based on the different literacy learning levels, individual literacy learning preparation, and students' interest while learning in the classroom.

Besides other students' age levels like primary to high school level, literacy learning is essential for students in life by adapting themselves to society, regardless of their role in the academic sphere (Mirizon et al., 2021). Reading literacy for students not only becomes the basis of achievement in each learning subject but also determines their reading literacy skill (Alharbi et al., 2023). Based on Damaianti et al. (2020) statement, literacy is essential in community life as people who can read, write, and count may contribute significantly to society and can learn about the world. Ng & Graham. (2017) and Greenleaf et al. (2010) state that the concept of literacy has been developed based on the basic concept of reading and writing skills to apply every skill and competence in life. Literacy learning for higher education students, as such, is applied to develop their literacy learning.

Technology readiness for students, according to Kurniaman et al. (2022), is one of the essential skills to utilise technology in the literacy process, and digital-based learning is a learning resource to enhance critical thinking, creative thinking, and innovative skills. Technological readiness research is growing rapidly conducted by several researchers in order to increase the effectiveness and efficiency of the achievement of learning objectives (Ulfatin et al., 2022). In line with Ulfatin et al. (2022); Hadi et al. (2022) state that the advances in ICT have rapidly increased in today's modern era, especially in multimedia. Multimedia nowadays is commonly used as a learning facility and media because it can increase students' skills. Thus, the researchers conduct the research in this paper in order to find out

how target needs, literacy learning needs, and ICT readiness are applied to students. Three research questions can be described as follows:

RQ1 : How well are students prepared to use ICT?
RQ2 : How significant are the target needs for students in literacy learning?
RQ3 : How significant is literacy learning needed by students?

Literature Review

ICT Readiness of Students

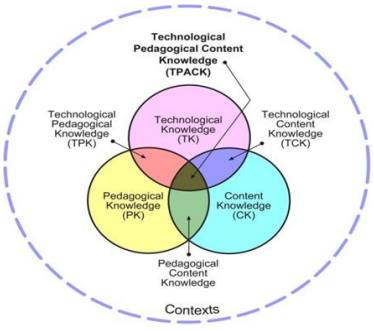
Society 5.0 enables us to use modern science in order to make humans able to live comfortably. Society 5.0 was inaugurated a few years ago for Industry 4.0. The concepts of Industry 4.0 and Society 5.0 overlap considerably, but Society 5.0 focuses more on the human context. As presented by Chernbumroong et al. (2023), learning in the post-Industrial Revolution era is ideally no longer teacher-centred but student-centred nowadays. Industrial Revolution 4.0 is an era where every aspect of technology, including the utilisation of digital media in the teaching and learning process. Thus, digital learning requires readiness in the teaching and learning process to utilise digital technology, such as the use of a Learning Management System (LMS, Pinto, 2020).

ICT readiness for higher education students is determined by Technological Pedagogical Content Knowledge (TPCK) to describe students' understanding of technology. This model is developed by focusing on the component of students' readiness for technological knowledge and is an attempt to increase mastery of ICT. As stated by (Alhabshi & Abdelaziz, 2022) This model's mechanism must be subsequently made based on the student's needs. As regards this model, every learning is different along with the era and is developed sustainably based on the teaching context of how lecturers can integrate their knowledge of thinking, learning, and ICT.

Knowledge regarding the utilization of ICT for students is used as a characteristic of advances in education and self-directed learning that needs a technique to obtain problem-solving in the learning process. It is intended to determine whether the transition can increase the teaching quality without training, education, and preparation for students (Marini et al., 2022). The advanced interconnected framework is called Technological Pedagogical Content Knowledge (TPACK). There are four main concepts of this framework. They are context, content, pedagogical knowledge, and technological knowledge (Mishra & Koehler, 2006) that can be described in Figure 1. TPACK also can be integrated with TPACK in the digital age. It means that it changes the role of technology in the classroom. TPACK needs to adapt as new technologies emerge and how they reflect shifting paradigms in education. Exploring how specific technologies like AI and VR/AR influence the TPACK framework and shift teaching practices.

Figure 1

Technological pedagogical content knowledge (TPACK)



Technological Pedagogical Content Knowledge (TPACK) framework above is a reference for the researchers to learn how higher education students can use ICT in learning in this paper (Mishra & Koehler, 2006). As stated by Armiyati & Fachrurozi (2022), the need for TPACK in higher education provides a different impression in teaching and learning that commonly applied conventional method turning into an essential technology application for learning in terms of increasing students' knowledge. The researchers assess the students' knowledge based on four main concepts of this framework, namely context, content, pedagogical knowledge, and technological knowledge. The development of the instrument, according to Aka (2020), refers to TPACK, which is developed as the theoretical framework and used to find out students' ICT readiness, which can be seen in Figure 2.

Figure 2

Indicator of ICT

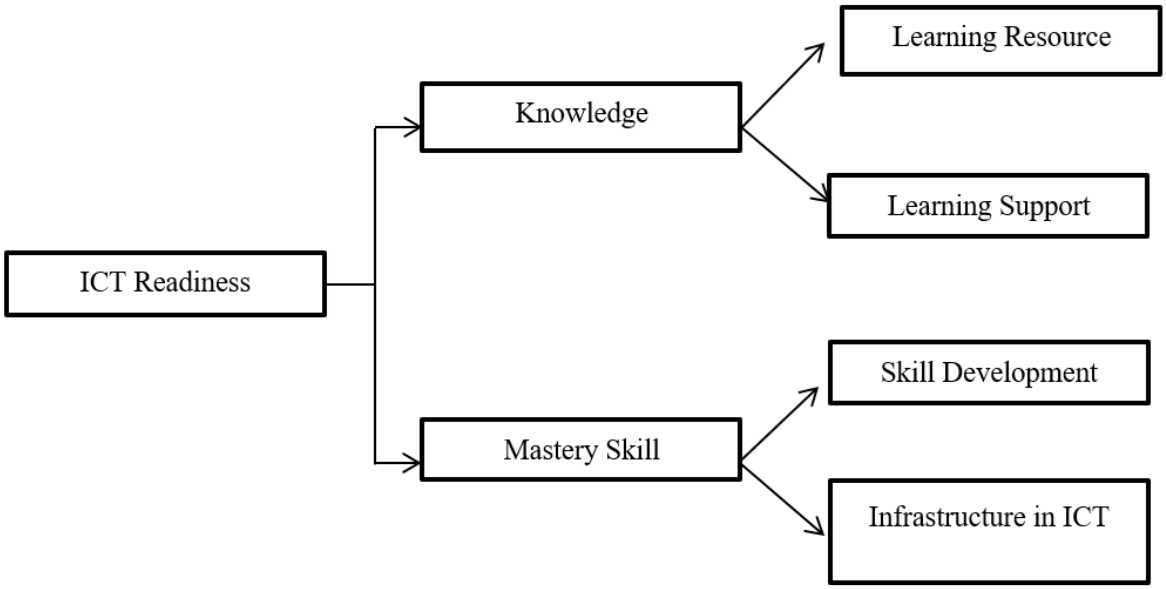


Figure 2 indicates that the indicators of ICT readiness that are distributed to students are based on the theoretical framework above. The indicators consist of knowledge and mastery skills. Knowledge refers to learning resources and learning support. On the other hand, mastery skills refer to skill development and infrastructure in ICT. This means that these indicators are developed to be questionnaires. As stated by Damaianti et al. (2020), carrying out a systematic review of questionnaire development in analysing students' perception of technology in literacy learning is crucial to be considered as a basis in the development and input. Therefore, the ICT readiness is distributed to students in this paper.

Students Need Analysis in Literacy Learning

Students' needs in literacy learning are an attempt to involve the whole stakeholders of higher education, peers, and teachers' roles (Fauzan et al., 2023). Saryono et al. (2017) explained that the development of a literacy culture is implemented alongside character building and ethics in higher education. Hence, a literacy culture will be developed among students as the basis for creating a lifelong learning process. Target needs to help students identify what they require in literacy learning and highlight areas that need attention in higher education. According to Suadi et al. (2022), literacy development for students has a positive impact by building advanced literacy skills through specific programs that encourage and motivate students to read textbooks in their leisure time. This means that literacy encourages students to engage in positive activities like reading. Getting used to reading activities will increase students' advanced literacy skills.

According to Hutchinson & Waters (1987), "target needs" is a general term that encompasses notable differences in implementation based on students' needs in the target situation, including necessities (what students should know), wants (what students want), and lacks (what students do not know yet). In terms of necessities, these are the types of needs determined by the demands of the target situation, meaning what students should know to function effectively in that context. The term "wants" refers to the learners' personal desires in literacy learning, which may not fully align with the objective target needs. However, students may have their own perceptions about their needs in literacy learning, especially regarding areas they find difficult, and they may feel that lecturers do not frequently guide them in literacy. The term "lacks" is intended for matters that are not comprehended by students and refers to the gaps in their knowledge. It means students need to identify what they do not know yet, as well as recognize what they already know, to determine the areas where they lack knowledge. Moreover, the target proficiency should be aligned with the student's current proficiency levels. The gap between the two needs can be called the students' lack.

Literacy Learning Needs

Literacy learning in Indonesia is commonly called a literacy movement implemented from the basic education level to the higher education level (Pratama et al., 2023). In implementing the literacy movement program, we must create and utilize various learning resource facilities as well as provide meaningful learning experiences (Pradana, 2020). To meet expectations and foster cultural behaviour, the Ministry of Education and Culture of the Republic of Indonesia (Kemendikbud) has intensified the literacy movement through the Minister of Education and Culture's Regulation Number 23 of 2015, aiming to cultivate virtuous behaviour in students through language from an early age to the higher education level (Hanin & Islamy, 2020). Thus, it becomes an expectation to increase interest and advanced skills in reading.

Literacy is the ability to access, comprehend, and use information wisely (Dirjen, 2020). As stated by Kemendikbud, increasing virtuous behaviour in students should indeed be strengthened through the literacy movement. According to Listanto & Firmansyah (2022), the literacy movement must be applied as early as possible to create an intelligent and cultured nation. Because, as stated by Laksono & Retnaningdyah (2018), literacy mastery is essential for the younger generation to comprehend information through reading as an attempt for self-improvement, personal branding, professional development, school, and national development. Similarly, Reder & Davila (2005) state that reading literacy is essential for self-improvement, personal branding, professional development, school, higher education, and national development. Condie & Pomerantz (2020) assert that the awakening of a nation begins with sustainable enlightenment and understanding of literacy-related books. Literacy mastery is essential for the learners to contribute to building the country.

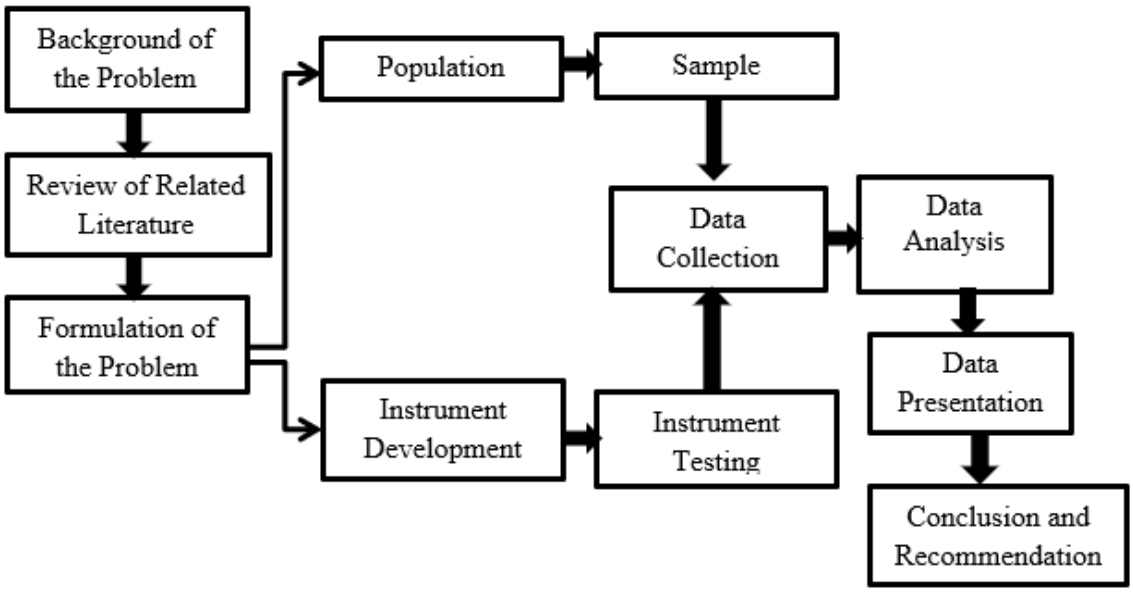
The needs for literacy learning are examined from aspects of learning needs—what students require in reading literacy learning—which includes goals, procedures, teacher's role, learners' role, and setting (Hutchinson & Waters, 1987). Learning needs are considered in relation to the target situation to understand the information required regarding goals, procedures, teachers' roles, learners' roles, and settings. To provide appropriate learning, the researcher needs to use survey methods in order to obtain concrete data.

Methods

The research method used is quantitative survey research. According to Sugiono (2019), a survey is research conducted on large or small populations, but the data are collected from samples based on the population to find out relative events, distribution, and the relationship between sociological and psychological variables. The process of survey research in this paper can be seen in Figure 3.

Figure 3

Stages of survey quantitative research



The survey research in this paper, according to Figure 3, begins with determining the background of the problem. The researcher reviews relevant literature based on the topics in this paper. After formulating the problem, the researcher determines the population and samples and develops instruments. The instrument is subsequently tested before data collection and analysis. Data are collected through a survey using Google Forms that are distributed to five universities in Indonesia contributing to the research of this paper. Data collection is done through a standardized questionnaire allowing for objective comparisons between the universities. The data are subsequently analyzed by calculating the percentage selected from the sample to find out how they assess the needs for ICT readiness, target needs, and learning needs. The researcher also includes the results to present the data and make a conclusion and recommendation at the end of the research.

Research Instrument

According to the theories of Hutchinson & Waters (1987) and Macalister & Nation (2010), the instrument needs are based on needs analysis consisting of target needs and learning needs. Target needs are what the students require in the target situation, and learning needs are what the students need during learning. ICT readiness is knowledge about technology and the improvement of mastery of technology. It can be seen more clearly in Tables 1, 2, and 3. The instrument should be suitable for testing in order to obtain the data. Instrument analysis is carried out using SPSS to facilitate data processing.

The questionnaire is distributed to the try-out sample, and the data are subsequently analyzed using SPSS software. Tables 1, 2, and 3 describe statistical data and Cronbach's Alpha coefficient data for the questionnaire.

Table 1

Students' readiness for ICT

Aspects	Indicators	Items	Result			
			r_{count}	r_{table}	Alpha Cronbach	Category
Knowledge of ICT Utilization	ICT Utilization in Learning Resources	1	0.324	0.1396	.73	Valid
		2	0.251			Valid
		3	0.196			Valid
		4	0.188			Valid
		5	0.190			Valid
	ICT Utilization to Support Learning	1	0.186			Valid
		2	0.291			Valid
		3	0.379			Valid
		4	0.346			Valid
		5	0.395			Valid
		6	0.298			Valid
Attempt to Increase Mastery of ICT	Participate in Activities or Carrying Out ICT Seminar or Workshops	1	0.322			Valid
		2	0.355			Valid
		3	0.209			Valid
		4	0.411			Valid
	Completing Various ICT-based Facilities and Media to Support Teaching and Learning Activities	1	0.338			Valid
		2	0.270			Valid
		3	0.212			Valid
		4	0.208			Valid
		5	0.272			Valid

According to Table 1 above, Alpha Cronbach of students' ICT readiness indicate 0.73 from the aspects of knowledge of ICT utilization and attempt to increase mastery in ICT, the result of each indicator is valid. Based on the Alpha Cronbach coefficient data, the value of the test instrument is 0.73, which reveals an acceptable level of reliability because it is higher than 0.6. The instrument in Table 1 about students' ICT for technology based on two aspects are divided into four indicators with 20 question items by using SPSS version 25 indicates that an invalid statement has not been included and used for data collection so that the data that were retrieved from the table 1 are valid with a number of 20 question items. It implies that instrument test items for every variable have a high-reliability level.

Table 2

Students' target needs in literacy learning

No	Indicators	Items	Result			
			r_{count}	r_{table}	Alpha Cronbach	Category
1.	Necessities (What students should know)	1	0.440	0.1396	.574	Valid
		2	0.462			Valid
		3	0.434			Valid
		4	0.349			Valid
2.	Wants (what students want)	1	0.436			Valid
		2	0.552			Valid
		3	0.405			Valid
		4	0.457			Valid
		5	0.408			Valid
		6	0.434			Valid
3.	Lack (what students do not know yet)	1	0.326			Valid
		2	0.304			Valid
		3	0.170			Valid
		4	0.327			Valid
		5	0.303			Valid

Related to Table 2 description above, the analysis instrument of students' target needs in learning literacy above refers to three indicators. It is divided into 15 question items. It is subsequently validated with SPSS version 25. It indicates that the result of $r_{count} > r_{table}$ is valid. It can be seen from the coefficient data of Alpha Cronbach result for the test instrument at 0.574. It implies that the reliability level is acceptable enough because it is lower than 0.6. Hence, instrument test items from all variables indicate quite reliability levels. Nevertheless, this instrument can be used as long as the validity and reliability are categorized as enough.

Table 3

Students' learning needs

No	Indicators	Items	Result			
			r_{count}	r_{table}	Alpha Cronbach	Category
1.	Goal	1	0.351	0.1396	.767	Valid
		2	0.588			Valid
		3	0.429			Valid
2.	Procedures	1	0.454			Valid
		2	0.598			Valid
		3	0.442			Valid
		4	0.627			Valid
		5	0.342			Valid
		6	0.478			Valid
3.	Teachers' role	1	0.508			Valid
		2	0.435			Valid
		3	0.557			Valid
4.	Learners' role	1	0.414			Valid
		2	0.396			Valid
		3	0.298			Valid
		4	0.367			Valid
		5	0.259			Valid
5.	Setting	1	0.390			Valid
		2	0.421			Valid
		3	0.463			Valid
		4	0.259			Valid

The instrument of students' learning needs, which is described in Table 3, describes the feasibility of the instrument in the research of this paper. The calculation of item validation with $r_{count} > r_{table}$ reveals that all items are valid and able to be used for questionnaire distribution. Based on the Alpha Cronbach coefficient data, the value of the test instrument is 0.767. It means acceptable with a high-reliability level because it is higher than 0.6. It implies that instrument test items for all variables indicate a high reliability level.

Research Sample

We distribute the questionnaire to elementary school teacher education students by using a purposive sampling technique. The purposive sampling technique is a sampling technique where samples are selected based on specific criteria relevant to the research topic (Sugiono, 2019). A total of 140 students from two universities in Pekanbaru that have elementary school teacher education programs were selected.

Data Analysis

In data analysis, after the data are collected from the research sample, the data are then analyzed by using percentage calculation to interpret the responses to see how the students assess their ICT readiness, target needs, and learning needs in literacy learning at the higher education level. The result of the data is presented in tables with percentages to describe the research findings. The lecturers' and students' responses regarding their perceptions of needs in literacy learning highlight the importance of conducting research development using validated instruments. After getting the result of the survey data, percentage calculations were carried out to quantify the students' needs. Therefore, response criteria were established based on the questionnaire, as described below:

Table 4

Students respond criteria

Interval	Category
82-100	Strongly Agree
63-81	Agree
44-62	Disagree
25-43	Strongly Disagree

Results

The result of the research indicates students' perceptions of ICT-based literacy learning using the survey method and three research instruments: students' ICT readiness, students' target needs in literacy learning, and students' learning needs. The analysis of perception data implies that there are various needs among students in literacy learning at the higher education level, which have been the focus of this research. Table 5 describes students' ICT readiness from students' self-development to the infrastructure in higher education.

Table 5

ICT readiness for students

Aspects	Indicators	Items	Result	
			Percentage	Category
Knowledge about the ICT Utilization	ICT Utilization in Learning Resources	The Internet is used for searching for learning resources.	63.75	Agree
		Google Classroom as the platform is used for lecture assignments.	63.93	Agree
		I will use the internet if I am constrained in finding out lecture assignments.	60.71	Disagree
		It is difficult for me to find out any sources using the internet.	58.39	Disagree
		I do not prefer to read journal articles online.	59.82	Disagree
		The lecturer frequently provides assignments with the source of digital literacy.	59.29	Disagree
	ICT Utilization to Support Learning	Learning is not interesting when the source comes from the internet.	58.04	Disagree
		The lecturer uses LMS in learning in the classroom.	66.43	Agree
		The use of LMS is easier for learning.	61.43	Disagree
		The use of ICT makes learning difficult.	64.29	Agree
		The use of LMS makes learning difficult.	56.43	Disagree
Attempt to Increasing Mastery of ICT	Participate in Activities or Carrying Out ICT Seminar or Workshops	I participate in ICT workshops to increase self-efficacy.	62.14	Disagree
		I have attended training on the use of LMS organized by Faculty and the University.	60	Disagree
		I have never learnt to develop competence in the use of ICT.	61.61	Disagree
		Participating in the technological workshop and seminar is a time-consuming activity.	59.64	Disagree
	Completing Various ICT-based Facilities and Media to Support Teaching and Learning Activities	The Internet can be accessed easily everywhere.	60.54	Disagree
		The institution provides a facility or place to learn outside classroom with the Internet access.	61.79	Disagree
		The Internet is very fast to access learning resources.	63.21	Agree
		The institution provides LMS for lecture activities.	60.36	Disagree
		Internet access outside the classroom is not essential enough.	61.96	Disagree

ICT readiness for students is an essential issue because of current technological development. Based on Table 5 above, the result of students' responses on ICT readiness reveals five items where students agreed and 15 items where they disagreed. The knowledge aspect of ICT utilization includes the indicator of technology utilization in learning resources, consisting of two statements to which students agreed. The internet is a learning resource in the lecture process utilized by students, so Wi-Fi needs to be facilitated in every place in order to ease their access to the internet. Teaching and learning are conducted by the lecturer and students in the classroom; students agree on utilizing Google Classroom because it makes submitting assignments online easier.

Furthermore, students' responses who disagree with the statement of ICT utilization in learning resources include three items. 60.71% of students still do not use the Internet to complete their assignments. 58.39% of students disagree with the statement that it is difficult to find sources using the internet, implying they find it easy. Related to another item that supports what obstacle the

students faced, 59.82% of students disagree with the statement that they do not prefer to read online journal articles. It provides a description of ICT utilization in learning resources that is not still optimally used in literacy learning.

In addition, based on ICT utilization to support students in learning, 59.29% of students' responses disagree with the lecturer frequently providing assignments using digital literacy resources. 58.04% of students' responses disagree with the statement that learning is not interesting when the source comes from the internet, indicating they find it interesting. Nevertheless, there is a response that indicates that the use of LMS makes learning difficult because there are a number of assignment features that must be delivered, and they must learn independently. Students' self-development in ICT readiness on students' response to the participation of ICT training to increase self-efficacy is severely lacking. They assume that the facilities provided by the institution are still lacking because the internet cannot be accessed everywhere. To see target needs for students, it can be described as follows:

Table 6

Target needs for students

Aspects	Indicators	Sub Indicators	Result	
			Percentage	Category
Necessities (What Students Should Know)	Urgency and Role of Literacy Learning	Know the definition of literacy learning	74.28	Agree
		Understand the use of literacy learning	76.25	Agree
		Understand the importance of literacy learning taught to students	81.25	Strongly Agree
		Know literacy learning that can change national exam	68.39	Agree
		Understand the concept of the literacy learning model	75	Agree
Wants (What Students Want)	Literacy Learning-Related Students' Wants	Know literacy learning designed with an appropriate concept	79.46	Agree
		Knowing a reading text that will be discussed should be given in literacy learning	77.32	Agree
		Know the method of practical literacy learning directly	79.46	Agree
		Know the learning material should be contained in Riau Malay Culture	68.03	Agree
		Use learning media	79.82	Agree
Lack (What Students Do Not Know Yet)	Aspects that are not mastered in literacy learning	Know the obstacle in developing an appropriate reading text for students	69.10	Agree
		Do not prefer to read article and book that supports learning	63.39	Agree
		Never prefer to read the book (thrice a week)	62.67	Disagree
		Must re-read to get an understanding of the text	73.21	Agree
		Do not know fast methods to understand a reading text	66.42	Agree

As regards the table above, the response that is obtained between the aspects of necessities, the indicator of urgency and the role of literacy learning and knowing about literacy definition is 74.28% agree. Likewise, the response on understanding the use of literacy learning needed by students indeed agrees with 76.25%. For the importance of literacy learning taught to students, students' responses strongly agree at 81.25% because they recognize its impact on changing national exams at various educational levels in Indonesia. In terms of the aspect of wants on the indicator of students' wants related to literacy learning, the lowest agreed response on the statement item of the material should be focused on Riau Malay culture is 68.03%. They assume that learning material is better

varied without being restricted so that the material scope becomes broader in order to develop competency. The highest agreed response on the literacy learning statement item of using learning media is 79.82%. This is because it eases them to interpret the information provided in the text they read.

Of the aspect of lacks on the indicator of aspects that are not mastered in literacy learning, the students are lacking in developing an appropriate reading text, and their response is 69.10%. This is because students do not prefer to read articles and books that support learning. Students agree response on that statement item is 63.39%. They also lack quick methods for understanding reading texts, with 66.42% agreeing that they do not know fast methods to understand a reading text. To see the students' needs in literacy learning, it can be seen in Table 7 below.

Table 7

Learning needs for students

Aspects	Indicators	Sub Indicator	Result	
			Percentage	Category
Goal	Purpose of Literacy Learning	Improving reading skill	76.25	Agree
		Improving advanced literacy skill	87.32	Strongly Agree
		Being able to understand a reading text or information quickly	83.21	Strongly Agree
Procedures	Activities that are required to increase advanced literacy skill	Use varied learning methods	84.46	Strongly Agree
		Increase discussion	82.5	Strongly Agree
		Enhance assignments and work on the question	66.96	Agree
		Increase literacy practice	80.71	Agree
		Enhance lecture activity	67.14	Agree
		Increase field observation	78.21	Agree
Teachers' role	Teachers' role in literacy learning	Become a facilitator in lecture	79.28	Agree
		Become a role model	78.39	Agree
		Become the source of science	82.85	Strongly Agree
Learners' role	Learners' role in literacy learning	Students learn with guidance	78.75	Agree
		Students participate in lectures actively	81.25	Agree
		Students learn independently by using the internet or book	66.96	Agree
		Students prefer to read journal articles more	66.07	Agree
		Students like more storybooks, novels, short stories, etc.	78.21	Agree
Setting	The place that is liked in literacy learning	Some are placed in the classroom, and some are placed outside the classroom	76.96	Agree
		Outside the classroom	75.89	Agree
		In the classroom	73.39	Agree
		Learning use LMS	75.89	Agree

Related to Table 7 above, need analysis in literacy learning for students in higher education based on the aspect of goal with the indicator of purpose of literacy learning reveals that reading skill is improved because the agreed percentage of students' advanced literacy skill by understanding

information in reading quickly is 87.32%. On the other aspects of the procedure with an indicator of the activities that are required to increase advanced literacy skill, the highest sub-indicator is using varied learning methods with an agree response of 84.46%, while the lowest agree response from students on the sub-indicator of enhanced assignments and work on questions is 66.96%.

Concerning the aspect of teachers' role on the indicator of teachers' role in literacy learning, the highest response belongs to being the source of knowledge that agrees with 82.85%, and the lowest percentage refers to the lecturer who becomes a role model with an agreement response of 78.39%. The aspect of learners' role with the indicator of learners' role in literacy learning implies that the highest response is 81.25% agree with the statement item of students participating in lectures actively, and the lowest response is 66.07% agree that students prefer to read journal articles. Regarding setting as another aspect of the indicator of the place that is liked in literacy learning, the highest students' response agreed with 76.96% based on the statement item of literacy learning applied in and outside the classroom to provide different teaching and learning situations. Whereas the lowest response refers to the statement item of teaching and learning are carried out in the classroom with an agree response of 73.39%.

Discussion

It is essential to recognize the needs of students in dealing with the use of technology in literacy learning so that lecturers and universities can enhance students' technology readiness (Kurniawan et al., 2021; Çil, 2022). The utilization of ICT as a source of knowledge encourages the need for digital-based learning. As stated by Reddy et al. (2023b), the dependency on digital technology has increased rapidly, and a lot of consideration needs to be given to every individual in order to see how they apply ICT readiness to interact with others online and the skills they possess to complete assignments requiring digital resources. There is no obstacle based on the student's response to the use of the internet in finding resources. The obstacles only come from the lack of intensity in how they use it. It is seen that they prefer to use social media like Facebook, Instagram, and so on more than to read articles that support learning. According to Suyamto et al. (2020), it can influence students' readiness when becoming educators who should be competent. Because, according to Kurniaman et al. (2020), a competency that is related to behaviour and habits is formed on how students build their behaviour and habits as future educators. Hence, educational institutions are facilitators in providing skills for the use of ICT that are appropriate for future educators through innovative learning.

Target needs for students in literacy learning consist of the necessities (what students should know), wants (what students want), and lacks (what students do not know yet). Based on the student's responses, they need literacy learning to increase their critical thinking, creative, and problem-solving skills through the information from reading texts. As stated by Supriadi et al. (2022), the low students' literacy comes from the conventional teaching and learning styles, which lead to low learning systems based on the time, resources, and lecturers that play important roles. According to Ulfatin et al. (2022), the use of learning media is intended to ease students in literacy learning, which encourages the interests that grow within the students themselves. Self-motivation will appear from the curiosity about assignments assigned by the lecturer, and the students will try to read more frequently and find appropriate learning resources for individual learning.

The students' needs in literacy learning are intended for students to be able to find out the importance of understanding information within the text. It is added by Luyten (2022), that students' literacy awareness is the main factor in enhancing their skills and determining the reading strategies applied in learning activities. According to Anuar et al. (2023), when the students read, they will be involved and have a dialogue with the author to question, analyze, interpret, and evaluate the content and reading structure, and relate the reading text to the student's life experience. Thus, discipline in literacy learning will increase various skills that are essential to encourage critical thinking and involve the reader.

Conclusion

The present study examined how much ICT-based literacy learning is needed in terms of ICT readiness, target needs, and literacy learning needs. In general, the highest student needs are in the literacy learning aspect, while the lowest needs are in the aspect of students' ICT readiness. For the aspect of ICT readiness, the key needs for students are the availability of ICT-based learning infrastructure and the ease of using the infrastructure. The main target need is that students need learning media as a tool for interpreting information they read, so they like reading several articles more based on their lecture needs. In contrast to literacy learning needs, the most essential ones are to use varied methods and increase the assignments that are able to encourage students to read. The lecturer should create learning resources so that learning activities can occur both inside and outside the classroom, fostering effective learning. The research implication is that ICT-based literacy learning is needed by prospective elementary school teachers because the current technological development requires them to adapt to a new paradigm in higher education. Literacy learning in higher education should combine the use of ICT as learning resources and learning media that are able to contribute to the improvement of 21st-century skills.

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Enhancing scientific communication skills in junior high school pupils: A mixed methods investigation of engineering design process tools

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ABSTRACT
Effective scientific communication is crucial for effective science education, as it allows for the sharing of ideas and research findings. This study investigates the impact of the Engineering Design Process (EDP) on pupils' scientific communication skills. A mixed-methods approach was used, combining both quantitative and qualitative data to assess the effectiveness of EDP tools in improving communication skills. The study involved 68 eighth-grade pupils, with 12 selected for in-depth observation to better understand the development of their communication abilities. Pre- and post-tests were conducted to measure improvement in scientific communication skills. Additionally, the Systematic Gravity (SG) method was applied to analyse the qualitative progression of these skills. The results showed that EDP tools positively influenced pupils' communication abilities, with a gradual shift towards more effective scientific communication (SG ++). These findings suggest that EDP tools can be an effective strategy for educators to enhance learners' problem-solving and communication skills. Further research with a larger sample size is recommended to confirm and expand these findings.

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Introduction

Communication skills are fundamental to the effective delivery of scientific concepts in science education (Karasheva et al., 2021). They play a crucial role in helping learners not only understand science but also engage with engineering practices. Engineering practice is implemented in science education for practical applications and fostering interdisciplinary learning (García-Carmona & Toma, 2024). The Next Generation Science Standards (NGSS) underscore the importance

of communication as a key component in the learning process, enabling learners to articulate scientific ideas and present findings clearly and persuasively (NGSS, 2013). However, despite widespread recognition of their importance, research on how learners communicate scientific concepts remains underdeveloped because scientific communication skills manifest differently across learners at various academic levels (Kelp & Hubbard, 2021). For instance, early-stage learners typically focus on structured reporting and evidence-based claims, while graduate and doctoral students demonstrate advanced proficiency through peer-reviewed publications, methodological rigor, and the ability to tailor communications for both specialized and general audiences (Aslan, 2021; Fernández-Costales, 2023), particularly concerning how students connect their ideas to the integration of science and engineering practices (Kulgemeyer, 2018). Existing studies often focus on written communication, such as vocabulary use, data presentation, or formulating conclusions (Fatihah et al., 2022; Noviana et al., 2019). However, these studies often neglect broader aspects of communication, particularly in conveying complex scientific ideas effectively across various formats (Asfar et al., 2021). This gap in research limits our understanding of how learners use evidence to support their scientific claims and connect their learning to real-world scientific issues, especially within the realm of scientific ideas (Kagan et al., 2023; Kulgemeyer & Wittwer, 2023).

An essential component in fostering effective communication skills in science classrooms is the teaching approach. The interaction between everyday language and scientific language requires careful attention to ensure pupils can navigate both (Putra et al., 2024; Wahyuni & Ilham, 2024). A promising approach to fostering these skills is the implementation of the Engineering Design Process (EDP), which offers learners the opportunity to solve problems by exploring multiple potential solutions (Guzey & Ring-Whalen, 2018). This study addresses the gap in research by investigating the potential of EDP as a tool to enhance junior high school pupils in scientific communication skills (Xue et al. 2024). While previous studies have examined how EDP fosters critical and creative thinking (Levrini et al., 2021; Putra et al., 2023), its role in improving communication skills within the science classroom has been less explored (Eppler et al., 2021).

The novelty of this research lies in its focus on the iterative, problem-solving nature of EDP, which offers junior high school pupils opportunities to develop their communication skills while engaging in scientific and engineering practices. By integrating communication tasks within EDP, such as defining problem, collaborating with peers, and using evidence to support arguments (Anwar et al., 2022), this study proposes a learning approach to integrating scientific communication in a specific science topic. This perspective offers a more holistic understanding of how scientific communication can be developed as an integral part of the scientific process, particularly within the context of the Sustainable Development Goals (SDGs), rather than being viewed as a stand-alone skill set (Afkarina et al., 2024).

The study aims to investigate the integration of communication skills within the Engineering Design Process (EDP) framework, which emphasises iterative design as a means of enhancing learners' ability to effectively present their scientific ideas in specific science topic. Additionally, the study seeks to explore how these communication skills develop throughout the process. The research is guided by two central questions:

1) How does the integration of the EDP framework in the classroom influence the proficiency of junior high school pupils' scientific communication skills?

2) What is the developmental trajectory of junior high school pupils' scientific communication skills as they engage with the various stages of the EDP?

Theoretical Framework

Scientific communication is defined as the process of conveying technical or scientific information clearly and effectively, using valid evidence (Gregory et al., 2024; König et al., 2024). It involves not only the delivery of information and ideas but also the application of reasoning to ensure the audience's understanding (Borowiec, 2023). In the fields of science and engineering, scientific

communication serves as a crucial mechanism for disseminating research findings and innovative ideas (NGSS, 2013). Kulgemeyer (2018) argued that the focus of scientific communication should align with specific topics and mastery within the context of science education. Effective scientific communication is not only about understanding scientific concepts but also about how these concepts are communicated to others using evidence-based reasoning (Shivni et al., 2021). Thus, the integration of communication skills with conceptual mastery is essential for fostering a comprehensive understanding of science and enhancing the ability to present research findings effectively.

However, despite the recognised importance of scientific communication, there remains a challenge in the exploration of specific domains that define and measure these skills. While various frameworks for scientific communication exist, many focus primarily on general competencies rather than reflecting proficiency across multiple aspects of developing skill levels in a particular area. For example, previous research has developed scales for measuring scientific communication, including dimensions such as awareness, enjoyment, interest, opinion formation, and understanding (Wu et al., 2019). Additionally, research in the field of scientific communication within education has evaluated on evaluating aspects such as clarity, factual accuracy, relatability, and purposeful targeting (Olesk et al., 2021). However, this framework does not include science concepts specifically in scientific communication. This study further explores the domain of scientific communication with a particular focus on mastering science concepts and integrating them into effective classroom learning approaches.

The domains to be explored in this study include the organisation of specific concepts, the demonstration of scientific phenomena, the use of scientific terminology, and the representation of evidence within the field of science (Afkarina et al., 2024; Yustika et al., 2023). Using these domains, this study will provide students understanding of how scientific communication can be developed and assessed with the specific context especially in science education (Kulgemeyer & Wittwer, 2023).

In the context of learning environments, scientific communication can be integrated with educational approaches that focus on facilitating students' ability to think iteratively and communicate effectively. One such approach that can be applied in the classroom is the Engineering Design Process (EDP). EDP allows learners to collaborate with peers, share ideas, and present their product to others (Lottero-perdue et al., 2015). The EDP is structured in stages that guide learners through a problem-solving process. These stages enable them to define the problem, learn relevant concepts, plan solutions, prototype, test, and evaluate their solutions (Guzey et al., 2019). Each stage of the EDP provides an opportunity to enhance their communication skills.

In the EDP, learners are faced with a real-world problem connected to scientific phenomena, requiring them to work collaboratively to identify the most effective solution (Sulaeman et al., 2021). In the define stage, they are expected to clearly articulate the problem they are addressing, which necessitates the use of evidence to communicate their understanding to the group. Next, during the learn stage, they take on roles within the group to gather information related to the problem, using scientific concepts to inform their research. In the plan stage, they must discuss their proposed solutions and the rationale behind their choices, justifying them with scientific evidence. Furthermore, in the try and test stages, they communicate their findings, including both successes and limitations, through clear, evidence-based communication. Finally, in the decide stage, they collaborate within their group to reach a consensus on their final solution. By integrating scientific communication into each stage of the EDP, they not only understand of scientific concepts but also develop the ability to present their ideas in a scientifically rigorous manner, using relevant concepts and topics (Yenice & Özden, 2022).

The focus topic of this study is on the Sustainable Development Goals (SDGs), which are widely recognized as a pivotal issue for students to comprehend, emphasizing the delicate balance between technology and the environment (Killian et al., 2019). However, teaching SDGs poses a significant challenge in the classroom, particularly within the science domain, as both pupils and teachers may find the concept unfamiliar (Clark et al., 2022). Overcoming this challenge necessitates

innovative approaches to integrate SDGs effectively into the curriculum, fostering a holistic understanding of the intersection between science, technology, and sustainable development.

Methods

This research adopted a mixed-methods approach, combining both quantitative and qualitative methods, aligning with Creswell's recommendations (2012). The chosen methodology was the convergent parallel mixed-methods design, wherein two distinct sets of data were collected simultaneously and subsequently analysed independently using quantitative and qualitative analytical approaches (Dawadi et al., 2021). This approach provides a comprehensive understanding of the research questions, offering insights from both numerical data and qualitative observations (Alshehri, 2024), thereby enriching the overall exploration of the implementation of the EDP tool in the context of microplastics to enhance students' scientific communication skills.

In the quantitative phase, the implementation of the EDP tools was tested, and statistical analyses were employed to measure its impact on students' Scientific communication skills, particularly in science, within the experimental class in comparison to a control group. The study meticulously observed and analysed the distinctions in communication between the two classes, focusing on aspects such as comprehension, engagement, and overall effectiveness of the STEM-microplastic topic integration.

Complementing the quantitative phase, the qualitative aspect encompassed in-depth interviews and content analysis. These methods were chosen to capture rich, contextual insights from participants, offering a deeper understanding of their perceptions and experiences with the microplastic-case curriculum. Together, these mixed methods provide a comprehensive exploration of the multifaceted aspects of the research question.

Context of Study

The inception of the EDP tool, integrated with the contextual case and centred around the critical theme of microplastics, marked the initiation of an 8-week learning process aligned with the SDG number 14 (see table 1). This goal aimed to instil in pupils a commitment to preserving underwater environments. Originally conceived as a tool to enhance communication skills in science, the EDP tool underwent a meticulous validation process. Three experts evaluated its content, ensuring its relevance to the enhancement of students' scientific communication skills.

Furthermore, the structure of EDP tool was meticulously crafted, following the systematic approach of the engineering design process, as outlined by (Sulaeman et al., 2021). The sequence adhered to a thoughtful progression: define, learn, plan, try, test and decide. This deliberate framework was implemented to provide pupils with a comprehensive and structured learning experience.

Table 1

The 8-week learning process in EDP and SDGs program in science class

Week	Duration	Activities	Goals
1	80 min	Introduction of EDP and SDGs Programme	Assess pupils' initial understanding of the EDP stages and the SDGs program through a pre-test.
2	80 Min	Defining Problem	Students define the problem related to SDGs number 14 (Life below water), addressing water pollution caused by microplastics (example in appendix).
3	80 Min	Learning Scientific Concepts of the Ocean Environment	Pupils define the problem related to SDGs number 14 (Life below water), addressing water pollution caused by microplastics.

4	80 Min	Planning a Solution	Pupils plan solutions to address the defined problem by designing equipment based on given criteria.
5	80 Min	Try	Pupils construct prototypes and test their designs to filter microplastics from water.
6	80 Min	Test	Pupils conduct tests, compare results with peers, and evaluate the effectiveness of their designs.
7	80 Min	Decide	Pupils present solutions to the audience, receive feedback, and engage in the redesign process.
8	40 Min	Evaluation of the program	Assess the impact of the EDP and SDGs programme on pupils' understanding and scientific communication skills through a post-test.

Participants

The participants in this research were categorised into two groups based on the employed methods. The first group underwent quantitative research, comprising N = 68 junior high school pupils from one school where the location near a coastal area, with a female-to-male student ratio of 1:1. All participants were in the 8th grade, distributed into two separate classes representing the control and experimental groups. In the experimental group, the STEM approach was applied, utilising EDP tool focused on the preservation of the underwater environment. Conversely, the control group received conventional classroom instruction with a broader emphasis on environmental topics. Conventional learning emphasizes a textbook-centred approach where knowledge is transmitted primarily through teacher-led. Furthermore, qualitative methods were exclusively implemented in the experimental class, involving only 12 specific pupils, based on group that an equal distribution of female and male students. The students' selection was also considering the abilities of medium, low, and high in their learning outcomes. These pupils focused on the discussion to solve the problem based on the EDP tools about microplastic project.

Data Collection

All participants in this research took part in both a pre-test and a post-test, which aimed to assess their scientific communication skills. The pre-test was administered at the beginning, prior to the participants engaging in an experimental and control class, while the post-test was conducted at the end of the programme. The questions in both the pre-test and post-test covered four dimensions of scientific communication skills, as shown in table 2.

Table 2

The dimension of the scientific communication skills measured

Dimension	Criteria
Dim – 1	Organising topics based on the condition of SDGs issues.
Dim – 2	Demonstrating skills in conveying examples of scientific phenomena.
Dim – 3	Using scientific terms in the relevant field of science.
Dim – 4	Presenting representative forms of scientific evidence findings.

In addition, the qualitative aspect of the research focused on how pupils addressed problems presented by their science teacher using a digital book developed for the study. Their discussions were recorded and transcribed to generate data for analysis. The triangulation data collecting, towards the end of the programme, participants in the qualitative research were interviewed to gather their responses regarding the use of the digital book and how they approached problem-solving based on their ideas.

Data Analysis

The quantitative research results underwent analysis using SPSS, encompassing an examination the post-test in the end of the programme. The *t*-test was administered to investigate disparities in scientific communication skills between the experiment and control classes. The progress in scientific communication was evaluated via N-gain based on the differentiation of pre-test and post-test results, classifying improvements as low, medium or high.

For qualitative data, a code book was formulated and organised based on the driven-theory code outlined in the appendix. Transcripts from discussions were categorised by domains. The findings were then elucidated using semantic gravity (Lee & Wan, 2022) to chart the degree of improvement in each domain of pupils' scientific communication skills on a weekly basis. The levels of semantic gravity are described in table 3.

Table 3

Definition of semantic gravity based on the domain

Domain	Level Range	Criteria
Dom – 1	SG++ to SG --	SG++: Clearly and comprehensively articulate the problem's topic and its impact. SG+: Accurately address both the problem's topic and its impact, though the coverage may be incomplete. SG-: Inaccurately and incompletely state both the problem's topic and its impact. SG--: The prepared topics remain overly abstract.
Dom – 2	SG++ to SG --	SG++: Clearly and precisely explain the causes and consequences of the natural phenomenon of global warming. SG+: Specifically explain the causes and consequences of the natural phenomenon of global warming, but with some lack of precision. SG-: Explain the causes and consequences of global warming, but with less specificity and precision. SG--: Unable to articulate the causes and consequences of the natural phenomenon of global warming.
Dom – 3	SG++ to SG --	SG++: Proficiently utilise all four types of scientific language terms (e.g., microplastic, PET, waste treatment, and life ocean)., SG+: Effectively use three types of scientific language terms. SG-: Use only 1-2 types of scientific language terms. SG--: Use everyday language.
Dom – 4	SG++ to SG --	SG++: Incorporate accurate scientific concepts supporting appropriate design choices. SG+: Mention scientific concepts supporting design choices, but some may be inaccurately applied. SG-: There is no mention of scientific concepts supporting the design choices. SG--: Students mention scientific concepts, but they do not effectively support appropriate design choices.

Note. This criteria was modified from lee & Wan (2022)

Findings

The primary research question in this study centres on the implementation of Engineering Design Process (EDP) tools and their influence on the scientific communication skills of students. Prior to the *t*-test the collected data underwent evaluation for normality and homogeneity, with detailed findings presented in Table 4. This table is expected to provide information on the distribution of data and the normal distribution of variances, offering crucial insights into the statistical aspects of the research. Additionally, Table 5 likely contains a description of the homogeneity test, further elucidating the equality of variances across groups.

Table 4

The normality data of variance of post-test based on the scientific communication skills

Domain	Class	Statistic	df (n-1)	Sig.
Dom – 1	Experiment	.952	34	.064
	Control	.957	34	.613
Dom – 2	Experiment	.929	34	.138
	Control	.975	34	.198

Dom – 3	Experiment	.929	34	.124
	Control	.975	34	.056
Dom – 4	Experiment	.935	34	.626
	Control	.954	34	.066

Table 5

The description of the homogeny test between the experiment and control class

Domain	Levene statistic	df (n-1)	Sig.
Dom – 1	5.571	66	.078
Dom – 2	5.043	66	.067
Dom – 3	4.936	66	.083
Dom – 4	5.088	66	.086

The results of the normality and homogeneity tests, indicating significance values above 0.05, suggest that the collected data is both normally distributed and homogenous between the experiment class and the control class. These findings validate the appropriateness of proceeding with further analysis. The impact of implementing Engineering Design Process (EDP) tools could now be systematically investigated using a 2X2 ANOVA facilitating a nuanced comparison between the experiment class and the control class. This statistical approach aims to discern any significant differences in outcomes, providing valuable insights into the effectiveness of the EDP tool implementation in enhancing scientific communication skills among pupils in the experiment class compared to the control class.

Table 6

Independent t sample Test

Domain	Max Score	Class	N	X	Sd	t	P
Dom – 1	100	Experiment	34	78.53	4.48	0.021*	0.05
		Control	34	55.47	3.43		
Dom – 2	100	Experiment	34	76,42	4.60	0.000*	0.05
		Control	34	66.75	7.52		
Dom – 3	100	Experiment	34	75,82	4.32	0.000*	0.05
		Control	34	64.74	4.25		
Dom – 4	100	Experiment	34	78,50	4.45	0.000*	0.05
		Control	34	70.24	7.56		

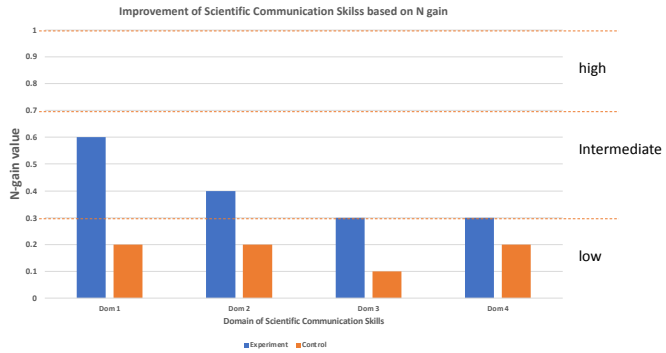
Note. *Significant p value < (α) 0.05

Table 6 elucidates a comparative scrutiny of mean scores derived from post-tests administered to both the experimental and control classes. Utilizing a predetermined significance level (α) of 0.05, the *t*-test analysis, centring on scientific communication skills, unveiled a statistically significant result ($p < 0.05$). This discovery signifies a conspicuous differentiation in scientific communication skills between the control and experimental classes. The assimilation of EDP tool encompassing SDGs-related issues manifested a positive influence on the communication skills of the pupils. Notably, the mean scores reveal that the experimental class outperformed the control class in each domain of scientific communication skills.

The improvement of each domain of scientific communication could be described in figure 1. The figure 1 presents a diagram to evaluate the improvement in scientific communication skills of pupils in this study. The colour-code described to different the achievement based on the three-development stages in low, intermediate, and high. The improvement in the scientific communication skills of pupils is depicted, with the experimental class exhibiting a higher improvement compared to the control class. The values representing the improvement in the experimental class fall within an intermediate level, ranging from 0.3 to 0.7. In contrast, the control class shows improvement at a lower level.

Figure 1

Comparison between the experimental and control class groups regarding the improvement of students' communication skills



In the experimental class, Domain 1 exhibited the most substantial improvement compared to other domains in scientific communication skills. This indicates that the pupils successfully organised microplastic topic within the context of SDGs. Conversely, Domain 4 displayed lower improvement, suggesting that they encountered challenges in providing scientific evidence to substantiate their ideas using various representations such as tables, figures, graphs and textual information.

In the control class, the domain showing the lowest improvement was Domain 3, where pupils faced difficulties in using scientific terminology accurately. Furthermore, it is notable that the improvements between Domain 1, Domain 2, and Domain 4 were equal in magnitude.

The qualitative investigation focused on the active involvement of two groups in collaborative problem-solving discussions within a classroom setting. Figure 2 serves as a visual representation of the Semantic Gravity Wave Model, providing clarification on the communication processes among group members. This model contributes valuable insights into the development and evolution of scientific communication skills domains throughout the diverse activities conducted in the classroom.

Figure 2

The Semantic Gravity Wave Model applied to the scientific communication skills of pupils

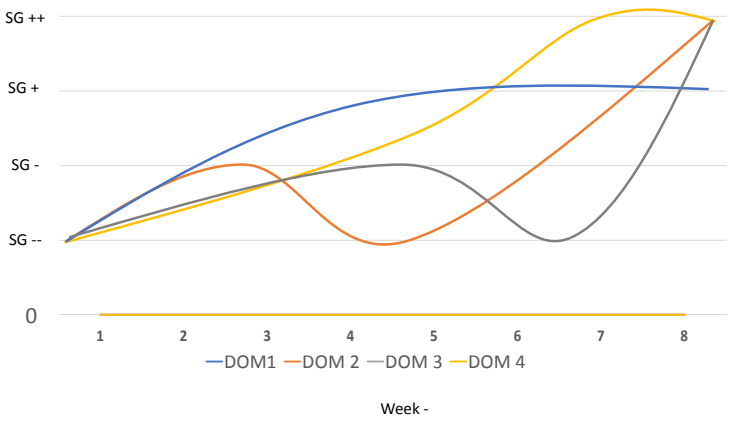


Figure 2 presents the Semantic Gravity Wave Model, offering a visual representation of the evolution of communication processes among pupilss during problem-solving discussions in the experimental classroom. This model serves as a trajectory, capturing the dynamics and intricacies of communication development, providing a framework to understand the progression of scientific

communication skills. Initially, pupils faced challenges in providing detailed descriptions of scientific phenomena, particularly in domains 1, 2, 3, and 4 (SG--), with explanations being abstract. However, over time, especially in domains 1, 2, 3, and 4, they transitioned towards explaining scientific phenomena with appropriate evidence, indicating a positive trend towards SG++. This shift reflects the improvement and refinement of their scientific communication skills throughout the week.

In Domain 1, pupils start at SG-- and progress toward SG++` Initially, they find it challenging to grasp the Sustainable Development Goals (SDGs) issue. They perceive that discussions about global warming rarely take place in their daily lives. For instance, when students engage in conversations in week 1 (students define the problem stage) with friends unfamiliar with global warming, they may express their experiences like this (all the translation had been validated Deviandri et al., 2023).

[A10]: I've discussed global warming with my friend. During that conversation, I encountered some confusing materials related to physics after my studies. Seeking clarification from friends and delving deeper into the subject through additional studies helped me understand better. However, I haven't explored discussions about ocean pollution or other SDGs issues yet (SG --).

In domain 2, pupils encountered the challenge of developing explanations for scientific phenomena in the world, particularly in expressing these explanations scientifically in their daily lives. The EDP tool played a crucial role in fostering connections between real-world phenomena and scientific concepts. The conversation among them serves as an illustration of their struggle in explaining a world phenomenon related to the ocean environment. This interaction highlights the progress achieved in narrowing the gap between everyday observations and a more scientific understanding through the application of the EDP tool. This specific example occurred on the fourth day when they found it challenging to explain the concept of a tsunami.

Vignette 1

[A1]: Can you name three examples of natural phenomena commonly found around beaches and oceans?

[A2]: Well, when people are near the coast or ocean, one common question is, "Is there a tsunami around here?"

[A1]: True, if there's a beach nearby, the possibility of a tsunami exists.

[A2]: What causes tsunamis? Is it because the sea water rises onto the land? (SG --]

It is fascinating to see how pupils are actively incorporating scientific terminology into their discussions while using the EDP tool. The guided nature of the EDP tool seems to play a pivotal role in shaping the students' ability to employ scientific language. Their use of terms like "magnetic field," "iron powder," and "microplastic" reflects not only an understanding of scientific concepts but also an aptitude for effectively communicating their ideas within a scientific context. The dialogue showcases their thoughtful consideration of the sequence in implementing solutions, indicating a structured and scientific approach fostered by the EDP tool. Vignette 3 showed the pupils interaction to use the scientific terminology (Domain – 3)

Vignette 3

[A1]: Our design involves the use of a magnetic field, so we need to collect iron powder, oil and a magnet.

[A2]: Should we start with the magnet first or introduce the iron powder into the water?

[A6]: We experimented with adding oil to gather microplastics. Once the microplastics clump together, we can sprinkle in the iron powder and then use a magnet to create a magnetic field to lift them (SG ++)

It is evident from Domain 4 that pupils are not only adept at communicating their ideas but also versatile in choosing diverse forms of expression and providing supporting evidence. The use of both text and visual representation, such as pictures, to convey the scientific phenomena during the equipment design phase showcases their ability to employ multiple mediums for effective communication. [A4]'s contribution in proposing a solution through text and presentation further emphasizes the students' proficiency in articulating their ideas with clarity and detail. This

multifaceted approach to communication aligns with the complexity of scientific problem-solving and demonstrates their capacity to convey intricate concepts through various means.

[A4]: For the experiment aimed at removing microplastics from the sea, we acquired six tools and materials. Initially, we utilised sticks, plastic, iron powder, cloth, and oil. In the first trial, we employed a stick by directly submerging it into the water. We observed that microplastics adhered to the popsicle sticks. However, we demonstrated that this method was relatively ineffective, as only a small amount of microplastics was removed. Therefore, it proved to be inefficient and time-consuming [SG-].

Discussion

Question Research 1: How does the integration of the EDP framework in the classroom influence the proficiency of junior high school pupils' scientific communication skills?

This research focused on investigating learners' scientific communication using a EDP tool that integrate with the SDGs topic, specifically addressing goal number 14 in SDGs. The evidence indicates that the EDP project tool has a positive impact on pupils' scientific communication skills at this level. In the experimental class, they actively engaged in discussions to solve case-problem given in the tool, facilitating communication of their ideas within their groups. On the other hand, the control class followed conventional approach, where the material is solely delivered by the teacher, and students work on their worksheets in groups.

The EDP tool serves as a systematic guide for learners to methodically define and solve real-world problems (Fan et al., 2020). This structured approach encourages them to gather evidence, explore solutions, and delve into relevant scientific concepts and phenomena. Throughout the EDP process, they articulate and share their problem-solving ideas, aligning the content with the challenges presented in the tool. Importantly, they organize their ideas to connect with the SDGs, ensuring that their problem-solving goals contribute to sustaining human life in a healthy environment. This integration of problem-solving, scientific concepts, and alignment with SDGs creates a comprehensive and meaningful learning experience (AlAli et al., 2023).

The EDP tool is like a guide that helps learners solve real-world problems. In this case, the challenge is about dealing with pollution caused by small bits of plastic in water. Pupils use the tool to talk about how using too much plastic in their daily lives can harm the environment, especially water. They collect evidence, like facts and observations, to explain the situation scientifically. The evidence they find helps them connect scientific ideas, like why plastic is hard to break down. This process not only improves their problem-solving skills but also helps them better understand the science behind environmental issues related to plastic pollution. Notably, the experimental class exhibits higher pupil hands-on activity using EDP than the control class, emphasising the effectiveness of the EDP tool in guiding pupils to explore and communicate their ideas systematically. This aligns with previous research highlighting the importance of fostering pupil activity in the classroom to encourage idea development and structured communication (Sarıoğlu et al., 2023).

In the experimental class, pupils showed a heightened awareness of using scientific terminology, especially when explaining phenomena related to the environment. During discussions, they fluently incorporated scientific terms, reflecting a proficiency likely developed through guided instructional approaches. This aligns with research by Sharon & Baram-Tsabari (2020), highlighting the role of teaching methodologies in facilitating adept usage of scientific language. The EDP tool, through its integration of environmental issues and relevant materials, prompts learners to articulate their design work with a language influenced by their learning experiences within the tool's scientific context. This dynamic interaction showcases how instructional tools can shape learners' linguistic expressions in scientific discourse.

Scientific communication skills showed notable improvement in the experimental class compared to the control class, particularly in domain-1. Initially, pupils in the experimental class were unfamiliar with SDGs terms and struggled to connect them with scientific concepts. For instance,

during an early interview, one pupil [A10] expressed unfamiliarity with SDGs and faced challenges in linking it to scientific ideas. However, by the end of the sessions and following the steps of the EDP tool, they were adeptly employing SDGs terminology, especially in the context of preserving the underwater environment. Consequently, the gain in domain-1 was the most significant. Pupils in the experimental class demonstrated enhanced fluency in discussing topics related to the EDP project.

Domains 3 and 4 displayed lower N-gain scores, indicating challenges in mastery of scientific knowledge and its application to real-world concepts. In these domains, pupils were tasked with explaining their design work to solve problems, which proved to be more challenging. They tended to focus more on describing how their designs addressed the problem rather than delving into the underlying scientific knowledge embedded in their designs. This aligns with previous research highlighting that transitioning from scientific problems to design solutions can lead to multiple possible solutions, but it also poses a risk if not balanced with a well-organised instructional approach (Bozkurt Altan & Tan, 2021). Without proper guidance, pupils may prioritise the design aspect over mastering the scientific concepts (Putra et al., 2023).

Research Question 2: What is the developmental trajectory of junior high school pupils' scientific communication skills as they engage with the various stages of the EDP?

The development of pupils' communication skills follows a gradual improvement in their ability to articulate ideas. This progression is characterised by a shift from abstract concepts to more tangible, visually representable comprehension over time. Through the EDP tool, they engage in a step-by-step process, beginning with defining solutions and progressing through the design stages until they arrive at a final resolution for the given problem. This engineering design approach allows them to navigate from simpler to more complex thinking, fostering future-oriented thought processes (Levrini et al., 2021). Moreover, the EDP tool enables learners to communicate their findings using multiple modes, facilitating clear understanding for their peers. The incorporation of evidence in their communication is a crucial factor that influences the audience's acceptance of their ideas (Johnson et al., 2020) .

The observations of Domains 3 and 4 reveal underperformances in learners' mastery of scientific communication skills could this also relate to the mother tongue? A key challenge in scientific communication lies in their proficiency within these domains. In Domain 3, they struggle not only with understanding the appropriate use of scientific terminology but also with applying these terms in specific contexts. For instance, many are unfamiliar with the term "microplastic" and mistakenly believe it refers to a type of plastic that can be manually removed from water to solve pollution problems. This misconception highlights the need to shift their thinking towards a more scientific understanding of terms, which involves integration scientific concepts with real-world applications (Canfield et al., 2020). Furthermore, exposing learners to specific scientific topics during their learning stages enables them to better understand and familiarize themselves with the terminology and issues at hand. The EDP framework tool in this study helps clarify the steps they should follow, providing a structured approach to advance their understanding and application of scientific concepts (Rees Lewis et al., 2023).

In Domain 4, pupils face difficulties in presenting their results using multiple forms of representation. For instance, while they may effectively visualise steps for removing microplastics from water through images, they struggle to integrate text and visuals coherently. This challenge underscores the need to combine textual and visual elements to convey their ideas effectively. Previous research has also highlighted that using multiple representations to communicate scientific concepts is a significant challenge in scientific communication (Holford et al., 2023). In this domain, learners are tasked with collecting evidence and visualising their ideas using appropriate imagery to minimise misconceptions. The EDP framework supports this by allowing learners to present their results through various formats, helping ensure that the audience understands the presenter's intent.

Conclusion and Implications

The integration of the EDP tool in the science classroom has demonstrated a positive and significant impact on enhancing junior high school pupils' scientific communication skills. The improvement in scientific knowledge was found to be moderate in the experimental class and lower in the control class. The study specifically focused on evaluating science concepts rather than general communication skills. The trajectory of scientific communication in the experimental class showed a gradual shift from [SG --] to [SG ++] over the course of meetings. This progression indicates that pupils engaging with the EDP tool in the classroom were able to develop their scientific communication skills, transitioning from abstract to more representable comprehension understanding.

This study underscores the pivotal role of a well-structured instructional approach in elevating school learners' scientific communication skills. Progressing from simple to complex concepts, educators guide learners in seamlessly integrating evidence with scientific knowledge, fostering a holistic understanding. Effective communication, underpinned by evidence-backed reasoning, becomes a cornerstone of problem-solving. Moreover, this research emphasises the profound impact of connecting environmental teachings with the SDGs. By intertwining scientific concepts with future-oriented SDGs, educators contribute to shaping environmentally conscious individuals equipped to tackle global challenges like climate change. The findings affirm that cultivating robust scientific communication skills is not merely about solving problems but empowering learners to articulate, justify, and contribute to a sustainable future.

This study acknowledges certain limitations in its scope, particularly the exclusive focus on SDGs Goal 14. This choice was influenced by the geographical context of the pupils, primarily residing near coastal areas. Additionally, the implementation of the EDP tool was confined to a single junior high school, necessitating broader application across diverse schools and educational levels for more comprehensive insights. Future research endeavours could replicate this study across varied populations to substantiate the efficacy of the EDP tool in enhancing scientific communication skills. Expanding the study's reach can contribute to a more nuanced understanding of the tool's effectiveness in different contexts.

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Two decades of STEM education studies in higher education: A bibliometric analysis

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ABSTRACT
STEM education is gaining more attention due to its significant contribution to educational development. The authors employed bibliometric analysis to determine how STEM education research was developing. The study aims to present an up-to-date overview of the STEM education research landscape in the context of higher education from 2002 to 2022. After applying inclusion and exclusion criteria, a total of 1,282 papers were downloaded from the Scopus database for further analysis. Data analysis included publications and citations, the most frequently cited documents, sources, institutions, the most influential countries, the most prolific authors, co-authorship for authors and countries, and co-occurrence of author keywords using VOSviewer software. There has been an increasing trend in the number of publications from 2002 to 2022, peaking in 2020 with 180 articles. The work by Henderson et al. (2011) is the most frequently cited document, with 554 citations to date. In terms of the most productive source, the ASEE Annual Conference and Exposition leads the field. The United States and Purdue University emerged as the most productive country and institution, respectively. Carmen C. is identified as the most active author, while Wang X. is the most influential. Frequently occurring keywords include "STEM education", "STEM" and "Higher education." The findings highlight the practical need for higher education institutions to prioritise active learning strategies, diversity, and international collaboration to advance STEM education globally.

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Introduction

STEM first emerged in the 1940s as the primary educational focus of the National Science Foundation (NSF) in the United States. The NSF provides encouragement to continue and develop educational programs in every field of science and technology (Ortiz-Revilla, 2020). Despite the fact that STEM was first developed in the year 1940, it wasn't until the year 2001 that Judith Ramaley, the assistant director of the NSF's Education and Human Resources Directorate, popularised the term STEM as an inquiry-based education that focused on solving problems in the real world. As a result of national evaluations conducted in the United States, it was discovered that STEM education in that country lagged behind that of other countries. Then, the United States realized that STEM education was needed to increase the country's competitiveness in the world and to become a leading country in

this field (Daugherty, 2013; Gil-Doménech, 2020; Jamali, 2022). According to Martín-Páez (2019), individuals will understand the significance of STEM when they observe for themselves how quickly social, environmental, economic, and technical aspects are evolving to fulfill societal requirements. Currently, STEM education encompasses five fields (STEAM) rather than simply four (STEM) (Aguilera, 2021). The existence of art serves as evidence that pupils' inventiveness must be taken into account. The term "creativity" here refers to novelty and originality so that the end result is something brand-new, distinctive, and in line with standards. The constructivist method, which stresses that knowledge is constructed by individuals to account for variances in how people see the world, is used as a model for STEAM learning (Ozkan, 2020). Future occupations will demand improved job skills (such as flexibility, collaboration, and communication), which are projected to occur as a result of STEAM learning (Perignat, 2019).

The implementation of STEM gained a lot of attention in the last decade (Irwanto et al., 2022; Irwanto & Ananda, 2024; Marín-Marín et al., 2021). The study of STEM/STEAM research is important (Prabowo et al., 2024) because human life is continuously evolving and accompanied by technological advancements (Irwanto et al., 2023; Irwanto & Rini, 2024). Conducting scientific experiments alone is insufficient for developing 21st-century skills. It is necessary to apply scientific concepts in order to design and create new products/technologies that can address societal issues. The implementation of STEM plays a crucial role in enhancing 21st-century skills (Wahono et al., 2021) to overcome global challenges and promote national economic progress.

Every year, papers on STEM topics are consistently released and made accessible. A bibliometric analysis will be used in this study to examine the most recent developments in STEM/STEAM research. A thorough overview of the literature is provided by bibliometric analysis, which also gives data on research trends based on citation, co-citation, co-authorship, and co-occurrence (Donthu, 2021). The most frequently cited works that will ultimately be chosen as the most significant works in the topic of research under study can be identified using citation analysis (Irwanto et al., 2023). Co-citation analysis will reveal information about the connections between works and whether there are any thematic overlaps. An analysis of co-authorship will look at relationships or partnerships between authors or between countries (Prahani et al., 2024). Co-occurrence analysis was used to identify the authors' shared use of terms (Donthu, 2021; Van Eck, 2021). VOSviewer, a piece of software that allows for the visualisation of bibliometric networks as graphical maps, is the program utilized for this investigation (Zhang, 2022).

Bibliometric analysis has already been reported on STEM applications in the literature. In a research done by Gil-Doménech (2020), an overview of STEM education was given using the Web of Science database's quantity of publications and citations, citation thresholds, and h-index. The data revealed a rise in the number of papers on the subject, but no increase in the number of citations. Le Thi's (2021) paper also outlines a bibliometric examination of STEM education in secondary schools using the Scopus database. The most prominent authors, according to the quantitative study, are from the United States; yet, collaborative links between the United States and other nations appear to be poor. The growth of STEM education and high-quality education research at the school level from 1993 to 2020 was examined by Jamali in 2022. Trends in publishing and citation, commonly used keywords, and well-known authors and journals were all studied in the study. The findings showed that early childhood education, computing education, and environmental education are the main foci of STEM research, with the United States being the most prolific country for STEM publications.

Objectives and Research Questions

In this study, we examine publication and citation trends, documents that are frequently cited, sources, institutions, the most influential countries, the most productive authors, co-authorship for authors and countries, and the co-occurrence of authors. The results of this bibliometric study will provide a summary of the current state of scientific production in the STEM fields of higher education. In addition, based on data collected from the Scopus database, this study will be important in

determining which research has been the most fruitful and impactful in the history of STEM education. Other researchers can use a bibliometric study to select the hottest topics for their field of study. In addition, readers can learn about the top universities, top journals, top authors in their field, and even where to get the papers most relevant to their research by reading this research.

The study is primarily centered around higher education institutions, as there has been a significant surge in the demand for STEM/STEAM disciplines, evident through the proliferation of seminars, webinars, workshops, and training sessions. These endeavors are conducted in partnership with both local and international universities or affiliated organizations, and are open to participation from students and educational staff. This research will serve as a valuable addition to prior bibliometric studies conducted by Aldás-Onofre & Cordero (2023), Marín-Marín et al. (2021), who utilized the Web of Science database as a solitary data source, as well as the investigation carried out by Thu et al. (2021), who relied on the Scopus database for their research in Middle Schools. This bibliometric study can be used as an early depiction of growing trends in STEM research. The questions for this research are:

RQ 1: What is the distribution pattern of publications and citations every year?

RQ 2: Which documents are the most cited, the most relevant sources, and the most productive institutions and countries?

RQ 3: Who is the most prolific author?

RQ 4: What is the status of the co-authorship for authors and countries, and the distribution of author keywords?

Methodology

Design

This research employed bibliometric analytical methods that are used to uncover developing trends in specific fields of study (Donthu, 2021). This method was performed to analyse large amounts of scientific data, such as the number of publications and citations, the most referenced documents, sources, institutions, the most influential nations, the most prolific authors, co-authorship for authors and countries, and co-occurrence of author keywords in this study. Because of its ability to uncover emerging trends in publication performance, we utilized bibliometric analysis to explore the growth of publications in STEM education in higher education.

The publications examined were taken from the Scopus database and covered the years 2002 to 2022. Document types included articles, book chapters, reviews, books, conferences, notes, errata, editorials, and letters. The following inclusion and exclusion standards were used when searching for documents (see Table 1).

Table 1

Inclusion and exclusion requirements

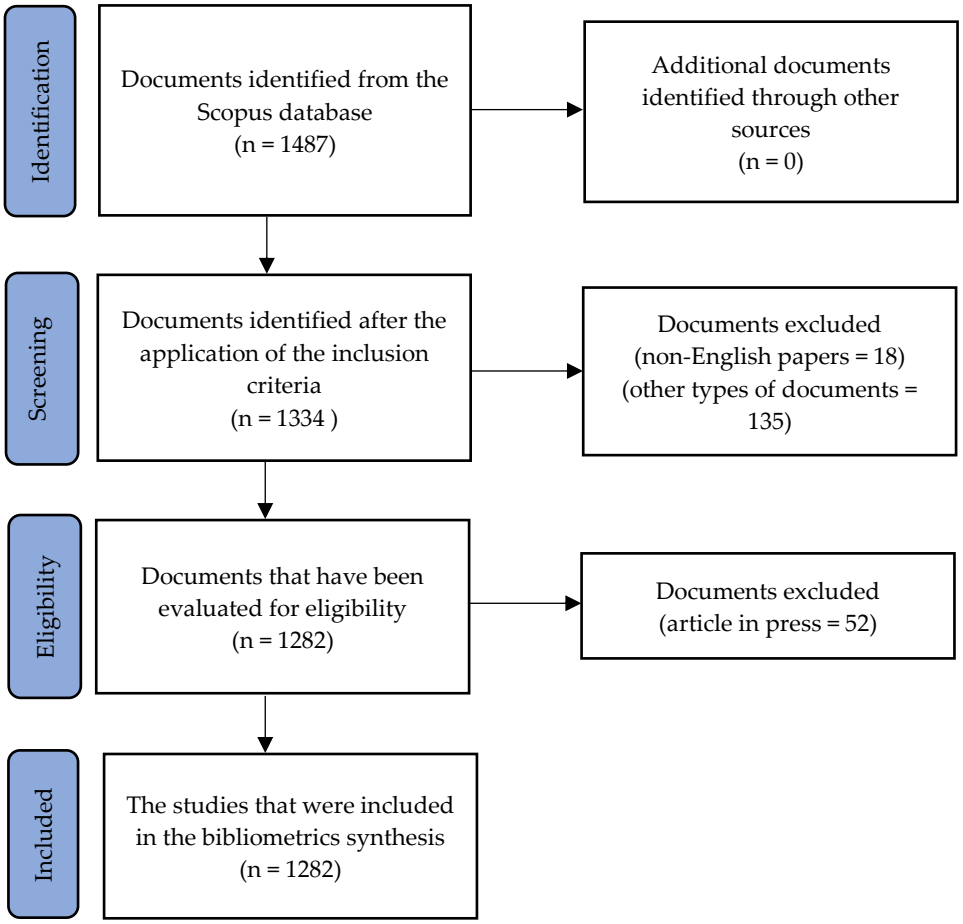
Inclusion Criteria
1. Documents published between January 2002 and September 2022
2. Documents related to STEM or STEAM education in higher education
3. Documents are written in English
4. Documents in the form of articles and conference papers
Exclusion Criteria
1. Documents published before January 2002 or after September 2022
2. Documents not related to STEM or STEAM education in higher education (e.g., secondary education, primary education, K-12, etc.)
3. Documents are not written in English
4. Documents other than articles and conference papers (e.g., books, book chapters, etc.)

Data Collection

TITLE-ABS-KEY ("STEAM education" OR "STEM education" AND "university" OR "college") were the search terms used, and 1487 documents were found as a result. The keyword search of STEM education is based on previous research (e.g., Batdi, 2019; Marín-Marín, 2021), so the researchers focused on the field of STEM/STEAM education. Because Scopus is the largest indexer in the world and one of the largest databases for abstracts and citations, it was selected (Osman, 2021). In addition to 77.8 million records (books and book series, trade publications, journals, and conference proceedings), the database also contains more than 25,100 journal titles from 5000 publishers, more than 70,000 affiliation profiles, and more than 16 million author profiles (Elsevier, 2021). Additionally, this database was chosen because Web of Science (WoS) can only export 500 records at a time, while Scopus can export up to 2000 records at once. Scopus data may be exported as CSV, BibTeX, RIS, Plain Text, and other file types (Agbo, 2021). In this study, the data were exported in CSV format, and the VOSviewer program (https://www.vosviewer.com/) was used to evaluate the data once it had been collected.

Figure 1

PRISMA flow: The research protocol



In the present study, the procedure for searching the study's data using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) is shown in Figure 1 (Moher, 2009). The graph illustrates a comprehensive overview of how the researchers gathered data, using the PRISMA flowchart as a guide throughout the process. During identification, researchers searched Scopus for publications by modifying search phrases in the title, abstract, and keywords. Keywords must appear

in the title, the abstract, and the keywords of the selected publications. At this point, 1487 papers have been received. This is followed by the screening stage, in which the researchers select publications that meet the previously established inclusion and exclusion criteria. A total of 18 papers were not written in English, and 135 documents were in the form of a book chapter, review, book, note, erratum, short survey, letter, or editorial. There were 1334 qualified papers at that time. Published papers were selected by the investigators in the final step of the qualifying phase, at which time up to 52 articles were still under review. A total of 1282 eligible papers were collected in the last stage, which was the inclusion stage. This was done with Microsoft Excel.

Data Analysis

VOSviewer and Microsoft Excel were used to analyse and visualise the data collected in the study. VOSviewer is used for the analysis, construction, and visualization of bibliometric nets, while Microsoft Excel is used for the visualization of tables and charts regarding publication language, annual number of publications, most cited papers, and most productive sources, institutions, countries, and authors. The researchers first extracted data from the Scopus database in CSV file format to perform the analysis using the software. They then performed statistical analysis using frequencies and percentages, as well as citation, co-authorship, and co-occurrence analyses. Descriptive statistics were utilized to examine yearly publication growth, most referenced papers, sources with the largest publication volume, productive institutions, productive nations, and prolific authors. Citation analysis was used to determine the frequency with which a paper is cited by other researchers. Author cooperation was examined through co-authorship. Co-occurrence is used to examine the most important keywords and illustrate their relationships with other phrases related to STEM education. Co-authorship analysis requires at least two documents per author, while co-occurrence analysis requires at least five keyword occurrences. It should be noted that the full counting method was employed in this bibliometric analysis, meaning that a co-authored publication was counted with a weight of one for each co-author. To discover emerging topics in the STEM education field, the threshold "minimum number of occurrences of a keyword" was set to 5, and 88 items met the threshold. To determine the cooperation relationship among scholars, the minimum number of documents of an author was set at 2, and 337 authors met the threshold. To reveal the cooperation link among countries, the minimum number of documents of a country was set at 2, and 62 met the threshold.

The results of the study were presented in a network visualisation map, where nodes represent the total number of publications, lines between nodes represent the strength of relationships, and colors represent clusters. The size of nodes increases with the number of documents published, and the strength of the link between the two things is shown by a line connecting the nodes (Kushairi, 2021; Van Eck, 2021; Zhang, 2022).

Results

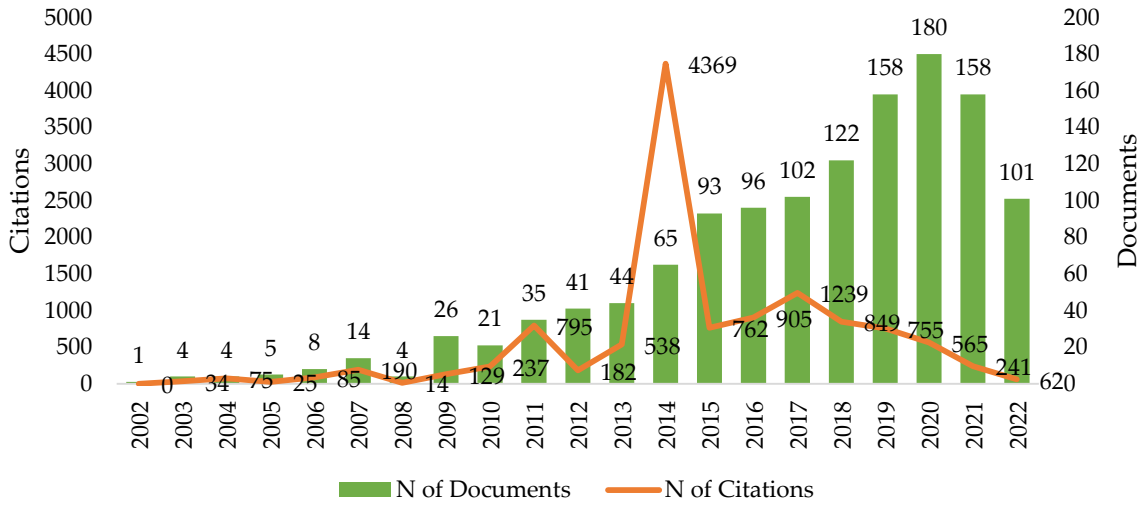
Publication and Citation of Trends

After applying the inclusion and exclusion criteria, 1282 documents from 2002 through 2022 were included in the data analysis. Figure 2 displays the distribution of document publishing by year. The first STEM publications in colleges were published in 2002, with only one document. The overall number of STEM publications for the first ten years (2002–2011) was 122, with an average of 12 articles per year. However, this rise was not very substantial. This publication considerably expanded in the years that followed (2012–2021), reaching 1059 documents with an average yearly release of 105 documents. In 2022, there were 101 publications between January 1 and September 17, 2022. The number of these publications grew steadily between 2010 and 2020. The year with the most STEM

publications was 2020, with 180 papers, 12051 citations, or 9 citations per paper made in total between 2002 and 2022.

Figure 2

Distribution of STEM publications 2002–2022



Frequently Cited Documents

The top 10 most frequently cited documents related to STEM in higher education are presented in Table 2 along with the number of citations (C) and the number of citations per year (C/Y). The authors of the most frequently mentioned works were Henderson et al. (2011) with 554 citations and an average of 50.36 each year. C/Y is a metric used to describe the impact of published articles in terms of the number of citations each year (Kaffash, 2021).

Table 2

Most frequently cited documents

Author(s)	Title	Source	C	C/Y
Henderson et al. (2011)	Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature	Journal of Research in Science Teaching	554	50.36
Dennehy & Dasgupta (2017)	Female peer mentors early in college increase women's positive academic experiences and retention in engineering	Proceedings of the National Academy of Sciences	183	36.60
Palmer et al. (2011)	A qualitative ınvestigation of factors promoting the retention and persistence of students of color in STEM	Journal of Negro Education	113	10.27
Matarić et al. (2007)	Materials for enabling hands-on robotics and STEM education	AAAI Spring Symposium – Technical Report	94	6.26

Shadle et al. (2017)	Faculty drivers and barriers: laying the groundwork for undergraduate STEM education reform in academic departments	International Journal of STEM Education	81	16.20
Madden et al. (2012)	Rethinking STEM education: an ınterdisciplinary STEAM curriculum	Procedia Computer Science	79	8.70
Rozek et al. (2015)	Gender differences in the effects of a utility-value intervention to help parents motivate adolescents in mathematics and science	Journal of Educational Psychology	78	11.14
Ertl et al. (2017)	The impact of gender stereotypes on the self-concept of female students in STEM subjects with an under-representation of females	Frontiers in Psychology	73	14.60
Beier et al. (2018)	The effect of authentic project-based learning on attitudes and career aspirations in STEM	Journal of Research in Science Teaching	70	23.30
Manduca et al. (2017)	Improving undergraduate STEM education: The efficacy of discipline-based professional development	Science Advances	68	13.60

Most Productive Sources

The most effective sources to publish STEM-related articles are listed in Table 3. It turns out that they originate from 524 distinct sources out of the 1282 papers that have been studied. Based on ranking the top 10 most prolific sources, it was discovered that the ten sources together produced 450 papers and were cited 2195 times. The *ASEE Annual Conference and Exposition*, which produces 226 documents with a total of 495 citations, is the source that publishes the most STEM-related documents. With 73 documents and a total of 183 citations, the *Proceedings-Frontiers in Education Conference* is ranked second. *The International Journal of STEM Education* came in third with 31 papers and 361 citations.

Table 3

Top 10 most productive sources

Source	A	C	C/A
ASEE Annual Conference and Exposition	226	495	2.19
Proceedings – Frontiers in Education Conference	73	183	2.50
International Journal of STEM Education	31	361	11.64
Proceedings of the International Astronautical Congress IAC	30	18	0.60
Journal of Physics: Conference Series	26	34	1.30
IEEE Global Engineering Education Conference Educon	15	70	4.66
Education Sciences	14	26	1.85
CBE Life Sciences Education	14	141	10.07
Lecture Notes in Computer Science	11	27	2.45
Journal of Research in Science Teaching	10	840	84.00

Most Productive Institutions

With 19 published papers and a total of 35 citations, Purdue University in the United States is the most prolific organization for STEM education research (see Table 4). With 10 published papers and 19 citations, Arizona State University is in second place. Khon Kaen University, located in Thailand, is in third place with 7 published documents and 13 citations. Overall, institutions from the United States dominate the list, with nine of them originating from this country.

Table 4

The most productive ınstitutions

Institution	Country	A	C
Purdue University	United States	19	35
Arizona State University	United States	10	19
Khon Kaen University	Thailand	7	13
University of Alabama in Huntsville	United States	5	8
Texas A&M University	United States	4	2
Utah State University	United States	4	28
Northwestern University	United States	4	27
College of Marin	United States	4	15
Skyline College	United States	4	15
New Jersey Institute of Technology	United States	4	9

The Most Productive Countries

A total of 123 different nations published the 1282 documents that have been examined. The top 10 nations for publishing STEM-related publications are listed in Table 5. The United States is in first place with a total of 834 publications published and 9853 total citations. The majority of the papers examined (65.05%) came from the United States. Australia (41) is in second place, followed by Thailand (33) in the ranking third place. 85,61% of all papers come from these ten nations. The United Kingdom has the most documents that are mentioned per document (C/A = 17.82), followed by Australia (17.58) and the United States (11.81).

Table 5

The 10 most productive countries

Country	A	%	C	C/A
United States	834	65.05%	9853	11.81
Australia	41	3.19%	721	17.58
Thailand	33	2.57%	135	4.09
China	32	2.49%	61	1.90
Canada	31	2.41%	141	4.54
Spain	29	2.26%	106	3.65
United Kingdom	28	2.18%	499	17.82
Germany	25	1.95%	157	6.28
Russian Federation	25	1.95%	115	4.60
Turkey	20	1.56%	199	9.95

Most Productive Author

Table 6 lists the top 10 authors who discussed STEM in higher education the most frequently between 2002 and 2022. With 13 publications and 23 citations, Carmen, from The University of Alabama in Huntsville, is the most active author. Enriquez (from Canada College, US) and Fontecchio (from Drexel University, US), who both have six documents, are in second and third place, respectively. However, Wang (with 164 citations) is the most influential author, with an average of 32.8 citations per document. The most active authors are primarily from the United States, according to this list of the top ten authors.

Table 6

The most productive authors

Author	Affiliation	Country	A	C	C/A
Carmen C.	The University of Alabama in Huntsville	United States	13	23	1.76
Enriquez A.G.	Canada College	United States	6	14	2.33
Fontecchio A.	Drexel University	United States	6	14	2.33
Yuenyong C.	Khon Kaen University	Thailand	6	13	2.16
Gharib M.	Texas A&M University at Qatar	Qatar	6	6	1.00
Wang X.	University of Wisconsin-Madison	United States	5	164	32.80
Micari M.	Northwestern University	United States	5	75	15.00
Davis K.C.	University of Cincinnati	United States	5	11	2.20
Creel B.	Texas A&M University at Qatar	Qatar	5	5	1.00
Bagiati A.	Massachusetts Institute of Technology	United States	4	55	13.75

Co-authorship for Authors and Countries

The study of links between authors is done through co-authorship analysis. The co-authorship network illustrates the relationships between authors and nations, based on the number of academic publications they have collaboratively produced. In this study, the minimum for an author was two documents, and the minimum for an author's citations was two. 337 out of the 4123 authors satisfied the criteria. However, only 15 were well related and created the 4 clusters shown in Figure 3.

It is crucial to remember that each node corresponds to one author. The node size indicates how many documents the author has published. The larger the size, the more documents that are published (Tsai, 2020). Clusters are defined as groups: the first cluster is red (5 authors), the second is green (4 authors), the third is blue (4 authors), and the fourth is yellow (2 authors). Posey with 2 documents and total link strength (TLS) 8, Dennin with 2 documents and TLS 4, Finkelstein, Smith, and Miller each provided 2 documents, with a total link strength of 5 comes from the first cluster. In the second cluster, there are Ebert-May, Urban-Lurain, and Stowe, with the number of each document being 2 and the total link strength 5, as well as Ralph has 2 documents and TLS 1. Henderson (documents 3; TLS 4), Cole (2; 3), Stains (2; 2), and Apkarian (2; 4) are from the third cluster. Matz (4; 7) and Jardeleza (2; 1) are from the last cluster, which is the fourth cluster.

A co-authorship analysis for countries was also used to research the connection between authors and countries. A country must have at least two papers and two citations. These are the minimal requirements. 62 out of the 123 countries matched the criteria. However, only 57 were interconnected and formed 13 clusters, as shown in Figure 4.

Nine countries are in the first cluster (red), with Portugal's most prominent node (number of documents 17, total link strength 14). Eight countries comprise the second cluster (green), with

Malaysia having the most prominent nodes (documents 18; TLS 5). Seven countries are represented in the third cluster (blue), with Australia having the most excellent nodes (41; 8). Six countries are represented in the fourth cluster (yellow), with Thailand having the most excellent nodes (33; 3). Five countries are represented in the fifth cluster (purple), with Canada having the most excellent nodes (31; 18). Five countries are represented in the sixth cluster (gray), with Spain (29; 14) and the United Kingdom (28; 17) having the most excellent nodes. There are five countries in the seventh cluster (orange), with the United States having the most excellent nodes (834; 86). Four countries are in the eighth cluster (brown), with South Africa having the most excellent nodes (12; 5). Four countries are in the ninth cluster (pink), with China having the most excellent nodes (32; 15). One country in the tenth cluster is Croatia (2; 1), one country in the eleventh cluster is Ethiopia (2; 1), one country in the twelfth cluster is Northwestern (4; 3), and one country in the thirteenth cluster is Uruguay (2; 2). Figure 4 shows that the most prominent nodes are located in the United States, Canada, China, and Australia. This demonstrates that they are the country that collaborates with other countries the most.

Figure 3

Visualisation map of co-authorship for authors

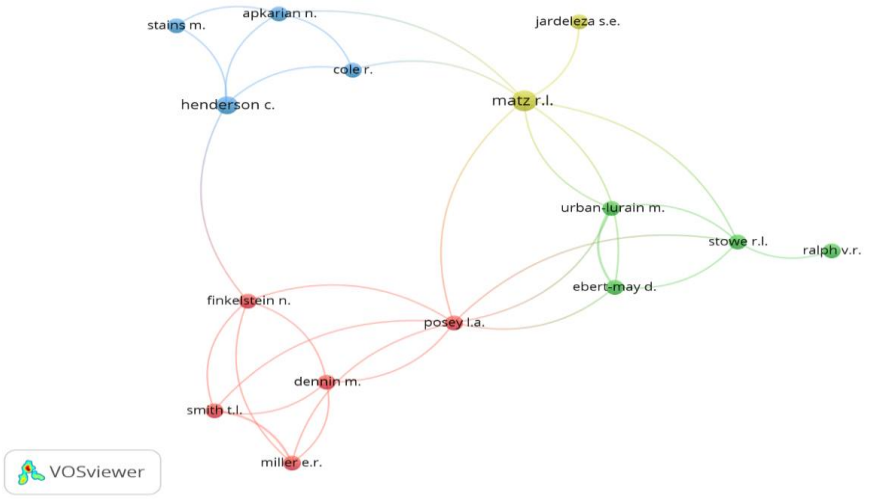
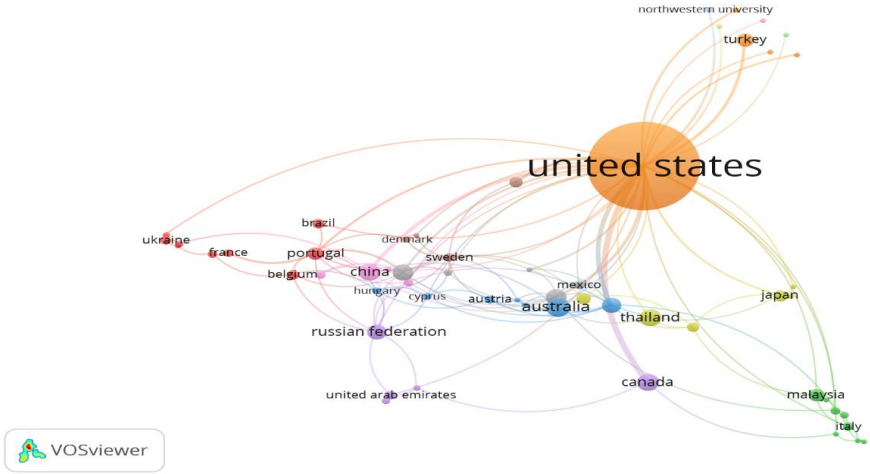


Figure 4

Co-authorship visualization map by country

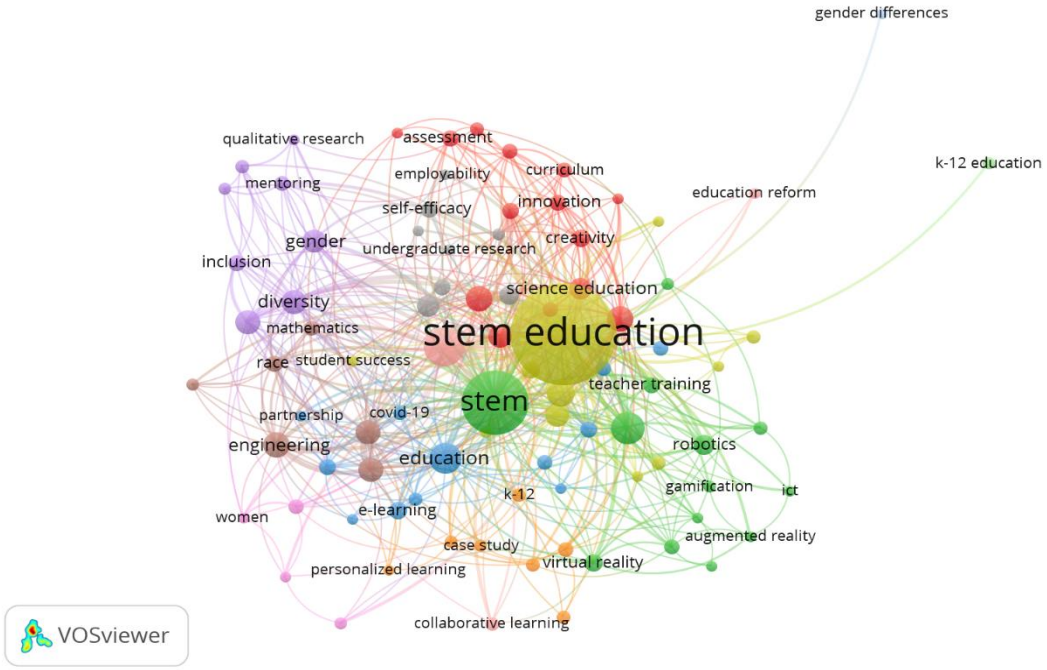


Co-occurrence of Author Keywords

The most frequently shared keywords used by authors while producing STEM articles are identified using the co-occurrence of author keywords. When two terms appear in an article simultaneously, this is known as co-occurrence (Kushairi, 2021). This explains why the two terms are related to one another. Out of the 2536 keywords present, 88 fall under the required minimum of 5 occurrences. In Figure 5, we can view the visualization map.

Figure 5

Visualisation map of author keyword co-occurrence



It is assumed that keywords with a tight link exist when they appear in the same color (Kushairi, 2021). Table 7 lists the top 10 keywords, some of which will set the direction of future studies.

Table 7

Top 10 most used keywords

Author Keywords	Occurrences	TLS
STEM education	382	352
STEM	152	192
Higher education	57	99
Engineering education	39	54
Education	37	67
Active learning	25	29
Diversity	23	51
Equity	22	41
Project-based learning	21	38
Gender	20	39

Discussion

Using bibliometric analysis, 1282 scholarly papers published between 2002 and 2022 were examined. The bibliometric analysis's findings reveal information on STEM trends in education. This knowledge may be utilised as literature to develop STEM instruction in a school or university setting. This document is continuously published annually. However, in the first ten years, the number of documents issued annually was less than 40. In the first ten years, 122 documents were published. Then, during the past ten years, STEM publications increased by ninefold (the total number of documents issued was 1059). This annual publication is proof that STEM research will continue to develop in the future. 2020 turned out to be a fruitful year since there were more publications than in previous years (180), while the year with the most citations was 2014, with 4369 citations and 67,21 citations per document (C/A). According to the graph of the distribution of publications per year in Figure 2, a comparison of the number of publications and the number of citations does not show a positive relationship, implying that there is no correlation between the increases in the number of documents and the increases in the number of citations. The year the document was issued is one element that affects the high number of citations. Older documents might garner many more citations than recently released publications.

The most often referenced article (554 citations) with the highest yearly citation total of 50.36 was Henderson et al.'s (2011) work. This article, published in the *Journal of Research in Science Teaching*, evaluated 191 publications published between 1995 and 2008. The objective is to pinpoint global shifts in STEM education to raise the standard of instruction. Reflective teachers, curriculum and pedagogy, shared vision, and policy are some of the transformation tactics covered in this article. Dennehy and Dasgupta (2017) investigated the role of female peer mentors in enhancing women's experience and retention in engineering. According to the research that was conducted, peer mentors were discovered to boost women's motivation, confidence, and retention in the engineering field. Additionally, more and more female students are continuing to plan to work in engineering. From these articles, it can be inferred that the STEM scientific areas are crucial to contemporary advancements. As a result, many activities are created to ensure students have a solid understanding of these four scientific disciplines. Therefore, STEM activities should be created to encourage student engagement and allow them to use their creativity to solve challenges across various disciplines (Jamali, 2022).

The *ASEE Annual Conference and Exposition* is the most fruitful venue for publishing STEM, with 226 documents published, 495 total citations, and an average citation rate of 2,19 per document. *The Journal of Research in Science Teaching* only published 10 articles, yet the average document received 84 citations, and the overall number of citations was relatively high (840). These two articles are United States publications. The *ASEE Annual Conference and Exposition* quartile had not yet been determined in Scimago at the time this research was written, but it had an h-index of 37, while *the Journal of Research in Science Teaching* is a Q1-indexed journal with an h-index of 139. In terms of the review process, articles published in journals differ from those presented at conferences. Because journal articles take longer to review than conference articles, academics prefer conferences over journals (Resurchify, 2022; Vrettas & Sanderson, 2015). Furthermore, the requirements for writing articles for conferences are simpler than those for journals. The CiteScores of the ten journals in Table 3 have been checked. The *Journal of Research in Science Teaching* ranks first with a score of 9.3, followed by the *International Journal of STEM Education* with a score of 8.8, and *CBE Life Sciences Education* with a score of 6.1. The Citescore is a metric for tracking the evolution of a journal's publication and citations over time. Citescore encourages an increase in the SJR score (Scimago Journal Rank) (Teixeira, 2020).

With 19 documents published, Purdue University is the most productive institution publishing papers related to STEM education in higher education. Arizona State University and Khon Kaen University are in second and third place, respectively. According to the paper by Gil-Doménech (2020) and Jamali (2022), similarly, Purdue University is the most productive university, with Arizona State University coming in second. The United States holds the top spot among the most productive nations for producing STEM content, providing 65.05% (834 documents) of the total data examined. There

have been 9853 citations, with an average of 11,81 per year. Most studies on STEM education are published in the United States (Marín-Marín, 2021). Remember that STEM originated in the United States, where STEM research developed (Ortiz-Revilla, 2020). As for the factors causing STEM education to develop rapidly in the United States, it is one of the industrialized nations with significant financing for STEM programs (Ha, 2020). Furthermore, the availability of adequate infrastructure has an impact. As science and technology advance in the United States, new environmental problems arise that can pose a serious threat to society (Pengyu, 2021). The United States has finally recognized that there is a continuity between science, technology, and society. STEAM is therefore employed in an effort to address community-wide social issues. The following are some STEAM academic projects are underway in the United States, including The New School Project in North Carolina, Concordia University's teacher education program on STEAM education offers major courses such as Foundations of STEAM Education, STEAM Integration in K-12, and Developing STEAM-Enhanced Curriculum, and there are many more STEAM projects in the works. Various universities in the United States, including Harvard University, the Massachusetts Institute of Technology, Yale University, the Franklin Institute, the Rhode Island School of Design, and Boston University, are also involved in the STEAM project (Shashidhar, 2022).

Then the author with the most publications is Carmen, who is likewise American and has 13 documents published. Enriquez A.G. and Fontecchio A. from the United States are in second and third place, respectively. Up to eight authors on the list of the top 10 most productive authors are Americans. Christina Carmen is the most productive author in STEM education in higher education because she is an expert in the field. She earned a doctorate in mechanical engineering from the University of Alabama in Huntsville. Carmen is also the founder and CEO of The Talon Company, which provides STEM education and training to a variety of educational programs. Then, there is Xueli Wang, a professor at the University of Wisconsin-Madison, with the highest number of citations in the field. His research focuses on STEM education, and he has collaborated with a number of universities as well as on NSF-funded research projects.

Co-authorship analysis describes the connection between two authors who wrote for the same publication. Total link strength (TLS), on the other hand, shows the total strength of a co-authorship between two authors (Ali, 2021). Matz is an author with a significant network of collaboration with other writers, according to the study of co-authorship for authors (documents: 4; TLS: 7) (Figure 3). Meanwhile, according to the findings of the co-authorship for countries (Figure 4), the United States is the country that collaborates with other countries the most (documents: 834, TLS: 86). It might be argued that the United States has significantly contributed to the growth of STEM research. To learn the keywords that are used together by authors, use co-occurrence analysis of author keywords. According to the analysis's findings, the author frequently uses the terms "STEM education," "higher education," "engineering education," "active learning," and many more (Figure 5). These terminologies might signify current research trends regarding study variables, methods, and research topics.

Conclusions and Limitations

The study's bibliometric analysis of STEM from 2002 to 2022 is included. The search results produced data for 1487 documents extracted from the Scopus database and exported as a CSV. Once the inclusion and exclusion criteria have been applied, 1282 documents were further evaluated. According to the findings, an increase in the volume of publications in STEM education studies in higher education from 2002 onwards was observed, with a peak in 2020. The works of Henderson et al. (2011), Dennehy and Dasgupta (2017), and Palmer et al. (2011) received the highest number of citations. The sources with the highest number of documents were *ASEE Annual Conference and Exposition*, *Proceedings–Frontiers in Education Conference*, and *International Journal of STEM Education*. In terms of the most productive affiliations, Purdue University, Arizona State University, and Khon Kaen University stand out. The most productive countries are the United States, Australia, and Thailand.

This may be seen by the fact that the United States is the leading country with the most academic institutions publishing STEM-related research. According to an examination of co-authorship for countries, the United States also works with other countries the most. Furthermore, eight authors on the list of the top 10 most productive authors are are from the United States, including Carmen C. (The University of Alabama in Huntsville), Enriquez A.G. (Canada College), and Fontecchio A. (Drexel University).

The limitations of this study are that the only data used for analysis in this study came from the Scopus database, which may have influenced the findings. This is one of the study's shortcomings that should be considered. We recommend future studies to combine it with other databases, such as WoS. The current study was limited to documents published in the period 2002-2022 and only in English. Future studies should use a longer time frame and consider documents written in languages other than English to obtain more comprehensive findings.

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Pupils' metaphors regarding the concept of astronomy in a secondary school social studies course

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ABSTRACT

The year 2019 was proclaimed the year of astronomy literacy by the European Astronomical Union (EAU). Several countries around the world have now started to focus more on space and astronomy endeavours and have shaped their curriculum as a result. Therefore, the perceptions and views of secondary school pupils taking social studies courses on astronomy and astronomy literacy are equally significant. The purpose of this study was to reveal the metaphors used by 5th, 6th and 7th grade pupils taking social studies courses regarding the concept of astronomy. In the present study, a metaphor application was administered to a total of 222 pupils, 74 pupils from each grade level. The research questions were "What are the metaphors of the pupils regarding the concept of astronomy?" and "Which categories are the metaphors created by the pupils related to?". The data obtained were analysed using descriptive analysis and content analysis. In the present study, it was evident that the pupils mostly associated astronomy with concepts such as space, universe, planet, and astronomy, and concretised astronomy through science and social studies concepts. Only a few of the participants, unlike the others, associated astronomy with concepts such as mine, picking flowers from the mountains, fireflies flying, the unknown, and cells. The concepts are grouped into six categories: science, science and social, social, fear, imagination and nature. The pupils associated astronomy metaphors with science (*f* 118) the most and with the nature category (*f* 2) the least.

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Introduction

From ancient times to the present day, the celestial bodies have always been a subject of curiosity for people (Unat, 2013). Since the beginning of their existence, human beings have looked up to the sky and have always speculated about what was happening at the point they could not reach up into the sky. They were sometimes frightened of the events that took place at a point where they could not reach up in the sky, and sometimes they deified them, but in the end, they tried to apprehend and make sense of them. and associated celestial bodies with deities. As a guide for themselves, people

realised that they could modify the work they did on Earth, the planting and sowing activities, and the control of time when they observed the sky. The efforts to make sense of the sky and the movements of celestial bodies eventually led to the emergence of the astronomy (Berea, et al., 2019; Gertsch & Gertsch, 2000, p.2; Taşcan, 2019; Unat, 2013). Therefore, astronomy commenced to develop.

Astronomy was generated by combining the Greek words "Astron", meaning celestial body, and "nomos", meaning determination and law (Göker, 2000). In Arabic, it is called *İlm-i Heyet, İlm-i Felek*. Astronomy fundamentally investigates space, celestial bodies in space, and the universe (Taşcan, 2019). Astronomy is a branch of science that investigates the structures of celestial bodies, explaining concepts such as the universe, space, meteor, galaxies, black holes, etc., in qualitative and quantitative terms (Pena & Quilaz, 2001, p. 1129; Düşkün, 2011, p.40). Astronomy is a systematic science that collects information from the farthest points of the universe, starting from the planet we live on and interprets this information.

In this day and age, while the International Space Station, the world's eye candy in space, the space telescopes such as Hubble and James Webb and efforts to search for signs of life on Mars and make space a livable place have been increasing, it is certainly inconceivable for Turkey to turn a blind eye and deaf ear to all these developments. Turkey has accelerated its space endeavours and established the Turkish Space Agency, established the first celestial to go into space and conduct experiments, and attempted to produce its own rocket. While the issue is so vitally crucial, many areas such as the accumulation of knowledge about astronomy, space tourism, and the space economy have emerged in Turkey and the world (Civelek & Türkay, 2019, p. 960; Yurgiden, 2023, p.3). In such a situation, it is inconceivable for the school curriculum to keep away from all these developments.

The social studies course is the integration of social and human sciences to raise functional citizens in line with the requirements of the age. (Barr at al., 1977; Güleç and Çelik, 2022). Social studies is an interdisciplinary course that aims to educate citizens who can solve problems in developing countries and existing world conditions, follow the developments in the world, and take responsibility and make decisions on critical issues (Bayar & Çepni, 2022; Demirezer & İlkörücü, 2023; Öztürk, 2009, p.2), which aligns with the aims of science education, real-life problem solvers (Ormancı, et al., 2020).

In Turkey, when considered from the perspective of the disciplines that make up its content, social studies can be traced back to the Tanzimat (Reform) period, when teaching it as a distinct subject was seriously deliberated at the 5th National Education Council held on February 4-14, 1953. The council suggested that history, geography, and civics courses be collectively taught under the name of social studies in general education. A social studies course was first introduced in teacher training colleges and village institutes in 1953 and was included in primary school programmes as a social studies course in the 1968 curriculum. In 1985, three different courses were introduced, namely national history, national geography and civics. In 1998, the social studies course was included in the curriculum once again (Çiydem & Kaymakçı, 2021, p. 180). Even though the social studies course curriculum was renewed from time to time, it was always a programme that emphasised the value of education, and the development of pupils' life skills.

The social studies course firstly aimed to ensure that people kept up with the wave of immigration from different regions, were raised with citizenship awareness, and lived in harmony (Aktan & Saylan, 2013, p.56; Bara & Xhomara, 2020; Evans, 2006, p. 319). In this sense, the social studies course has an interdisciplinary design that aims to educate individuals who can solve problems, make informed decisions, and use their rights. Many sciences, such as history, geography, citizenship, communication, law and astronomy, have been integrated into the social studies course (Sunal & Haas, 2005). While the concepts and skills related to astronomy are taught to pupils through life sciences courses in primary schools, they are taught mainly through science courses at secondary school. Nevertheless, astronomy is also a subject of social sciences; it is also among the subjects of social studies courses. (Berea et al., 2019). There is specifically a relationship between the science of astronomy, and the sciences of history, geography, economics, and psychology in the social studies course, which are discussed in this study, and it is crucially important to address the topic of

astronomy in social studies (Güleç &Çelik, 2022; Erbudak & Yeşilbursa, 2023; Salimpur et al., 2024). The topics of how people today and posterity make sense of the universe they live in, that they are fully aware of previous astronomy studies, and the impact of space on the world we live in are also present within the social studies course curriculum. It is commonly acknowledged that specifically the technological developments in this day and age, many topics such as space, life in space, space tourism, space economy and sub-disciplines have come to emerge (Yurgiden, 2023). The International Astronomical Union (IAU), which aims to integrate astronomy, which conducts studies on space, in the curriculum, emphasises that astronomy, whether it is presented as a separate course or integrated into the content of another course, should be included within the primary and secondary school curricula of all countries. All these debates have led to the acceleration of scientific studies on astronomy education (Percy, 1998). Meanwhile, Turkey have started to focus on space studies as well. For instance, as a country Turkey, which has certain space-related goals, has sent its first astronaut, Alper Gezeravcı, into the space. It is crucial to include astronomy-related subjects and concepts within the social studies courses so that future generations can keep up with the current technology age, follow the advancements in space, and be intrigued by space (Marusici & Hadzigebovic, 2018; Güleç & Çelik, 2022; Erbudak & Yeşilbursa, 2024).

Metaphor is a data collection method that allows a subject to be investigated from a broader perspective and to distinguish the similarities and differences (Arnett, 1999). Metaphor studies first emerged with the 'Mental Metaphor Theory' put forward by Lakoff and Johnson in the 1980s (Şahin & Baturay, 2013, p.178). Mental metaphor theory recognises metaphors as conceptual models that shape people's thoughts about reality and the world. Thanks to the metaphor technique, people can make abstract and complex concepts concrete and understandable, and explain the concepts they see or hear through different analogies (Cerit, 2008, p.695). Enabling conceptual development for astronomy, helping pupils to develop a positive attitude towards astronomy, space studies, astronomy professions, and studies on astronomy skills are also related to social studies. Therefore, metaphors created for the concept of astronomy are important in social studies (Kövecses, 2020). Thanks to the metaphor technique, it is possible to identify how the pupils make sense of the astronomy concepts they have learned and encountered in the social studies course, which object or concept corresponds to the astronomy concept in their minds, and how they interpret astronomy in their minds (Altun & Apaydın, 2013; Güven & Güven, 2009; Uslu et al., 2016). Clearly, metaphors can be utilised in order to help children visualise and concretise the new concepts they have encountered in the social studies course (Riejos et al., 2001; Toplu, 2015).

As far as relevant literature is concerned, there exist various studies on the subject of astronomy. Studies on teaching astronomy concepts are mainly found in the field of science education. Oğuzman et al. (2020) investigated the studies on the concept of astronomy in the field of science education, 77 articles on astronomy that were accessed in the TR Index, Google Academy and ULAKBİM database were analysed using various criteria. Regarding the results of this study, the concept of astronomy is mostly in the field of science education, which focuses on teaching concepts and that the studies on the subject have increased in recent years. Master's and doctoral theses in the field of science education on astronomy have principally focused on misconceptions about the concept of astronomy, methods and techniques to be used in teaching the concepts thereof, perceptions and attitudes of pupils, teachers, and prospective teachers towards the concept of astronomy, and planetarium and augmented reality application activities (Meyer, 2000; Palmer, 2007; Chastenay, 2016; Taşcan, 2019; Ceylan, 2023).

In this respect, there are studies examining learners' metaphors and perceptions regarding astronomy concepts (Karamustafaoğlu, & Aktürk, 2010; Bülbül et al., 2013; Sadıkoğlu et al., 2022); studies in which astronomy was taken as a study subject (Plummer, 2009; Blown, & Bryce, 2018; Shen & Confrey, 2007; Yerlikaya & Yerlikaya, 2016; Merakchi, 2018; Eriksson, 2019; Salimpur & Fitzgerald, 2022; Salimpour et al., 2024; Likavcan, 2024); and studies establishing a connection between social studies and astronomy (Ekiz & Akbaş, 2006; Berea et al., 2019; Güleç & Çelik, 2022; Erbudak & Yeşilbursa, 2023). In the field of life science, there are studies focused on augmenting the astronomy

literacy in learners through various applications (Benli- Özdemir, 2022; Benli- Özdemir, 2023); studies that identified pupils' misconceptions about astronomy (Göncü, 2013); studies that measured the self-efficacy and attitudes of science teachers and teacher candidates regarding astronomy (Demirci, 2017; Yorgancı, 2019). Studies on the development of astronomy, on the other hand, are also available in the relevant literature of history (İhsanoğlu, 2003; Erginöz, 2008; Çelik, 2022).

In this respect, there are studies examining pupils' metaphors and perceptions regarding astronomy concepts (Karamustafaoğlu & Aktürk, 2010; Bülbül et al., 2013; Sadıkoğlu et al.,, 2022); studies in which astronomy was dealt with as a subject (Plummer, 2009; Blown, & Bryce, 2018; Shen & Confrey, 2007; Merakchi, 2018; Eriksson, 2019; Salimpur & Fitzgerald, 2022; Salimpour et al., 2024; Likavcan, 2024); and studies establishing a connection between the social studies and astronomy (Ekiz & Akbaş, 2006; Berea et al.,, 2019; Güleç & Çelik, 2022; Erbudak & Yeşilbursa, 2023). In the field of life science, there are studies on increasing pupils' astronomy literacy through various applications (Benli-Özdemir, 2022; Benli- Özdemir, 2023), studies that identified pupils' misconceptions about astronomy (Göncü, 2013); and studies that measured the self-efficacy and attitudes of science teachers and teacher candidates regarding astronomy (Demirci, 2017; Yorgancı, 2019). Some studies on the development of astronomy are also available in the history literature (İhsanoğlu, 2003; Erginöz, 2008; Çelik, 2022; Çelik, 2024).

This study aimed to identify junior secondary pupils' metaphors for astronomical concepts and identify misconceptions regarding astronomy. The present study also aimed to analyse pupils' perceptions of astronomical concepts, which constitutes the cognitive dimension of astronomy literacy, based on their concretisation and analogy of the concept of astronomy. The study sought answers to the following questions in an attempt to identify the metaphors of 5th, 6th and 7th grade pupils regarding the concept of astronomy.

A. What are the metaphors of 5th, 6th and 7th-grade pupils regarding astronomy?
B. Which categories are the metaphors of 5th, 6th and 7th grade pupils associated with?

Methods

This section includes the research model, data collection method, data analysis, how validity and reliability were ensured, and ethical permission.

Research Model

The aim of the study was to reveal the metaphors of 5th, 6th and 7th grade secondary school pupils regarding astronomical concepts and how they make sense of them. For this purpose, a qualitative research method was utilised in the study. The qualitative research method provides the opportunity to analyse a subject in depth and in multi-dimensional terms (Creswell, 2017; Yıldırım & Şimşek, 2018). The phenomenological approach, which is one of the qualitative research principles, was used in the study. The phenomenological design is an approach that reflects the inner world of the individual and helps to identify the structures of consciousness (Mayring, 2000). In the present study, it was aimed to recognise and analyse the individual's perspective and conceptual connections using metaphors.

Data Collection Tool

The data in this study were obtained using the metaphor technique. Metaphor is an important method that enables an abstract concept to become concrete. While preparing the metaphor form, the studies conducted on this subject were scrutinised (Botha, 2009; Geçit & Gencer, 2011). The data collection form was prepared in agreement with the form prepared in the relevant studies. The participants were given a question such as "*astronomy is like ……. because ……..... …….*" (Yıldırım & Şimşek, 2018). After the form was prepared, the necessary rectifications were made

by consulting two field experts in an attempt to ensure the validity of the application of the metaphor form. A pilot study was conducted with two female and two male pupils in order to test whether the form was sufficiently clear and comprehensible. Following the pilot study, it was evident that the participants successfully comprehended the metaphor form and generated concepts appropriate for the purpose of the metaphor study. After the pilot study, the application phase of the form was started.

Prior to the onset of the study, the pupils were informed about the definition of metaphor, how to concretise a concept, and were offered a few examples. Then, the metaphor instructions were distributed to the pupils. The pupils were asked to write what they likened astronomy to or how they comprehended it, and in what way they likened the concept that it was related to astronomy in the second part. They were given 25 minutes to complete the form and were asked not to define the concept for their analogies and to be careful to produce a logical basis for their analogies. The information data obtained was analysed under two headings: first, the participants' perceptions of astronomy were analysed, and then the analogy aspects were analysed with categories.

Study Sample

After obtaining the required permissions, the metaphor tool related to astronomical literacy was administered to 222 pupils, 74 pupils each in the 5th, 6th and 7th grades in the town of Yenişehir of Bursa province in the 2021 and 2022 academic year. The participants were selected by the random method, which is a probability-based sampling method. The random method provides equal representation for each element of the sampling universe and lessens the effect of the researcher on sample selection (Reicharth & Rallis, 1994). It was stated that the privacy of the participants to whom the metaphor technique was applied would be respected, that the data would not be shared with anyone, and that their information would be kept confidential. The essential permissions were obtained during the application of the technique.

When selecting the pupils, stratified and random sampling methods of probability-based sampling were utilised. In the stratified sampling method, the participants who are thought to represent the universe from each level are selected (Baltacı, 2019). In this type of sampling, the universe is divided into subsets and samples are selected from these layers. Initially, the numbers that would represent the universe were identified equally from the girls and boys in the 5th, 6th and 7th grades using the stratified sampling method; afterwards, the pupils who would participate in the study were selected from each level based on class and gender using the random method. The analysis was performed according to the class levels, and the findings were compared with each other.

The participants were coded by their grade level and gender (5F, 6M, 7F). There were 74 participants from 5th, 6th and 7th grades, making a total of 222 participants. 37 participants were males and 37 were females in each grade. The number of participants at each grade level of the school where the study was conducted was significant in establishing the number of pupils. It was ensured that the number of participants was large so that the sample could reasonably represent the universe. Participants were nicknamed according to their grade levels, gender initials and file order. For instance, a boy from the 6th grade was coded as 6.M.1; a girl from the 7th grade was coded as 7. F.5. Participants were asked about their perceptions of the concept of astronomy. Ten of the 222 pupils' data were invalid. Some of the metaphors were deemed invalid because they were not readable, and some were left blank after the word. Grade information for invalid and valid data is illustrated in Table 1 below.

Table 1

Distribution of invalid and valid data by grade and gender

	Invalid data			Valid data		
Grade	Female	Male	Total	Female	Male	Total
5. grade	2	4	6	35	33	68
6. grade	2	0	2	35	37	72
7. grade	2	0	2	35	37	72
Total	6	4	10	105	107	212

Invalid data in Table 1 were excluded from evaluation. The data considered valid on the grade basis were analysed.

Data Analysis

In qualitative studies, data are analysed by descriptive analysis or content analysis. In the present study, data were analysed using both descriptive and content analysis. Descriptive analysis consists of creating a framework, organising data according to the thematic framework, and defining and interpreting the results (Baltacı, 2019). There are five stages in content analysis. These stages are coding the data, identifying themes, organising the codes and themes, defining and interpreting the results (Dilek et al., 2018, p.585). Codes were created and themes were organised by following these stages. Two data analysis methods were utilised in this study. While identifying the categories to which the metaphors belonged, the relevant literature was reviewed, and the areas represented by the metaphors obtained in the study were predicated on this, which implies that pre-existing categories were used. In many previous studies, it was clear that the categories generated in metaphor analyses studying astronomy and astronomy-related concepts were identical (Karamustafaoğlu & Aktürk, 2016; Gürkan & Kıraç, 2019; Sadıkoğlu et al., 2022). The metaphors were categorised as life science, social studies, science and social studies, fear, imagination and astronomy as nature.

Credibility and Consistency

In qualitative studies, instead of validity and reliability, the concepts of credibility and consistency are in use (Çepni, 2021). The steps followed in the study were presented in detail in order to enhance credibility. In order to ensure the integrity of the study and the consistency of the research, it was read by an expert who completed his doctorate in social studies and a teacher who completed his doctorate degree in Turkish education. In order to ensure consistency in the study, the codes and themes generated by the researcher were compared with the codes and themes generated by the expert who completed his doctorate degree. The codes created by the researcher and the expert were all compared. The coders examined each metaphor and determined the category it could be related to. At the end of the study, the metaphors that were obtained and the categories to which they could belong were compared. The coders examined each and every metaphor and identified the category it could be related to. At the end of the study, the emerging metaphors and the categories they could belong to were compared.

In the study, Miles and Huberman's formula for determining consensus and disagreement (Reliability = Consensus = Consensus/Disagreement) was used (Miles & Huberman, 1994, p.64). As a result of this analysis, it was found that the compatibility of the codes and themes was 92%. The codes and themes that were different were reviewed and arranged. In order to ensure transferability in the study, the stages of the study were explained in detail, and the participants' data were frequently included.

Findings

What Metaphors Do 1st, 5th, 6th and 7th-Grade Pupils Use Regarding The Concept of Astronomy?

In the metaphor study regarding the concept of astronomy, valid answers were analysed and the concepts that the participants associated with were identified. Different concepts were obtained from the available data. The frequencies and percentages of these concepts are illustrated in Table 2 below.

Table 2

Pupils' metaphors regarding astronomy

Metaphors	Frequency	%
Space	38	18
Universe	28	14
Other Metaphors	28	13
Planet	18	8
Earth	10	5
Astronomy	10	5
Research and Space Exploration	8	4
Emptiness - A Black Emptiness	7	3
İnfinity	7	3
Outer Space	7	3
Science	6	3
Unknown - Things We Don't Know	5	3
Space Science	5	2
Star	5	2
Astronaut	4	2
Sun	4	2
Life	4	2
Galaxy	3	1
Black Hole	3	1
Environment	2	1
Dream -Imagination	2	1
Everything	2	1
Mathematics	2	1
Flying	2	1
Alien	2	1
Total	212	100

As is clear in Table 2 above, the majority of the participants explicated astronomy with the concept of space *(f 38)*. The concept of Universe *(f 28)* was the second most associated concept. The concepts of Planet *(f 18)*, Earth *(f 10)*, Astronomy *(f 10)*, infinity *(f 7)*, outer space *(f 7)*, space science *(f 5)* were the other most mentioned concepts. As far as the concepts were concerned, it is evident that the participants offered a correct analogy and definition for astronomy. These concepts are already

available in the science of astronomy. The concepts of flying *(f 2)*, alien *(f 2)*, and imagination *(f 2)* were also the concepts that the pupils associated the least with. The concepts under the title of Others *(f 28)* were mentioned once each. These concepts are presented in Table 3.

Table 3

Metaphors that pupils expressed once

Metaphors	
Researcher	Universe
Firefly	Dark Room
Science Fairs	Mine
Imagination	Freedom
(Like) Us	Silence
Picking Flowers from the Mountains	Infinite Place
Extraterrestrial Beings	Endless Exploration
Saving the World	Social Studies Course
Thought	Space Vehicles
Place We Travel	Space Scientist
Future	Space Depth
Sky	Space Exploration
Invisibility	Human Living in Space
Cell	Life

As is clear in Table 3 above, the concepts of space vehicle, space scientist, space depth, space exploration and people living in space were mentioned once. Comparing space to a mine was important for projects to bring mines from space now and in the near future. Establishing a connection between astronomy and mines was important in this respect. A participant established a connection between astronomy and the social studies course. This was important because astronomy was a concept in the social studies course.

Which Categories Are the Metaphors of 5th, 6th and 7th Grade Pupils Associated with?

The pupils' responses starting with "because" regarding astronomy literacy helped to reveal how they interpreted the concepts they associated with astronomy. After these concepts were analysed, they were grouped into six categories. While those who defined astronomy with celestial bodies in space were directly included in the Science category, those who defined it with concepts that science and social studies dealt with together were included in the Science and Social Studies category. Definitions conveying fear and anxiety were included in the Fear category.

A detailed table was generated for the concepts included in the categories. Table 4 below illustrates the concepts included in the categories, as well as their frequencies and percentages.

Table 4

Frequency and percentage distributions of the categories of metaphors produced by the pupils regarding astronomy

Categories	Concepts	Frequency	%
Astronomy as fear	Alien	2	32
	Depth of Space	1	17
	Universe	1	17
	Emptiness	1	17
	Things We Don't Know	1	17
Total		7	100
Astronomy as nature	Firefly	1	50
	Picking Flowers from the Mountains	1	50
Total		2	100
Astronomy as a science	Space	25	21
	Universe	22	18
	Planet	16	13
	Astronomy	10	7
	Space	6	5
	Science	5	4
	Sun	4	3
	Emptiness	4	3
	Star	4	3
	Earth	3	3
	Black Hole	3	3
	Galaxy	3	3
	Space Science	3	3
	Research	2	2
	Mathematics	2	2
	İnfinity	2	2
	Everything	1	1
	Cell	1	1
	Universe	1	1
	Dark Room	1	1
Total		118	100
Astronomy as a social studies	Life	4	23
	Extraterrestrials	1	7
	Saving the World	1	7
	Future	1	7
	Place We Travel	1	7
	World	1	7
	Mine	1	7
	Space	1	7
	Freedom	1	7
	Social Lesson	1	7

Total	Endless Exploration	1	7
	Human beings living in space	1	7
		15	100
Astronomy as a life science and social studies	Space and its exploration, science, everything about it	16	37
	Earth	6	14
	Space Research	5	11
	Astronaut	4	9
	Universe	3	7
	Planet	2	5
	Flying	2	5
	Science Fair	1	2
	Environment	1	2
	Spacecraft	1	2
	Space Scientist	1	2
	Research	1	2
Total		45	100
Astronomy as a dream	İnfinity	5	20
	Unknown, the unknown	4	16
	Imagination	2	8
	Universe	2	8
	(Like) Us	1	4
	Emptiness	1	4
	Space	1	4
	Star	1	4
	Life	1	4
	It's fun	1	4
	Thought	1	4
	Endless Place	1	4
	Sky	1	4
	Invisibility	1	4
	Silence	1	4
	Space	1	4
Total		25	100

As far as Table 4 above is concerned, it is evident that some concepts (universe, space, emptiness, etc.) were included in more than one category. The reason for this was that the pupils interpreted them from a different perspective in the second part, where they explained the reason for the metaphor. It is clear that the participants offered most of the explanations in the science category *(f 118)*.

Participants interpreted the concepts through science and attempted to define them. The concept of space *(f 25)* was repeatedly mentioned the most through science. It was evident that the participants defined astronomy through space since the concept of astronomy was defined through science in the part that started with *'because'*. For instance, this is what participant 6, M.15, stated:

"Astronomy is like space, because astronomy shows us what is happening in space and tells us what is happening."

6.F.3 responded, *"Astronomy is like space, because there are stars, planets, meteors and meteorites there."*

The second most mentioned concept in the science category was the universe. On this subject, the participants said the following;

5.M.16, "*Astronomy is like the universe, because there are many planets and stars in the universe"*,

6.F.15 "Astronomy is like the universe, because there are, for instance, planets and stars in it".

Among the concepts mentioned once, the *cell* was mentioned 7 times. F.12. On the same subject, 7.F.12 responded, *"Astronomy is like a cell, because there are many planets inside it, just like in a cell"*.

The second highest mentioned category was space as science and social sciences *(f 45)*. Since astronomy was a common subject of science and social sciences, the responses in this category and the connection established were significant in defining astronomy through the two sciences. This illustrates that pupils associated the concept of astronomy with both social and life scientific issues. The most mentioned concept in this category was space and space science, which is everything about space and science that explores space *(f 16)*. Since all these concepts were used in the same sense, they were considered integrated. The participants' views on this subject are as follows;

5.M.25, *"Astronomy is like the science that explores space, because astronomy is about space"*;

7.F.35, "Astronomy is like everything about space, because astronomy is the science that investigates any information that can be obtained in space".

Spacecraft, one of the concepts mentioned once, was mentioned by participant 6. M.7. 6.E.7 said, *"Astronomy is like space crafts because they go into the space and explores it."* As is clear in these definitions, emphasis was placed on the concepts that directly dealt with celestial bodies and science. A definition was offered only to the extent that it was covered in both social and life science textbooks. Only to the extent that they are covered in both social and life science textbooks are definitions made.

The third highest dream category was astronomy *(f 25)*. The participants defined the concept that they found similar to astronomy with the concepts that fell into the dream category. Clearly, astronomy seemed utopian and just like a dream world to them. The most mentioned concept here was infinity *(f 5)*. Regarding this issue, the participants stated the following;

5.M.30 *"Astronomy is like infinity, because the end of space is not visible"*,

7.M.17, *"Astronomy is like infinity, because there are infinite things we don't know about the universe yet"*.

The Unknown *(f 4)* was the second most mentioned concept. In this respect, 6.M.11 stated, "*Astronomy is like the unknown, because astronomy enables us to find all the unknown things*."

The concept of (like) *us* was mentioned by 5.F.2, which was one of the least mentioned ones. In this sense, 5.F.2 said, "*Astronomy is like us, because it is very important for our dreams*."

The fourth category was astronomy *(f 15)* as a social study. The participants attempted to define the concept of astronomy directly through social studies. The concepts included in this category were generated from the concepts that fell into the subjects of social life and social studies. The concept of life (f 4) was mentioned the most. In this respect, 5.M.12 said, "*Astronomy is like life itself because it contributes to our lives*." 7.F.22 said, "Astronomy is like life because we live in it."

One of the least mentioned concepts was the mine. In this respect, 6.M.1, "*Astronomy is like a mine, because different mines can be established in space and this will generate a lot of energy*."

The least mentioned categories were astronomy as fear *(f 7*) and astronomy as nature *(f 2)*. 7 participants associated and defined astronomy with the concepts of fear. They associated and explained the concepts such as space as something we did not know and as aliens. The concept of alien *(f 2)* was mentioned the most in the category of fear. Regarding this issue, the participants stated the following;

5.F.28, "A*stronomy is like aliens because I don't like the space*",

7.M.27 "*When I think of astronomy, aliens come to mind because there may be other evil creatures in space."* The universe was mentioned only once in the category of fear.

In the category of astronomy as nature, one pupil likened astronomy to a firefly, while the other compared it to picking flowers from a mountain. Concepts are important in terms of

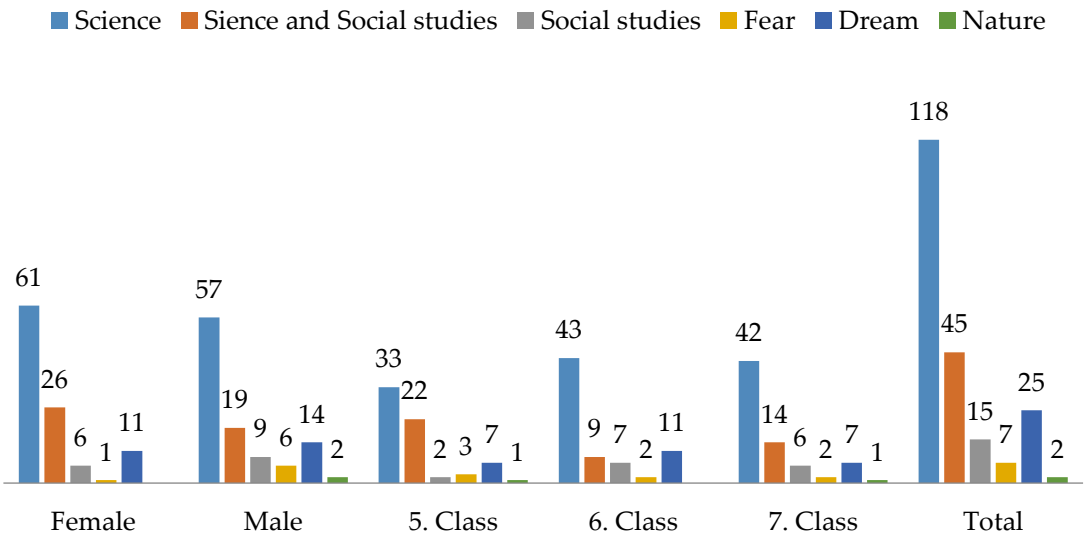
establishing an analogy between astronomy and nature. 5.M.28 stated "*Astronomy is like a firefly, because when an astronomer looks into space with his telescope, he sees stars that look like fireflies*";

7.E.36, on the other hand, stated, "*Astronomy is like picking flowers from a mountain, because discovering all the celestial bodies in the universe in astronomy is like picking flowers from a mountain.*" They established a connection between natural elements and astronomy. When the concepts that are likened are analysed, it is evident that they establish a connection with astronomy from the right perspective.

It is crucial to compare the six categories at the class levels. The distribution based on class levels is illustrated in the graphic below.

Graphic 1

General distribution of the categories related to metaphors



Regarding the Graphic 1 above, it is clear that the most connections were established between the science category (*f 118*) and astronomy. As far as gender is concerned, the female pupils (*f 61*) established more connections with the science category than the male pupils (*f 57*). It is evident that the 6th and 7th grades established more connections with science based on the grade level. The second most repeated category was science and social studies (*f 45*). The female pupils (*f 26*) associated astronomy with both science and social studies more than the male pupils (f 19). Based on the grade level, the 5th graders mostly regarded both science and social studies courses as related to astronomy. Even though there was little visual information about astronomy in the 5th-grade social studies course, the fact that they made such a connection with social studies may be related to the topics the teacher addressed in the social studies course. Fifteen pupils established a direct connection with the social studies course. Regarding gender, it was evident that the male pupils (*f 9*) established a connection between the social studies courses and astronomy more than the female pupils (*f 6*). Based on the grade level, 5th graders (*f 2*) established the least and 6th graders (*f 7*) the most direct connection with the social studies course. The reason for this particular result may be the existence of a few visuals directly related to astronomy in the 6th-grade social studies textbooks and the limited knowledge and information about observatories. The least repeated category was nature (*f 2*). Regarding gender, only males (*f 2*) established a connection between nature and astronomy. The reason for this result may be that the connection between astronomy and nature failed to be sufficiently established in the educational and cultural environment. It is evident that the pupils in the

5th (*f 1*) and 6th grades (*f 1*) established a connection on a class basis. By and large, it is possible to say that the pupils established a connection between astronomy and more scientific concepts as the grade level increased.

Discussion and Conclusion

In this study, metaphors related to the concept of astronomy of 5th, 6th and 7th grade pupils were investigated. Within this framework, a total of 222 pupils' metaphors were investigated, 74 per grade. Since 10 metaphor data points were deemed invalid, 212 metaphor data points were eventually analysed. The low number of invalid data in the study demonstrated that the majority of the participants could generate valid metaphors in order to define the concept of astronomy and concretise the information. When the pupils' metaphors and justifications were compared in general, it was evident that they could partially remember the basic information about astronomy. In the analyses, the metaphor that the pupils most closely associated with astronomy was the concept of space. The universe came second. As far as their responses are concerned, it is clear that the majority of the pupils thought that astronomy explored space and the universe.

One of the pupils made a connection between astronomy and mines and stated that there were many different minerals and mines in space. This finding is significant in terms of recognising the richness of space in terms of mineral and energy resources. As far as the relevant literature is concerned, it is evident that in addition to the metaphorical studies on astronomy, the pupils also made connections between the Sun and space and the Earth in studies on the concepts of space (Karamustafaoğlu & Aktürk, 2016); Earth (Bülbül et al., 2013; İbret Ünal & Aydınözü, 2011; Rampean & Rohaeti, 2025). In the study conducted by Gürkan and Kıraç (2019), in which they investigated pupils' metaphors regarding the concepts of space and satellite, it was revealed that pupils likened space to emptiness the most and a satellite to a television set. In studies examining prospective teachers' and teachers' metaphors regarding the concept of astronomy, it was determined that prospective teachers most closely resembled astronomy to the brain, while teachers most closely resembled astronomy to concepts such as infinity, the universe, and the human brain (Aslan, 2019; Uluçınar- Sağır et al., 2023).

It is possible to say that the emergent results of our study overlapped with these studies because astronomy was likened to infinity, emptiness and the universe. In the studies that investigated misperceptions about astronomy, the misconceptions could be changed with the help of conceptual change texts in such areas as planetariums and observatories through various activities, and it became easier for the pupils to make concretisations related to astronomy (Taşcan, 2019; Meyer, 2000; Palmer, 2007; Chastenay, 2016).

It was investigated which category the metaphors of 5th, 6th and 7th grade pupils were related to. The concepts that the pupils established relations with were classified in light of the answers they gave to the part of the study that started with because. In this context, six categories were created. The most mentioned category was astronomy as a science. The pupils explained the concept of astronomy mostly through the concepts they encountered in science. The second category was astronomy as a science and social studies. Pupils regarded astronomy as a common subject of science and social studies courses and established a connection with it because they encountered it in these courses. Astronomy as a dream was the third; astronomy as a fear was the fifth category. The least frequent belonged to the astronomical category in nature.

It was investigated in this study which categories the metaphors of the 5th, 6th and 7th grade pupils were associated with. The concepts that the pupils established a relationship with were classified in light of their responses to the part of the study that started with *`because`*. In this sense, six categories were generated. The most mentioned category was astronomy as a science. Pupils explicated the concept of astronomy through the concepts they encountered most in the life science course. In similar studies on this subject, it was clear that the pupils associated astronomy-related studies with science (Yolagiden & Bektaş, 2022; Sadıkoğlu et al., 2022). It was simply because

astronomy was also intensively studied in the science course (Gülseçen, 2002). The second category was astronomy as a life science and social studies course. In the present study, it was evident that as the grade level increased, the rate of establishing a connection with science increased as well. While the 5th graders associated astronomy with the science and social studies categories, it was clear that the 6th and 7th graders associated it more with the science category. In the previous studies conducted on this subject, it was evident that the increase in pupils' knowledge about astronomy had an impact on the metaphors they generated (Arıkurt et al., 2015; Yorgancı, 2019). The fact that astronomy concepts were addressed more in the 6th and especially 7th-grade science program compared to the other branches may be related to this particular result. As the grade levels of pupils increased, it became easier for the pupils to process the abstract concepts in their minds and create models (Serttaş & Yenilmez Türkoğlu, 2020).

Their pupils regarded astronomy as a common subject in life science and social studies courses and established relationships with them because they encountered them in these courses. Astronomy as a dream was the third category, and astronomy as a fear is the fifth one. In the study conducted by Karamustafaoğlu and Aktürk in 2016 on this subject, pupils defined the concept of space mostly abstractly through the categories of dream and fear. Specifically, the emergence of the fear category may be influenced by the pupil's erroneous learning about astronomy, misconceptions, and knowledge and information encountered in the media (aliens, UFOs, etc.) (Taşcan & Ünal, 2015; Taşcan, 2019; Gürkan & Kıraç, 2019).

In the study by Gürkan and Kıraç (2019), in which they investigated pupil metaphors related to space and satellites, space as science was the category with the highest frequency. Imagination and fear were the other most mentioned categories, succeeding space as science. The presence of the concept of alien in the fear category might be due to the fact that the pupils might have learnt incorrectly or structured their knowledge intuitively, devoid of scientific knowledge (Eriksson, 2019; Yağbasan & Gülçiçek, 2003). In their study on the astronomy concepts of pupils at different educational levels, Arıkurt et al. (2015) revealed that pupils had misperceptions about astronomy by considering the concept of aliens in the fear category. Nevertheless, places such as planetariums and observatories were quite instrumental in eliminating the misconceptions about astronomy or fears stemming from incorrect learning (Palmer, 2007; Meyer, 2000; Plummer, 2009).

It is compatible with the concepts of astronomy in social studies to establish a connection between the social studies course and astronomy. The concepts that pupils state about astronomy are social in content, such as profession, world, space, future, and saving the world, offered in social studies courses rather than planets and celestial bodies. In fact, Berea, Denning, Viaurri, Aracand (2019) and Remie (2019) emphasised in their studies that astronomy was also a subject of social sciences by analysing the concepts of astronomy in social sciences from an interdisciplinary perspective. Including these concepts in a more multidimensional way in social studies courses will make a considerable contribution to supporting astronomy studies in our country eliminating misunderstandings, and developing perspectives and analytical thinking skills (Taşcan, 2019; Güleç & Çelik, 2022; Erbudak & Yeşilbursa, 2023; Trumper, 2006; Rossenberg et al., 2014).

Ensuring that abstract concepts, such as astronomy, are more identifiable with metaphors and that they are linked to concrete concepts in the education process is sure to make the teaching more permanent (Shen & Confrey, 2007; Karamustafaoğlu, 2010; Sadıkoğlu et al., 2022). Nevertheless, the pupils' attitude towards astronomy also affects the level of knowledge about astronomy (Yorgancı, 2019). This particular situation makes it meaningful that the pupils in our study who developed a negative perspective towards astronomy or had misconceptions produced meaningless metaphors or concepts in the fear category.

Concretising astronomy and astronomy-related concepts is crucial in order to understand the universe and the world we live in better (Eriksson, 2019; Likavcan, 2024). In fact, astronomy perceptions can be developed through various applications and tools (Kaplan, 2011; Blown & Bryce, 2018). Astronomy enables pupils to connect with their environment and culture and, therefore, to comprehend and concretise the concept of astronomy more easily (Merakchi, 2018; Salimpur &

Fitzgerald, 2022). In this sense, identifying metaphors related to astronomy concepts, revealing misconceptions, and creating awareness about the concept in pupils will positively contribute to the correct development of the cognitive dimension of astronomy literacy (Shen & Confrey, 2007; Benli Özdemir, 2022).

Suggestions

- Now that there exist organisms in space, the possibility of finding intelligent life has been increasing. Therefore, stories can be incorporated in course books in order to overcome the fearful alien prejudice against life in space and other intelligent life in peace.
- In social studies textbooks, a unit that covers every aspect of astronomy or a direct topic in units that can be related to astronomy can be included.
- Astronomy topics in social studies textbooks and science textbooks can be arranged in a way that supports one another.
- Social studies textbooks can be enriched in terms of advances related to astronomy.
- Current events and news related to astronomy can be included more frequently.
- The social studies course can be enriched with astronomy concepts.
- In an attempt to eliminate the misperceptions about astronomy, more precise concepts can be taught instead of concepts such as aliens that may be associated with fear.
- Metaphor techniques can be utilized to ensure that pupils can internalize and concretize the concept in educational contexts.
- Metaphors can be utilized to prevent misunderstandings before and after teaching the astronomy-related topics and concepts.
- Social studies teachers can be offered astronomy or astronomy literacy courses in their undergraduate programs.
- The present study was limited to the 2022-2023 academic year and pupils studying in the town of Yenişehir in the Bursa Province. In order to identify the pupils' astronomy concepts, studies with more participants and in different provinces can be conducted.

Conflicts of Interest

The authors declare no conflict of interest for this research.

Ethical Considerations

For the present study, ethical approval was obtained from the Social and Human Sciences Research and Publication Ethics Committee of Bursa Uludag University (Number: 2022/01, Date: 28.01.2022).

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Ethno-STEAM science learning to improve prospective teachers' creative thinking and problem-solving skills

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ABSTRACT
This study was aimed at improving the creative thinking and problem-solving skills of prospective teachers and to identify the relationship between those skills during science learning using the Ethno-STEAM approach. The quantitative study was carried out with a pre-experimental design. The research design was a one-shot case study. The research subjects were 80 prospective teachers from two universities. The research instrument used was a test to measure creative thinking skills and problem-solving. The data were analysed using the N-gain test. The Pearson product moment correlation test was used to determine the relationship between creative thinking skills and problem solving. The results of the study showed that the students' creative thinking and problem-solving skills increased after the application of science learning with the Ethno-STEAM approach with the N-gain value in the medium category. A fair relationship between creative thinking and problem-solving skills was observed (r = 0.679).

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Introduction

The ability of the teacher to think creatively is directly tied to the level of success achieved by pupils in their educational endeavours in the classroom. Creative teachers will become initiators in developing creative thinking skills for their pupils through the learning designs they prepare and implement (Erdogan, 2019). Accordingly, prospective teachers need to be trained in creative thinking so that they may fulfil their roles effectively and educate individuals who are capable of creative thinking (Ramdani, et al., 2021). Teachers who have advanced creative thinking skills have an impact on the achievement of creative thinking of their pupils and increase their interest in science (Ernawati et al., 2022; Zubaidah et al., 2017). The results of previous research have found that creative thinking skills and problem-solving need to be foci for systematic training in the course of the learning process (Kiraga, 2023).

Problem-solving abilities are closely related to creative thinking abilities, and both are essential (Montag-Smit & Maertz, 2017). Teachers with good problem-solving and creative thinking skills can help learners learn how to build their knowledge and use it in creative ways (Yulianti et al., 2020). On the other hand, if teachers lack the ability to think creatively and solve problems, they will be unable to train their pupils to do so, and their pupils may be less able to solve the complicated difficulties they encounter in the real world (Ratnasari et al., 2019; Ulger, 2018).

Attempts are being made to raise this level of expertise through the introduction of novel science educational strategies that forge connections between scientific study and the cultural traditions of the surrounding area. The term "ethno-scientific approach" refers to a method of teaching and learning that integrates learners' cultural backgrounds with scientific concepts (Sarwi et al., 2019). Indonesia is a country of various tribes, religions and cultures, indeed every region in Indonesia has a diversity of cultures that have been passed down from their ancestors. Knowledge in the fields of arts, culture, health, agriculture, agriculture, culinary and others should be used by teachers to improve the learning process and learning outcomes. The ethnoscience approach conditions pupils to learn from the environment, society, and culture that prevail around where they live. The ethno-scientific approach is part of local wisdom and is based on Vygotsky's theory. This theory confirms that cognitive knowledge is acquired through interpersonal and intrapersonal (Sumarni, 2018).

Learning that draws on the scientific expertise of a community has been shown to enhance the critical and creative reasoning abilities of future teachers (Sumarni et al., 2022). Students' favourable attitudes toward science, their creative thinking in the classroom, and their problem-solving skills were all enhanced by the use of an ethnoscience approach during teaching and learning process as previously reported (McCarthy, 2018).

STEAM, which is an acronym for Science, Technology, Engineering, Arts and Mathematics, is a collaborative approach to encourage learners to be able to think broadly about problems that exist in the real world (Costantino, 2018). STEAM develops according to the needs of the times which aims to provide convenience and effective assistance to the community. One of the benefits of STEAM learning is that it helps learners think at a higher level, especially when it comes to being able to think critically about different kinds of information, think creatively when solving a problem, and make decisions supported by good arguments (Ozkan & Topsakal, 2021; Chung et al., 2018).

To develop high order thinking skills (HOTs) in science education, it needs to be supported by a learning system that is able to accommodate the rapid development of technology along with the changing times (Liline et al., 2024). This condition is a strong indication for the world of education to reform its learning strategies. One of the reforms carried out is the application of the STEAM learning model where participants are taught to learn to process through observing, fun activities, recognising patterns and practising creative thinking as well as becoming more skilled in collaborating and communicating in completing a task (Perignat & Katz-Buonincontro, 2018; Quigley et al., 2017; Kim & Bolger, 2017).

Previous studies have reported that ethnic crafts could be integrated in the teaching and learning activities to develop the students' creative thinking, critical thinking and problem-solving skills. The bamboo crafts in Hong Kong have been reported as a good tools to help learners to gain a proper mentality, through cultivating their 21st century skills (Ho & Shih, 2023). The bamboo crafts could appear as the daily life appliances such as cookware, containers and building techniques. In addition, the crafts could also occasionally appear in seasonal festivals or funerals such as bamboo theatres, offerings and lion-dance. One previous study has also reported that the Batik crafts as a traditional in Indonesia could improve pupils' creative thinking skills (Nursalim, 2020). Furthermore, the utilisation of the Batik crafts in the teaching and learning process could also courage the learners to work collaboratively with their friends, in addition to train them to be more critical, particularly in making decisions and solving problems (Rozie et al., 2021).

Bringing indigenous knowledge and practices especially the ethnic crafts into the teaching and learning dynamic has been reported in previous studies. The local culture of Troso woven fabric has been identified as being able to enable pupils to better understand scientific concepts such as

compounds and mixtures, heat and energy transfer, including measurement processes (Khusniati et al., 2023). The integration of such teaching and learning activities with STEAM education could be beneficial and have a big impact on the development of 21st century skills. The traditional game Pesapean in Madura culture has been reported to be able to develop the collaborative skills (Qomaria & Wulandari, 2022). The skill aspects were contribution, motivation, time-management and problem-solving skills, group dynamics, and interaction with other group members. The exploration of STEAM aspects in the traditional festival in Bali was also studied and the results could be used during the teaching and learning of social arithmetic – a mathematical subject that studies social life, such as buying and selling activities (Puspadewi et al., 2022). The traditional musical instrument Kacaping was reported to be able to enhance problem-solving skills and learners' motivation towards preserving local wisdom in South Sulawesi. Ethno-science-integrated STEAM provides a framework for integrating these various fields. The science learning programme incorporating the ethno-STEAM approach provides for learning the basic science concepts inherent in indigenous science on aspects of science, environment, technology, art and mathematics. The ethno-STEAM approach is also used as the basis for this research to improve these skills through learning that connects formal science concepts (science in schools) with science in society. The ethno-STEAM approach in the science learning as the integration of local wisdom and STEAM approach has not been reported before. This approach offers a holistic and systematic approach in developing learners' creativity and problem-solving skills. On the one hand, the creative thinking and problem-solving skills of prospective teachers during the teaching and learning process using the ethno-STEAM approach need to be clearly corelated. This study aimed to determine the increase in creative thinking skills and problem-solving skills, if any, after prospective teachers took part in science learning with the Ethno-STEAM approach and the relationship between these skills.

Methods

Research Design

The quantitative study was carried out with a pre-experimental design. The research design was carried out with a one-shot case study.

Participants

The subject of this study was the students of the Bachelor of Science Education programme in the 5th semester who have pursued the General Chemistry, Local Wisdom in Science Learning, Integrated Science and its Learning, STEM and Conservation Education courses. The participants of this study were 80 prospective teachers from two universities with the same curriculum. The sampling technique used was the purposive sampling technique. The respondent profile can be seen in Table 1.

Table 1

The profile of the participants involved in this study

Characteristic	University	
	A	B
Male	10	12
Female	35	23
Semester	5	5
Age	20-22 years	20-22 years
Residency	Central Java	Central Java

Learning Activities

The study was carried out in the Chemistry course 'Concepts and applications' learning activities for which are listed in Table 2.

In this study, the overall learning activities were in accordance with the syntax of the project-based learning. This was due to previous findings showing the success of project-based learning, i.e., enhancing the students' creativity, improving the students' learning outcomes and higher-order thinking skills (Ariyatun, 2021; Chung et al., 2022; Habibi et al., 2020). Moreover, the project-based learning integrated with the ethno-STEM aspects could help to improve the students' critical and creative thinking skills science literacy. During the learning, the students were positioned in the condition of posing the problems as the initial stage in collecting and integrating the new knowledge based on their prior knowledge in their daily lives.

Table 2

The learning stages during the teaching and learning activities using ethno-STEAM approach

Meeting	Learning stage	Online	Offline
1	Start With the Essential Question	The students are organised into groups. They are required to read various learning sources related to the Colloidal concept and its application, as well as Polymers and their applications.	The teaching and learning process was started by essential questions that required the students to conduct activities. The topics chosen were closely related to the reality of local wisdom of the community in the students' surrounding, i.e. pottery crafts and traditional Batik.
2	Designing a Plan for the Project and Creating a Schedule	The planning of learning was collaboratively conducted between the lecturers and students through discussion forum available in the e-learning ELENA. The plan consisted of the rules and the selection of activities that could support the project accomplishment.	The lecturers and students collaboratively developed the schedule of activities in accomplishing the project. The activities in this stage were preparing a timeline, deciding the due date when the project should be finished, and providing directions to the students to start the activity with a deep investigation through a primary source person regarding the local wisdom of making pottery and Batik. Supervisors intervened if students went off-track. They were questioned about the ethno-science, ethno-technology, ethno-engineering, ethno-art, and ethno-mathematics on both ethnic crafts.
3-6	Monitor the Students and the Progress of the Project	The lecturers made sure that the students' activities and the progress of the group project were well-monitored through ELENA. The students practised making traditional pottery and Batik. A progress report was submitted through a documentation using Powerpoint® slides and video blog. The monitoring process was conducted using a matrix to record all important activities.	The students presented the progress of their group project, as well as the results of the construction of society's indigenous knowledge related to STEAM in order to be observed by three experts for validation. The class discussion related to the colloidal system concepts and its properties, either directly or indirectly related to the project.
7	Assess the Outcome and Evaluate the Experiences	The students uploaded the project results to be graded. The lecturers evaluate and grade the project results to measure the standard of achievement and provide the feedback regarding the students' understanding level.	The students presented their project results either individually or in groups. In this stage, the students were asked to reveal their feelings and experiences during the project execution. The discussion was performed to improve their communication skills and draw conclusions as a solution towards the problems raised at the first stage.

Learning activities combined online and offline learning. Online learning facilitates inquiry planning, and offline learning activities are conducted to do group investigations. The investigations

were carried out by the students in groups involving the local wisdom in some Central Java areas, i.e., traditional Batik crafts and local ceramic industry and then integrated into learning as is shown in Table 3.

Table 3

Local wisdom integrated into learning (pottery and Batik crafts)

Pottery Crafts
Pottery is often also referred to as ceramics. Pottery/ceramic crafts are works of art made by human hands that use clay as the main raw material which has gone through a burning process. The word ceramic comes from the Greek, namely keramos. This means that glassware is made of clay that has gone through a burning process.
Ethno-science
Clay is a complex hydraaluminum silica with the chemical formula $Al_2O_3.nSiO_2.kH_2O$ where n and k are the numerical values of the bonded molecules and vary for the same mass. Clay is used to make various ceramic products such as decorative ceramics, roof tiles, bricks, sinks, kitchen utensils etc. Ceramics are products made from a mixture of inorganic, non-metallic minerals (clay and its admixtures) processed at high temperatures, and shows a crystalline, non-crystalline or a mixture of both structures. One of them for cement materials has the compound formula $Al_2O_3.K_2O.6SiO_2.2H_2O$. Clay mineral particles are usually negatively charged so that clay particles are almost always hydrated, that is, they are surrounded by layers of water molecules which are referred to as adsorbed water. This layer is generally two molecules thick and is therefore called a double diffusion layer. The double diffusion layer is a layer that can attract water molecules or cations around it. This layer will disappear at temperatures higher than 600^{o}C to 1000^{o}C and will reduce the natural plasticity. Water can also be lost simply by air drying. When the plastic ceramic body is dried, 3 important processes will occur: (1) Water in the layers between the clay particles diffuses to the surface, evaporates, until finally the particles touch each other and shrinkage stops; (2) Water in the pores is lost without shrinkage; and (3) the water adsorbed on the surface of the particles is lost. These steps explain why the drying process must be carried out slowly to avoid cracking, especially in stage 1. Processing in a too fast way would cause a cracking due to the sudden loss of water without being balanced by the perfect arrangement of the clay particles, which would result in a sudden shrinkage.
Ethno-technology
 Traditional equipment are a printing tool and turntable. Burning was done in an open kiln using a shallow clay pit with a burning grass fire. This pottery-making technique is still used today by some ceramic artists in Indonesia.
Ethno-Engineering
The stages in making ceramics were interrelated with one another. If the initial process was done well, it would produce a good product, and vice versa; errors in the early stages of the process would produce a low-quality product. Material processing The purpose of processing this material is to process raw materials from various materials that are not ready to use into ready-to-use plastic ceramic bodies. In the processing of materials there are certain processes that

must be carried out, including reducing grain size, filtering, mixing, stirring, and reducing the water content. Grain size reduction can be done by pulverizing or grinding. Screening is intended to separate materials with inhomogeneous sizes. The commonly used size is 60 – 100 mesh. Mixing and stirring aims to obtain a homogeneous mixture of ingredients. Reducing the water content is carried out in the wet process, where the resulting mixture of materials in the form of sludge is carried out in a further process, namely thickening to reduce the amount of water contained so that it becomes a plastic ceramic body. This process can be done by aerating on a plaster table or by using a filter press. The final stage is homogenising the mass of the clay body and free air bubbles that may be trapped. The ceramic body mass that has been kneaded is stored in a closed container, then cured to obtain maximum plasticity.

Formation

There are 3 formation techniques: hand-building, throwing, and casting. In making ceramics by hand-building, there are several well-known methods, namely: pinching, coiling (to raise or enlarge the ceramics being made), and slabbing (to make square or cylindrical ceramics). Rotary technique is used to produce spherical or cylindrical ceramics. The stages of formation in the rotary technique are: centering, coning, forming, rising, refining the contour. Another technique uses the help of molds made from gypsum. This technique is used to produce ceramics in large quantities with the same shape and size. Printing techniques can be done in 2 ways: solid printing and pouring printing.

Drying technique

The drying technique is carried out to remove plastic water bound to the ceramic body. In order to avoid drying too fast, ceramic objects are allowed to air dry at room temperature in the early stages. After there is no shrinkage, drying in direct sunlight or drying machines can be done.

Burning stage

Burning

Combustion is the heart of making ceramics in that it transforms a brittle mass into a solid, hard, and strong mass. Combustion is carried out in a high temperature furnace. The burning process is carried out continuously in the furnace, for 1 day (12 h). With a temperature range of 600 ºC to 1300 ºC. This temperature must be adjusted to the type of clay. For example, clay which is rather hard does not require a very high burning temperature. On the other hand, clay which is still somewhat soft requires a higher temperature for firing. In addition to making ceramics not easily crushed, the burning process is also intended to make this craft more solid and watertight. During firing, the ceramic body undergoes several important reactions, loss/appearance of mineral phases, and weight loss.

Burning of biscuit/bisque

Burning biscuit/bisque is a very important stage because through this burning an object can be called a ceramic. Biscuit is a term to refer to ceramic objects that have been fired at a temperature range of 700–1000 ºC. Burning biscuits is enough to make something strong, hard, waterproof. For glazed ceramic objects, baking biscuits is the initial step so that the object to be glazed is strong enough and able to absorb the glaze optimally.

Art	
Ceramic shapes and motifs	To get an attractive pottery, one of the things a pottery maker does is to give the pottery a decorative motif
	

Ethno-mathematics
The mathematical concepts contained in pottery can be used as innovative culture-based teaching materials so that students can more easily understand mathematics in everyday life. Mathematical concept of

'mortar' pottery: the mortar seen from above is a circular shape, the mortar seen from the side is a parabolic curve, while the parabolic curve is formed from the slice of a cone.
Other examples of pottery are flower pots, umbrella holders and jars. In this pottery, in addition to the concept of a circle, it can also be used to explain the concept of geometric transformation, namely reflection, because if one centre line is taken, the right side will be the same as the left side. For large flower pots it consists of a combination of parabolic curves, tubes and circles. For the body where the umbrella can also be used to describe the shape of a tube with one part uncovered. There is also a jar shape which is a combination of a circle and a spherical space. The bricks contain the concept of rectangles and blocks.
Mathematical concepts can also be identified in pottery craftsmen's activities which include counting activities, measuring activities, and designing activities. Ethno-mathematics in counting activities appears when the craftsman determines the ratio of raw materials for the mixture or clay and when the craftsman determines the clay needed to make a pottery item. Ethno-mathematics in the counting activity appears when the craftsmen use the term fist to estimate the amount of clay needed. Ethno-mathematics in measuring activities appears when the craftsmen determine the diameter of the base and lid and the height of the pottery. With the activity of calculating the composition of the material, the concept of percent and equivalent of comparisons will emerge.

Batik Crafts

Batik is the art of dyeing cloth with a barrier dyeing technique using wax. Batik is one of the popular ancient art forms in Indonesia which has gone worldwide and is recognized by many countries. Batik has been designated by UNESCO as Masterpieces of the Oral and Intangible Heritage of Humanity since October 2, 2009.

Ethno-science

Raw materials for making batik:

1) 'mori' cloth, which is a white material made of cotton (cellulose),
2) melted wax (a mixture of paraffin, microcrystalline and beeswax used to cover parts of the fabric that will be left plain/undyed).
3) starch liquid is a type of colloidal sol (solid in liquid)
4) Peanut oil solution belongs to the colloidal type of water-in-oil emulsion,
5) dyes natural belong to the type of colloidal sol (solid in liquid).
6) The smoke produced from burning wood in the process of pelorodan/boiling to remove batik wax is a type of colloidal aerosol (solid in gas)
7) *'lerak'* soap to remove dirt without fading the color of the batik

Ethno-technology

making batik uses more traditional tools passed down by the ancestors. Equipment in the batik process include: 1) *'canthing'* is a tool made of copper and the handle is made of bamboo. Used to take liquid wax from the pan to be etched on the surface of mori. Wax is the main ingredient used to make motifs on cloth. 2) a small frying pan as a container for heating the wax so that it melts, 3) *'Anglo'* (furnace for heating wax), and 4) *'gawangan'*. *'Gawangan'* is a tool for placing mori when batik is made. It is made of wood or bamboo so it is light and easy to move around.

Ethno-Engineering

Several things must be considered in order to obtain good batik cloth, starting from the preparation of the material. The processing of 'mori' into batik cloth is divided into 2 processes, namely the preparation process and the process of making batik. The preparation process is a series of work on mori so that it becomes a cloth that is ready to be made into batik. This preparatory work includes *'Nggirah'* (washing) and *'Ngetel'*. *'Ngetel'* is removing starch from the mori by wetting the mori with a solution of peanut oil, ash soda, typol and enough water, then drying it. This process is done so that the dye can seep into the fabric fibers perfectly.
When making batik, the temperature of the wax must be hot enough so that the wax seeps into the pores of the fabric.

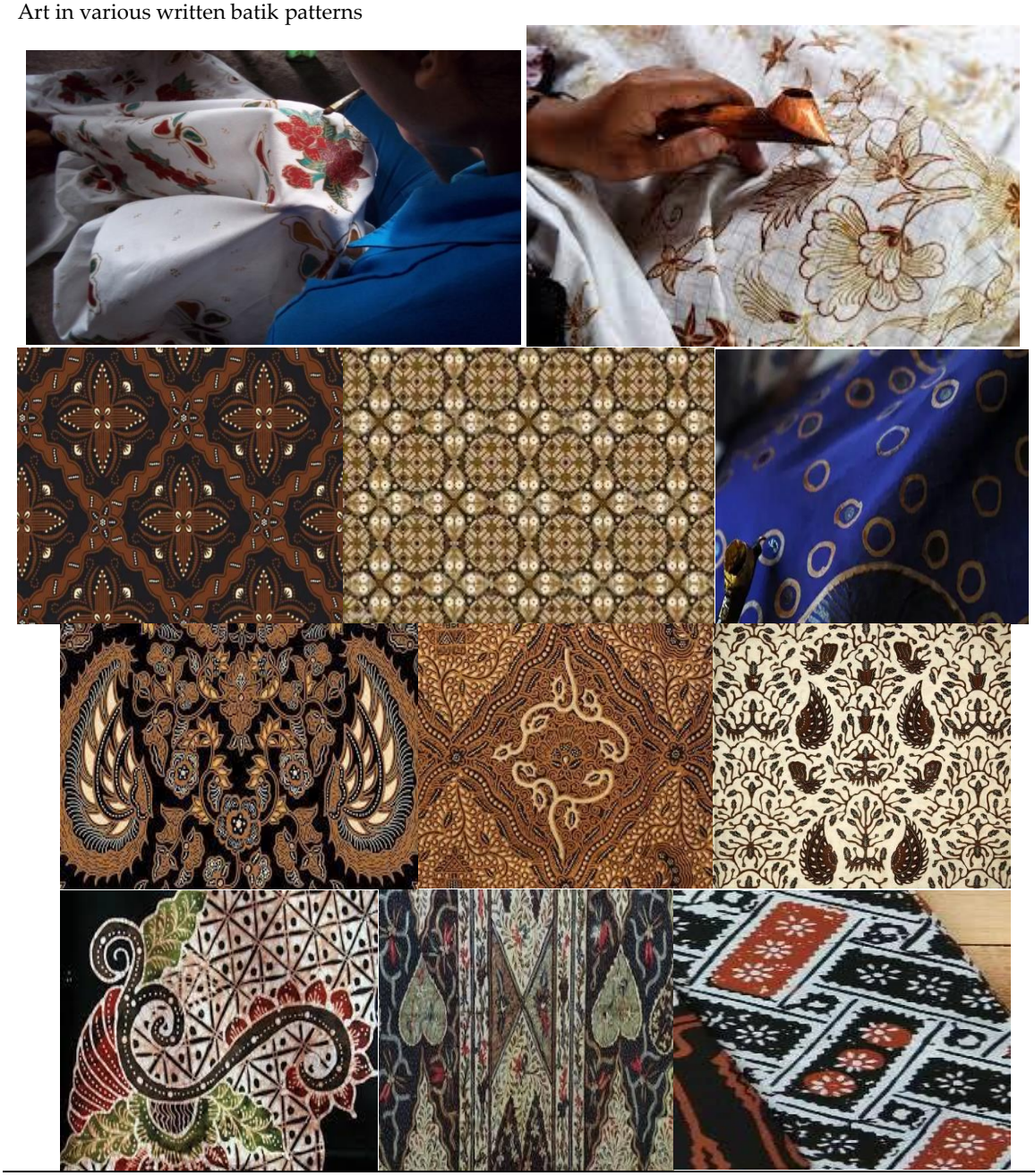
In the coloring process, batik dyeing starts from the lightest color and ends with the darkest color.
Natural dyes are used in traditional batik, especially dyes derived from plants, such as those found in wood, bark, roots, root bark, seeds, seed coats, leaves and flowers. Plants commonly used for batik dyes include mengkudu root (*Morinda citrifolia*) which produces a red color, tegeran wood (*Cudrania javanensis*) which produces a yellow color, tingi wood (*Ceriops tagal*) which produces a brown color, indigo or indigo leaves (Indigofera sp.) which produces a blue color, and mango leaves (*Mangifera indica*) which produces a green

color. Besides that, there are jolawe (elaocorpus folium), tegeran (Cudraina javanensis), Jati (*Tectonagrandis*), secang (*Caesalpinia sappan* Flem.), mengkudu (*Morinda citrifolia*), coconut (*Cocos nucifera*), durian (*Durio zibethinus* L.), mangrove (*Rhizophora mucronata*), and mangosteen (*Gracinia mangostana*).

One of the techniques carried out as an effort to prevent the color of batik from fading and maintaining its quality, when drying batik cloth, is best done in the shade and when washing batik cloth, do not use detergent, but use soap/*'lerak'*.

Art

Art in various written batik patterns



Ethno-mathematics

The process of making batik, if it is connected with mathematics, includes counting, measuring, and counting activities. Mathematical concepts contained in Batik motifs, for example, are straight lines, curved lines, parallel lines, symmetry, points, angles, rectangles, triangles, circles, parallelograms and the concept of congruence. The ethnomathematics contained in Jember batik motifs is geometric transformation which includes translation, rotation, reflection and dilation (Milenia et al., 2022).

The Kangkung Setingkes batik motif, if it is related to mathematics, it is one of the geometrical motifs. The geometric elements in the Kangkung Setingkes batik motif are in the form of points, lines, angles, congruence, congruence, and geometric transformations. One element in the Kangkung Setingkes batik motif can be arranged based on the concept of geometric transformation, namely translation, rotation, dilation, and reflection.

The mori needed is adjusted to the desired short length of cloth, usually rectangular in shape. There is no exact measure of the length of mori cloth because usually the cloth is measured traditionally. The traditional size is called *'kacu'*. *'Kacu'* is a handkerchief, usually square in shape. So, what is called "*sekacu*" is the square size of the mori, taken from the width of the mori. Therefore, the *'sekacu'* length of one type of mori will be different from the *'sekacu'* length of other types of mori. But nowadays, this measure is rarely used. It is easier for people to use the square meter measurement to determine the length and width of mori cloth. The national size is 1 piece of cloth 2.1 x 1.15 m.

Data Collection Tools

The data collection tools used in this study were the assessment instruments for creative thinking and problem-solving skills, as well as in-depth interviews about local wisdom of batik and ceramics. Evaluation of creative thinking and problem-solving abilities was done by using a standardised testing procedure.

Instruments to Assess Creative Thinking Skills

The open-ended test instrument for creative thinking skills consisted of 6 items and problem-solving consists of 10 items that had been declared valid by Indonesian experts and tested. In this study, creative thinking skills were assessed on four aspects: fluency, flexibility, originality and elaboration, while problem-solving skills were assessed through understanding, planning, implementing plans and evaluating problem plans. The aspects of fluency include the ability to solve problems and provide many answers to these problems; or provide many examples or statements related to a particular concept or context. The aspects of flexibility include skills of using a variety of problem-solving strategies; or providing various examples or statements related to a particular concept or situation. The aspects of authenticity include the ability to use new, unique, or unusual strategies to solve problems; or provide the new, unique, or unusual examples or statements. The detail aspects of elaboration included the ability to explain certain procedures, answers or situations in detail, coherently and coherently. These explanations used the appropriate concepts, representations, terms or formulae.

Calculation of test reliability using Alpha Cronbach showed the reliability of the creative thinking test instrument with alpha values of 0.812 and 0.714 for problem solving test items. The time allotted to complete this test is 120 min.

Data Collection Procedure

The data collection was carried out after the learning activities had been completed. The test was given to 80 students who were taking the course of "Chemistry: Concepts and Applications using an ethno-STEAM approach". To collect the data, a "paper and pencil" test was used. The test included an evaluation of students' creative thinking and problem-solving skills.

Data Analysis

The data collected from both tests and interviews were analysed using descriptive statistics and content analysis. The experts' validation was used as the main consideration in deciding whether a local wisdom-containing activity that was explored by the students could be categorized as an ethno-science, ethno-engineering, ethno-technology or ethno-mathematics. Three experts in ethno-STEM-based education have been involved in this study to make validation on the results of exploration and reconstruction of the indigenous knowledge in relation with the STEM activity performed by the students. The obtained quantitative data from the test was analysed using normalised gain values and statistical techniques to identify the Pearson correlation between creative thinking and problem-solving skills.

The gain value was calculated according to Hake (1998) using the equation (1). N-gain (%) obtained by each student both as a whole and per indicator are categorised as in Table 4.

$$N - gain\ (\%) = \frac{score\ postest - score\ pretest}{score\ maximal - score\ pretes}\ x\ 100\% \qquad (1)$$

Table 4

Category for increasing the ability to think creatively and solve problems

Percentage (%)	Category
70 < % ≤ 100	High
29 < % ≤ 70	Medium

Table 5

Interpretation of the correlation coefficient

r value	Interpretation
0.00-1.199	Very weak
0.20-0.399	Weak
0.40-0.599	Medium
0.60-0.799	Strong
0.80-1.000	Very strong

The qualitative data collected from interviews was analysed using content analysis to obtain information regarding students' insight into local wisdom around them in relation to STEAM. This analysis aims to reveal students' views on efforts to strengthen local wisdom values in the digital era, as well as factors that influence the understanding and application of local wisdom values in everyday life.

Findings

The Impact of Ethno-STEAM Learning on Improving Creative Thinking Skills

The average value of N-gain for creative thinking skills is presented in Table 6. Table 6 shows that the average N-gain of creative thinking skills is in the moderate category. The magnitude of this N-gain indicates that ethno-STEAM learning positively influences students' creative thinking abilities. The results of calculating the average score for each aspect of creative thinking skills are presented in Figure 1.

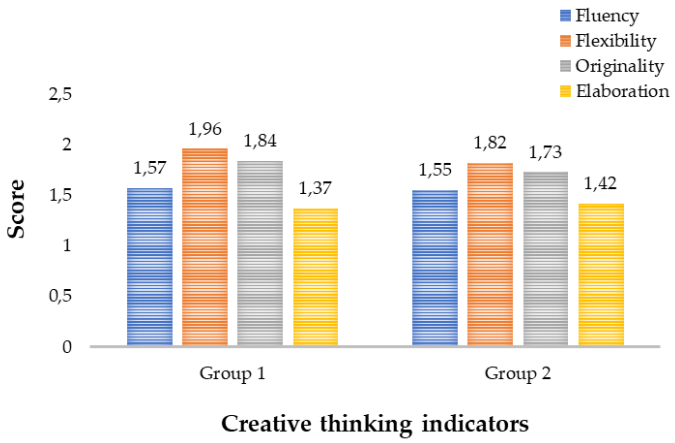
Table 6

The average value of N-gain creative thinking skills

Variable	Subject	Pretest mean	Posttest mean	Gain average score	Achievement level
Creative thinking	Group 1	1.33	6.36	0.3020	Moderate
	Group 2	0.35	5.75	0.3047	Moderate

Figure 1

Indicators of creative thinking skills



Based on Figure 1, it appeared that of the four aspects measured, the aspect of flexibility got the highest average score, followed by fluency and originality, and the lowest was elaboration/detail. This result followed the research by Ramdani et al. (2021) and Hidayati et al. (2023), where the increase in creative thinking in the elaboration aspect was the lowest after the highest originality, flexibility, and fluency. Different results were found by (Habibi, et al., 2020), which stated that the achievement of creative thinking skills in the originality aspect was the lowest, while the elaboration aspect was the highest. In the context of educational assessment, it is unlikely that students will generate completely new ideas that have never been generated before. Thus, in this research, an idea although not new in an absolute sense, can still be considered creative. For example, a student was considered to have produced an original idea when the idea generated is different when compared to the ideas of their classmates (Heard et al., 2025; Lucas, 2016).

The research results on flexibility for groups 1 and 2 obtained an average of 1.89 from the maximum value scale of 3. The aspect of flexibility obtained the highest average score compared to other aspects. This is as conveyed by Kenett et al., (2018). An indicator of flexibility in creative thinking is that students can provide alternative ideas/solutions with different and correct answers to solve the problem of clay scarcity because many clay quarrying locations have turned into housing or industrial areas. The

average experimental class students could provide answers that varied from one to another of the four alternative answers given. Prospective teachers are presented with water pollution problems due to dyes and other materials from batik industry waste. The solution is to treat waste before it is discharged into the waters, bioremediation in rivers and waters, and ask the industry to pay attention to the waste disposal process, using natural dyes in the colouring process. Examples of ideas conveyed by prospective teachers vary from one to another.

The Impact of Ethno-STEAM Learning on Improving Problem-Solving Skills

Gain scores of problem-solving skills are presented in Table 7. Table 7 shows that the problem-solving skills obtained through the ethno-STEAM approach science learning programme are in the medium category. Learning programmes that present problems found in everyday life and involve students in finding solutions to problems can train them in problem-solving thinking skills. Problems with pottery and batik craftsmen are related to raw materials, the decreasing number of artisans, and efforts to increase creativity so that products are competitive and of good quality. The problem of pollution in the environment of the batik and pottery industry also requires thought so that it is not harmful to living things and their environment. These problems were explored by prospective teachers who conducted investigations to find solutions based on STEAM aspects in this study (Bertrand & Namukasa, 2023). The results of the analysis of the achievement of each aspect of problem-solving skills are obtained as presented in Figure 2.

Table 7

Problem-solving score gain

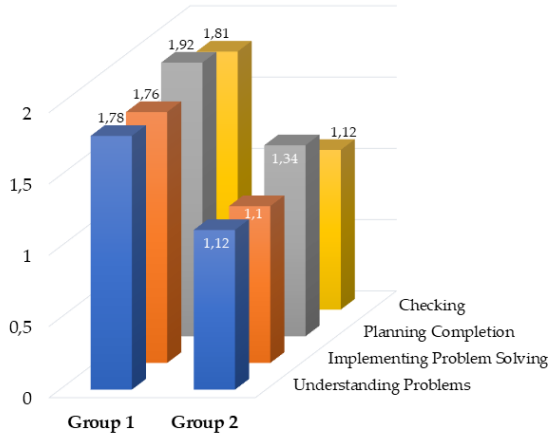
Variable	Subject	Pretest mean	Post-test mean	Gain average score	Achievement level
Problem-solving	Group 1	14.50	29.77	0.31	moderate
	Group 2	3.75	21.50	0.30	moderate

The results of the research indicator of understanding the problem on average are 1.45, with a maximum score of 3. The indicator of understanding the problem is the highest compared to other indicators. Students can write questions about polluted rivers and waters due to batik waste. On average, students can understand the problems marked by students being able to write science concepts, formulate questions, determine the main factors, and map problems. The study's results showed that the indicator for planning a solution averaged 1.63 out of a maximum score of 3. The indicator for planning for solving problems was the lowest compared to other indicators. Students only mentioned answers to science concepts but did not explain the relationship between concepts in the problem.

Individual characteristics in problem-solving are applying and using the right mathematical equations following the concepts, principles, rules, formulae and laws to solve problems (Ida et al., 2021). The study's results showed that the indicator of carrying out problem-solving averaged 1.43 out of a maximum score of 3. The indicator of carrying out problem-solving had the third highest acquisition. On the whole, students can write science concepts to solve river and water pollution problems due to batik waste. Those results indicate that the students able to implement problem-solving.

Figure 2

The average score of the problem-solving skill aspects



Correlation between Creative Thinking Ability and Problem-Solving Skills

Table 8 presents the findings of the correlation test conducted between creative thinking and problem-solving skills. The results of the correlation test between the variables of problem-solving and creative thinking skills are shown in Table 6, and they indicate a link with a value of 0.679. According to the interpretation of the correlation table, the correlation between the capacity to creatively think and the ability to solve problems falls into a category that is classified as very strong. Thus, it can be inferred that there is a positive and very substantial link between creative thinking and problem-solving skills. This correlation follows the findings of other researchers who found that there is a positive relationship between creative thinking and problem-solving skills (Meitiyani, et al., 2021).

Table 8

Correlation test of creative thinking and problem-solving skills

		Problem-solving	Creative thinking
Problem-solving	Pearson Correlation	1	0.679
	Sig. (2-tailed)		0.001
	N	80	80
Creative thinking	Pearson Correlation	0.679	1
	Sig. (2-tailed)	0.001	
	N	80	80

** *Correlation is significant at the 0.01 level (2-tailed).*

Discussion

Ethno-STEAM is a learning approach as an integration of two learning approaches, i.e., ethno-science approach and STEM aspects. Ethnoscience includes an activity to explain the indigenous science (knowledge developing in a society) in the scientific science point of view. In this case, if the teachers and lecturers wanted to implement the ethnoscience-integrated learning, they were required to understand and recognise the local practices and its potencies to be utilised during the learning process. STEAM is a learning approach relating the science, technology, engineering, art and mathematics strongly emphasized in the 21st century learning.

Scientifically, a learning could be categorized as a ethno-STEAM learning should fulfil the followings.

a. In the context of learning, the ethno-STEAM is a project-based learning model that could be used by the students to overcome the challenges and problems, as well design the problem solving.
b. This model integrates the methodological and conceptual aspects/elements to direct the students in designing and solving the problems using a practical approach.
c. This process is modelled based the stages similar to an engineering design process. First, the students are directed to identify the problems or needs that are essential to be solved, provide an initial understanding to the objectives of the project. After a while, the students would learn to collect/gather the relevant information and data through research and analysis. The subsequent process would involve the concept formulation; the students are invited to creatively think and result various design ideas as potential and effective solutions. In addition, the students are required to evaluate and do some improvements on the solution.
d. During the implementation of learning, the lecturers accommodate the formation of constructive learning environment; the lecturers as widely as possible would facilitate the information search on the local wisdom and analysis of the concepts containing in the local wisdom.
e. The lecturers as a facilitator, motivator, manager and supervisor should provide the students with motivation and feedback regarding the progress of the project they are working on.

The Impact of Ethno-STEAM Learning on Improving Creative Thinking Skills

From Figure 1, it can be seen that the aspects of fluency in groups 1 and 2 attain an average of 1.56 from the maximum value scale of 3. The aspect of fluency in creative thinking got the second highest rank after flexibility. This aspect of flexible thinking was shown by students being able to write down creative ideas to solve the problem of environmental damage due to pottery making by providing correct, complete, systematic, and acceptable explanations to all groups. On average, students can provide answers to more than three solutions to problems. Creative ideas for teacher candidates arose when given the problem of the difficulty of obtaining raw materials for making pottery. Apart from that, other ideas presented were innovations in shapes, colours, and motifs. The answers given by more than one student indicating that prospective teacher students in general already have fluent thinking (Larraz-Rábanos, 2021).

The originality aspect is measured when prospective teachers are presented with the problem of pottery craftsmen delaying the production process due to the rainy season so that the pottery they produce does not dry quickly. As a result, pottery production has decreased. The idea conveyed by prospective teachers regarding this problem is to use technology to dry pottery to fulfil the value of authenticity. Making an oven around the printing process is one of the original ideas because, so far, this technology has not been applied by craftsmen. The research results showed that originality aspect data for groups 1 and 2 obtained an average of 1.76 from a maximum value scale of 3. The indicator of originality in creative thinking has the third-highest score. The original indicator of creative thinking is that students can write down creative ideas to solve problems faced by pottery and batik craftsmen correctly and have original (unique/out of the box) characteristics (Ariyatun, 2021). The average student of the experimental class can provide unique answers.

For the elaboration aspect, the data from groups 1 and 2 obtained an average of 1.40 from the maximum value scale of 3. The detail indicator in creative thinking has the smallest gain compared to other indicators. The detailed indicator of creative thinking is that students can correctly write creative ideas to solve batik colouring problems accompanied by detailed explanations. The average student in the experimental class can provide detailed/detailed answers. Prospective teachers are presented with the problem of air pollution for people close to pottery kilns. Their suggestion was to build a chimney and a kiln far from residential areas. These ideas are explained in detail about the shape of a chimney

for pottery craftsmen. This indicates that prospective teachers were able to explain their ideas as a solution to these problems.

The increase in the four indicators of creative thinking in this study was not optimal based on the average acquisition being below a value of 2 out of a maximum range of 3. The lack of optimal improvement in creative thinking skills was suspected because students were not used to being given non-routine problems and real problems faced by society. In addition, this learning programme is designed for seven meetings, and students may need more time to develop their thinking skills optimally. According to DeHaan (2009) and Gube & Lajoie (2020) that students tended only to be able to solve problems that they often or have encountered (routine problems) and experience difficulties when facing unusual problems (non-routine problems) so that they can solve routine problems in the form of memorisation and difficulty solving problems that are reasoning. As the results, the learning could help students to produce and develop unique ideas (Ariyatun, 2021; Gube & Lajoie, 2020).

The Impact of Ethno-STEAM Learning on Improving Problem-Solving Skills

Self-evaluation of problem-solving skills involved the activity of re-checking of previous problem-solving and analysing the weaknesses and strengths of problem-solving (OECD, 2014). The results showed that the average problem-solving evaluation indicator for the experimental class was 1.55 out of a maximum score of 3. The second-highest problem-solving evaluation indicator was smaller than the problem-understanding indicator and higher than the other two indicators. This research is in line with what was conveyed by Joynes et al. (2019) that using the ethno-STEAM approach, students' abilities in defining problems, exploring problems, determining alternative solutions, and planning solutions with quite good category. Students were not accustomed to solve problems, especially those requiring linkages between science, technology, and engineering Students also still have difficulty if given complex problems. As seen in the research results, the increase in the problem-solving ability of prospective teachers was only in the moderate category (Wijayati et al., 2019). However, when viewed from the ability to plan and implement strategies, it is still low, possibly due to a common understanding of the science concepts (Yulianti et al., 2020).

Table 6 and Table 7 show that the average N-gain of the research subjects was in the moderate category, both in creative thinking skills and problem-solving skills. The magnitude of this N-gain indicates that Ethno-STEAM learning positively influences students' creative thinking and problem-solving skills. STEAM is the right learning model to provide a holistic competence for students in order to prepare for future challenges dominated by the use of technology, while still appreciating traditional culture (Chung et al., 2022). The increase in problem-solving and creative thinking skills that applies to Ethno-STEAM learning is due to learning activities designed to facilitate processes that develop these two thinking skills (Rohmantika & Kurniawan, 2021). Ethno-STEAM learning in this study presented the community's practices in making pottery and batik by linking science, technology, engineering, art and mathematics. In order to come up with the most effective response, the issue is analysed in groups. Students investigate STEAM-related facets of the community's conventional knowledge as part of the process of determining the best solution. In the local wisdom of making pottery, the colloid concept is associated with the technology of making handicrafts from clay with high-firing techniques. The pottery results from the heating process at high temperatures will produce pottery with a high selling value, especially if it is designed with a unique model and has a varied colour appearance.

Thus, learning that presents problems and carries out investigations to find solutions facilitates the emergence of creative and problem-solving thinking processes (Nur et al., 2020). Teachers may urge pupils to do autonomous research activities or encourage divergent thinking in scientific process skills in order for them to acquire creativity and problem-solving skills via discovery activities. As previously reported, that factors like a) experience in solving problems which can be viewed from memory, problem solving structure, speed and efficiency, and metacognitive monitoring skills; b) self-regulation related to thinking strategies in solving problems; c) the ability to identify problems and breadth of insight; d) the ability to use certain symbols or objects; e) the ability to identify goals, rules, criteria, and

assess the correctness of the solutions created; and f) insight/knowledge of the problems (Maltin, 1994). Meanwhile, four factors influencing the students' problem-solving skills are knowledge, beliefs and affect, control and sociocultural factors could influence the problem-solving skills (Carson, 2007).

Correlation between Creative Thinking Ability and Problem-Solving Skills

One context that supports the growth of creative thinking skills is a problem-solving activity. Students need the ability to solve problems, especially complex ones, creatively. The ability to think creatively is a cognitive skill to provide a solution to a user problem and to provide a novelty from simple ideas (Gube & Lajoie, 2020). Problem-solving skills train individuals who take information and use it, criticise, ask questions, and solve problems creatively. Experience, knowledge and intuition applied simultaneously to a single problem are the products of creative thinking that can be quickly and effectively used in problem-solving (Nurita et al., 2017).

Teaching science based on the scientific method could enhance students' degree of creative thinking, academic accomplishment, and attitude toward gaining science information (Cook & Bush, 2018). Learning activities that present challenges, exploring them, and discovering answers to them enhance creative thinking skills. Learning scientific process skills in schools is critical for encouraging creative thinking and developing science professionals' potential and prospects.

Deeper engagement with mathematics at each stage of learning encourages learners to construct in-depth understanding of concepts, while increasing their rigor. During the learning process, the teacher encourages pupils to be involved in the use of mathematical concepts, such as measurement, calculation and the use of tables or graphs (Bertrand & Namukasa, 2020). When they solve problems creatively, they practice fact-based mathematical concepts such as addition, subtraction, division and multiplication of numbers, rotating with angles specific measures, measure/calculate the circumference, area and volume.

In this study, the prospective teacher students were trained to analyse data, create, discover, explore, imagine, present, apply, and alter scientific knowledge. Learners' ability to think creatively in science may be nurtured via the introduction of inquiry-based activities and process skills. Prospective teachers' capacity for original thought and problem solving is honed via exercises drawn from the community's local knowledge and an examination of existing challenges. Students' creative thinking, problem-solving abilities, and curiosity were all found to rise, and a deeper awareness of the world and its possibilities was gained (Sumarni & Kadarwati, 2020; Sumarni et al., 2022).

Conclusion and Recommendations

It can be inferred from the foregoing analysis and discussion that prospective teachers were in the moderate range for critical thinking and problem-solving skills. It may benefit from a more in-depth understanding of scientific concepts by adopting an ethno-STEAM approach to their teaching and learning process. Science education with an ethno-STEAM focus has been shown to help moderately-competence teachers in increasing their capacities for creative thought and problem solving, as shown by the findings and discussions previously presented. The STEAM approach facilitated students to find related concepts in order to solve problems that exist in everyday life. Incorporating STEAM into the classroom helps students make connections between what they study and the actual world, leading to more relevant science education.

In the case of the students' creative thinking skills, the students were observed to not be well acquainted with complex and real problems. They seemed needed more time to get accustomed with the problems and to develop their thinking skills. In this study, it was clearly shown that the non-routine problems introduced to the students could produce unique ideas and thoughts. Meanwhile, in the case of the problem-solving skills, the ethno-STEAM approach in this study could help students to solve more complex problems, especially those requiring linkages between science, technology and

engineering. Moreover, the students' conceptual understanding of the basic concepts could help the students in improving their problem-solving skills.

In addition, in the case of the correlation between creative thinking and problem-solving skills, the students' ability to think creatively in science may be nurtured via the introduction of inquiry-based activities and process skills. Prospective teachers' capacity for original thought and problem solving is honed via exercises drawn from the community's local knowledge and an examination of existing challenges. Students' creative thinking, problem-solving abilities, and curiosity were all found to rise, and a deeper awareness of the world and its possibilities was gained. From the ethno-STEAM learning activities, all students explained that they felt happy, excited through the process, wanted to learn more and received challenges that would not be obtained through the learning they were used to.

For educators, researchers and policy makers, the authors recommend applying the ethno-STEAM learning approach as proposed in this study to equip students with immersive learning experiences in science, technology, engineering and mathematics as well as local culture. It is highly recommended that the educators (lecturers and teachers) could use this learning model with the ethno-STEAM approach as an alternative to train the students' creative thinking and problem-solving skills in studying science or other fields of study to address 21st century challenges. In general, the students' creativity would be hampered if students do not have an adequate mathematical basis and do not routinely think correctly. These thinking routines are useful for sparking questions and thoughts about a topic. Questions that should arise as a start include: Why… What is the reason… What if…… would it be different if… Other researchers in ethno-STEAM education could conduct the continued research the learning model with STEAM approach focusing on the improvement of effectiveness and flexibility in various educational contexts. In addition, examining the effectiveness and the suitability of the learning model with ethno-STEAM approach at various educational level; either at middle schools, higher education, or other educational levels.

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Overcoming stereotypes in teacher training: Responses from a systematic review to address the gender gap in STEM

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ABSTRACT
The unequal presence of women in scientific and technological fields compared to men may have its origins partly in the compulsory educational stages and performance of teachers involved therein. This study aims to systematically review the existing literature on science and technology teacher training to address the gender gap in STEM studies, identifying aspects with didactic implications. Following the PRISMA systematic methodology, 37 references published between 2008 and 2022 were selected. The studies were carried out in 14 countries following different qualitative and quantitative research methodologies, together with the design and implementation of training proposals. The result of the content analysis of the studies is expressed in five emerging categories: attitudes towards science and technology and their teaching, perceptions and beliefs regarding the student profile, educational methodologies in pre-service teacher training, and the emotions and invisibility of female role models. In view of the results, up to now not enough attention has been paid to teacher training in aspects to address the teaching of scientific-technological disciplines from a gender perspective. It is proposed to train teachers through reflection to detect the persistence of gender inequality, break down stereotypes and incorporate female role models into scientific-technological education, as well as consider the effect of emotions in the learning of these disciplines. The ultimate aim is to incorporate a gender perspective into the teaching identity of future science and technology educators and, so that it is reflected in their teaching and contributes to reducing the gender gap in STEM professions.

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Introduction

At present, and despite the high demand for jobs in Science, Technology, Engineering and Mathematics (STEM) related fields, this situation being of special concern in the case of girls (Cadaret et al., 2017; Gómez et al., 2022; Holmegaard et al., 2012). According to UN data (2023), female representation accounts for just over 35% in these studies and less than a third in the workplace, being even lower in cutting-edge sectors such as artificial intelligence, where only one in five professionals is a woman. According to various studies, this circumstance begins to manifest itself in the stages of compulsory education, mainly in the adolescent period where girls' lack of interest in scientific-

technological studies becomes apparent (Kerkhoven et al., 2016; Patall et al., 2018; Pey-Tee & Subramaniam, 2023; Vázquez & Manassero, 2008).

Barriers to Women's Participation in STEM

The underrepresentation of women in STEM disciplines is deeply rooted in a complex interplay of historical, social, cultural, economic, racial, ethnic and institutional factors (Avolio et al., 2024; Owuondo, 2023; Page, 2024; Shah et al., 2024). Historically, gender norms and stereotypes have positioned women in subordinate roles within families, societies and organisations, perpetuating their exclusion from fields traditionally dominated by men (Amirtham & Kumar, 2023; Cheryan & Plaut, 2010). Cultural and patriarchal traditions have further reinforced these disparities, particularly in regions where women face systemic barriers to access education and career advancement in STEM (Avolio et al., 2024; Studdard, 2002). Institutional practices and labour-economic dynamics exacerbate these challenges, as women often encounter a lack of role models, insufficient support mechanisms, and discrimination in leadership roles (Avolio et al., 2024; Hoyer, 2024). Moreover, the masculine culture prevalent in fields such as engineering, computer science and physics undermines women's sense of belonging and self-efficacy, contrasting with the comparatively better gender balance in disciplines such as biology and chemistry (Cheryan et al., 2017). These barriers, compounded by factors such as race, ethnicity and socioeconomic status, create a multilayered problem that hinders progress towards achieving gender equity in STEM worldwide (Amirtham & Kumar, 2023; Hoyer, 2024).

Among the key causes, studies such those by Archer et al. (2010) and Rossi and Barajas (2015) point to the lack of female role models in these knowledge fields, which could explain why girls do not opt for these disciplines. Kerkhoven et al. (2016) and Sáinz (2017) argue that another issue that could be having an influence on this is the presence of gender biases and clichés associated with people working in STEM fields (e.g. lack of empathy and antisocial characteristics) promoted by different spheres of society, including the education system. This gives rise to identity-related problems in girls who internalise an image of STEM disciplines loaded with stereotypes and disconnected from their own interests (Archer et al., 2010; Ceci et al., 2009; Martín-Gámez et al., 2022; Wang & Degol, 2017). Added to this is the traditional way of teaching and the androcentric image students have of scientific and technological disciplines, generally associated with gender stereotypes attributed to professionals in these fields (Del Olmo-Muñoz et al., 2022). In this regard, and although it is hoped that teachers do not explicitly support them, even unconsciously or unintentionally, it seems these gender stereotypes may persist and have been integrated into their own experiences since childhood, affecting their interaction with students (Bertrand et al., 2005; Gheith & Aljaberi, 2019).

Gender-Responsive Teacher Training and Educational Interventions in Scientific-Technological Disciplines

Studies such as that by Merayo and Ayuso (2022) reveal that very few teachers from scientific-technological fields receive gender-responsive training, and state that reducing the gender gap in science and technology education would have a positive impact on employment, helping to reduce bottlenecks in the job market and increase the productivity of women. There is a notable gap in existing research regarding practical training programmes for pre-service teachers training that effectively promote gender-perspective teaching practices (Hasenhütl et al., 2024; Miralles-Cardona et al., 2023; Rarieya et al., 2024). Although some studies have addressed gender-perspective STEM instruction (Hasenhütl et al., 2024; Miralles-Cardona et al., 2023), they largely focus on evaluating teaching ideas rather than developing comprehensive training programmes that equip educators with the skills and knowledge necessary to perform STEM teaching with a gender perspective. Miralles-Cardona et al. (2023) highlight that cultural and contextual challenges, such as those observed in Greece and Spain, often leave pre-service STEM teachers graduating without sufficient confidence in gender knowledge and skills, emphasising the need for culturally relevant training programmes. In this regard, Rarieya et

al. (2024) note that while ongoing professional development in a pedagogy with a gender perspective is crucial, the lack of structured programmes offering continuous learning opportunities, including mentoring, coaching, and reflective practices, hinders teachers' ability to effectively understand and apply these strategies. It is thus vital to set into motion interventions that respond to this gender gap and assure equal opportunities for learners, with the essential collaboration of the entire educational community (Holmlund et al., 2018; Sáinz, 2020). This, in addition, means following the guidelines of those who promulgate Nature of Science (NOS) teaching, asserting that attention also be paid to the socio-cultural, political, economic, etc., circumstances and contexts that influence its development in a decisive way, and which the Science, Technology and Society (STS) approach has integrated from the outset (Acevedo-Díaz & García-Carmona, 2016).

In this regard, teacher training should provide ideas and tools for promoting the creation and utilisation of didactic resources and materials that adopt a gender perspective, seeking to dismantle gender stereotypes and roles (Lleixa et al., 2020). Such training should raise awareness of gender inequalities, affording coeducation its true meaning and importance. The objective is a conscious and explicit intervention in the breaking down of gender biases and prejudices, revealing situations of discrimination and inequality, and favouring comprehensive training in all its diversity and richness. Furthermore, as Esteves (2018) and Martín-Gámez et al. (2021) set out, it is necessary to undertake an in-depth review of teaching resources such as textbooks, to include inclusive vocabulary, avoiding stereotyped and sexist content, and replacing images of roles traditionally assigned to women or men with the presence of both genders in the performance of various functions.

In short, the scarce participation of women in science and technology translates into a loss of talent, of new innovating scientific perspectives, socioeconomic development, competitiveness and social justice (Vázquez-Cupeiro, 2015). In order to make efforts to combat such a situation and promote diversity through equal participation and excellence of men and women it is necessary to reflect on what can be done from science-technology education. Teachers in this sense may be key, it being necessary to act from their initial training to make them aware of the problem and provide capabilities that permit them to tackle the teaching and learning of scientific-technological disciplines from a gender perspective.

Aims of the Research and Research Question

The aim of this work is to conduct a systematic review of what has been achieved so far in science and technology teacher training to help combat the gender gap in STEM studies, identifying aspects that may have didactic implications. The purpose is to summarise the available scientific information on this topic, increase the validity of the conclusions drawn from individual studies and identify aspects that may have didactic implications that can be extrapolated to future research (Petticrew & Roberts, 2006). Specifically, with the present study, the following research question is established: What strategies and methodologies have been researched in the context of science and technology teacher training to effectively incorporate a gender perspective and reduce the gender gap in STEM education?

The aims of the systematic review are to synthesise existing literature on gender perspectives in science and technology teacher training and to identify gaps in the current research, and to highlight key considerations to incorporate a gender perspective into teaching identity of future science and technology educators.

Significance of the Study

The findings of this study will have significant implications for science and technology teacher training. By synthesising the existing literature on gender perspectives, this review will highlight the critical need to address the gender gap in STEM education. Additionally, the results will serve as a valuable resource for policymakers in designing initiatives and frameworks that will foster gender

equity in education. Ultimately, this study will lay a solid foundation for future research aimed at integrating a gender perspective into pre-service science and technology teacher training.

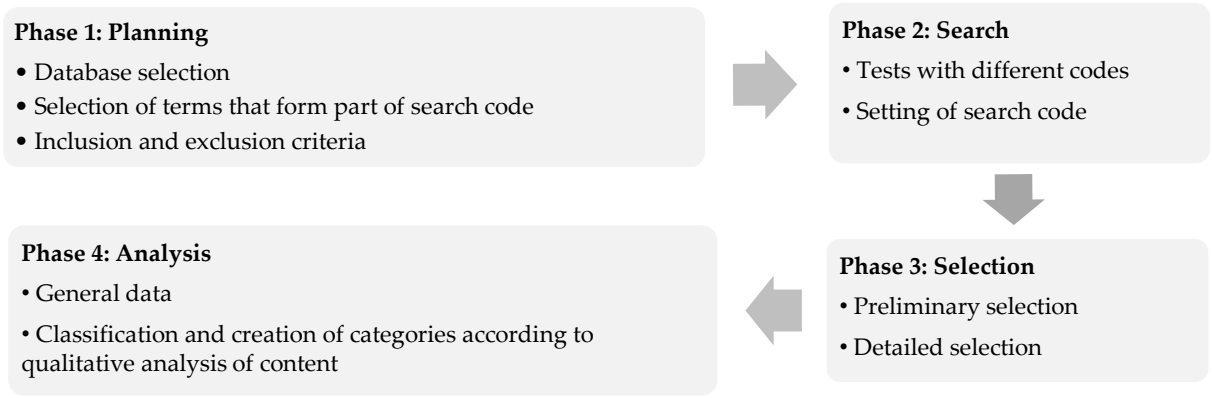
Method

Bibliographical Search Planning and Strategy

The bibliographical search was exhaustive and performed by selecting publications based on a series of criteria, in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, permitting valid and reliable evidence to be obtained. This statement is designed to make systematic reviews transparent, complete and accurate, facilitating evidence-based decision-making (Moher et al., 2009; Page et al., 2021). The review was carried out in four phases: planning, search, selection, and analysis (Figure 1).

Figure 1

Phases of bibliographical review method used



Phases 1 and 2: Planning and Search

The study followed the PRISMA guidelines to ensure transparency and rigor in the systematic review process. To ensure the methodological rigor of the included studies, the following custom quality assessment criteria were applied: relevance to the topic, clarity and transparency of objectives and research questions, rigor in methodology, consistency between study findings and conclusions drawn, and quality of publications. The process began with the selection of the two most categorise and comprehensive social science databases, Web of Science (WOS) and Scopus (Ramírez-Segado et al., 2021). In turn, the search code terms were selected, amongst those that had previously been observed in articles related to pre-service teacher education and the lack of interest in STEM studies on the part of girls.

There was then a planning of the specific search criteria in terms of inclusion and exclusion of references found, considering the following eligibility criteria:

- Studies specific to the pre-service teachers training and directly related to the subject addressed.
- References published in Spanish and/or English.

Considering this framework, the three authors of this work applied the inclusion and exclusion criteria, as well as reference selection. Subsequently, the results obtained were compared, and in cases where there were discrepancies, a discussion ensued until an agreement was reached among the three researchers. This validated process contributed to minimise the limitations of the study, i.e. the risk of bias.

The process of conducting this systematic review was designed to minimise the risk of bias at every stage, following a rigorous and validated methodology. The selection of databases (Web of Science and Scopus), recognised for their comprehensive coverage and categorisation of social science research, was the first step to mitigate selection bias. These databases ensured access to a broad and diverse range of high-quality references. The search terms used were carefully chosen based on prior observations in articles related to pre-service teacher education and the lack of interest in STEM studies among girls. This strategic selection aimed to reduce potential biases related to search strategy design, ensuring the inclusion of studies most relevant to the research objectives. Additionally, eligibility criteria were clearly defined before the search began, focusing on studies directly related to pre-service teacher training and published in Spanish and/or English. This predefined framework helped mitigate biases by applying consistent standards across all references. Regarding reporting biases, we acknowledge that the reliance on published literature can introduce certain limitations, such as publication bias, where studies with negative or non-significant findings may be underrepresented. To address this, we included references from grey literature sources where available and documented any potential evidence of selective reporting within the studies analysed. We also considered the possibility of language bias by incorporating studies published in both Spanish and English, expanding the scope of this review to minimise this form of bias. Finally, while our methodological rigor helped mitigate these biases, we acknowledge that some level of undetected bias may remain, particularly regarding the comprehensiveness of the available literature and the inclusion of unpublished studies. This limitation is inherent to systematic reviews. However, by combining independent evaluations, predefined criteria, and thorough discussions, the risk of bias has substantially been reduced, enhancing the reliability of this review findings.

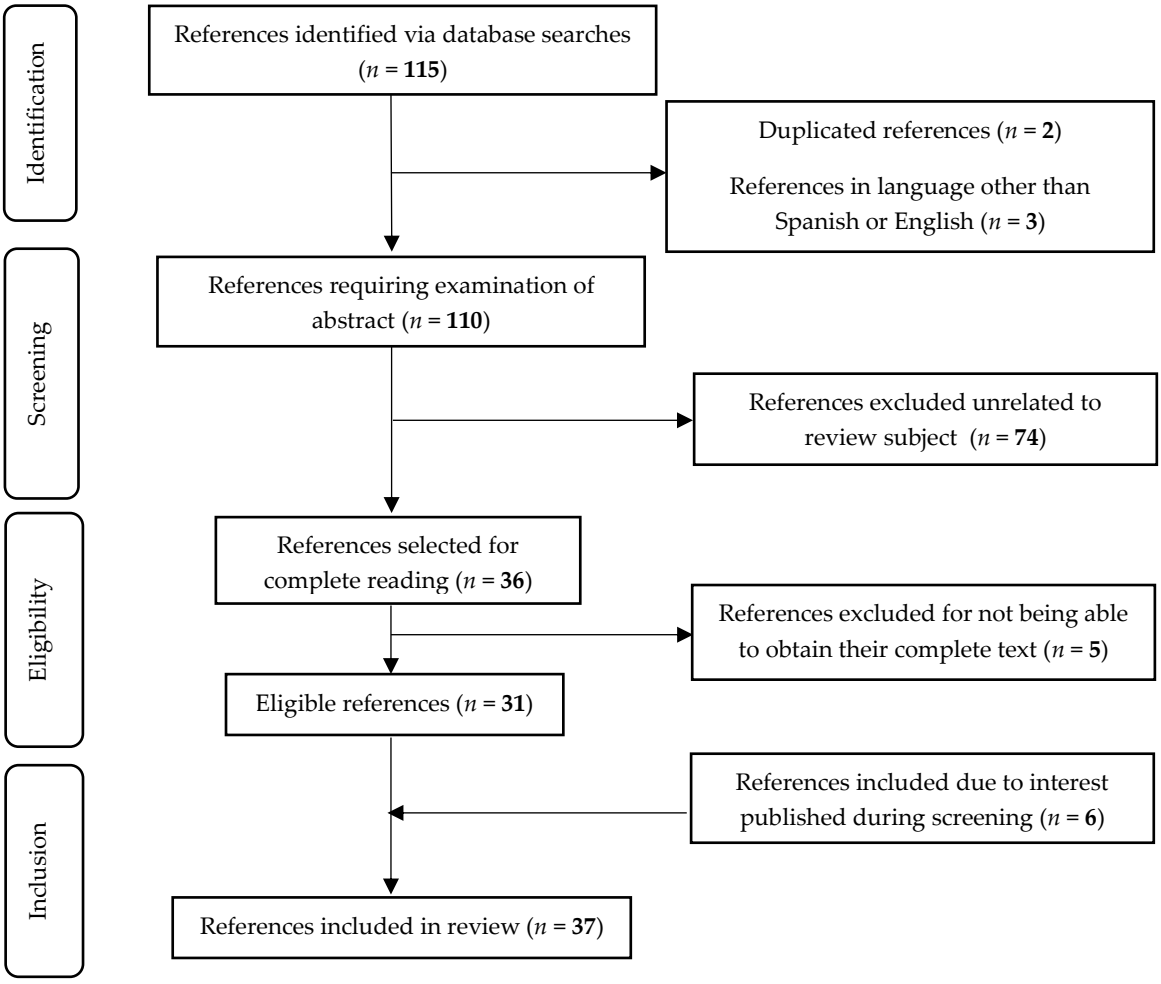
Next, tests were carried out with 24 different codes, in order to obtain results in the two databases that included all of the desired search terms, not only in the title, but also in the abstract and keywords of each publication. As a result of a long process of reflection, the chosen code was: (STEM study* OR STEM education* OR "science* education*" OR "attitude* toward*" science*) AND (teacher* training OR "pre service*" teacher*) AND (gender* role* OR gender* difference* OR gender* stereotype* OR gender* gap* OR gender* issue* OR gender* identity* OR gender* discrimination* OR gender* perspective*). The use of asterisks (*) allows finding declinations, and inverted commas (" ") restricts certain words to appear together.

Phase 3: Selection

The search strategy employed provided a total of 115 references (109 from WOS and 6 from Scopus), 2 of which were excluded as duplicates and another 3 were rejected for being written neither in Spanish nor English. Following the reading of their abstracts, of the 110 references, those that did not address the review subject were screened, leaving a remaining total of 36 publications. 5 of these were excluded as it was not possible to obtain their complete texts. 6 more examples were added to the 31 eligible studies that were considered to be of interest and published during the screening and eligibility process. Finally, a total of 37 bibliographical references (published from 2008 onwards) were considered as valid for the review, shown with an asterisk (*) in the bibliographical references section, of which 31 are articles published in scientific journals and 6 are proceeding papers included in conference record books. The complete process carried out for the selection of studies is outlined in Figure 2 flowchart.

Figure 2

Reference selection PRISMA diagram



Phase 4: Analysis

The analysis phase was divided into two parts. The first involved an initial analysis from which general data were extracted, including the country the research pertained to, the year it was carried out and the educational level of the participating teachers. In the second part an analysis was performed focusing on the content of the studies. Following the complete reading of the 37 selected works, they were classified, firstly considering what the study carried out consisted of and, secondly, what content it addressed. There was then an inductive categorisation process to identify common patterns. Following the generation of some initial categories, more specific categories were created as the analysis progressed, leading to a system of interrelated categories.

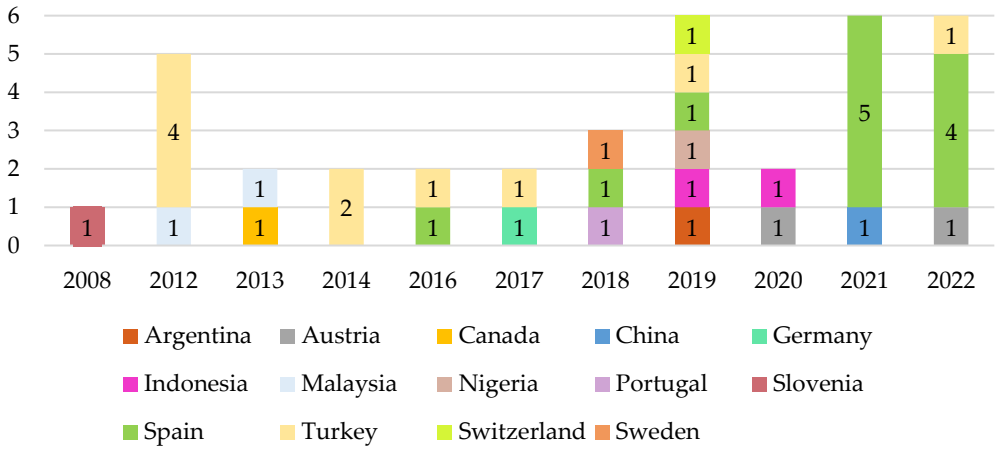
Findings

General Data

The 37 selected studies conducted their research in fourteen countries (Argentina, Austria, Canada, China, Germany, Indonesia, Malaysia, Nigeria, Portugal, Slovenia, Spain, Turkey, Switzerland, and Sweden) and were published between 2008 and 2022. The highest number of works came from Spain and Turkey, 12 and 10, respectively, and 2019, 2021 and 2022 were the years that saw the most studies published, 6 in each (Figure 3).

Figure 3

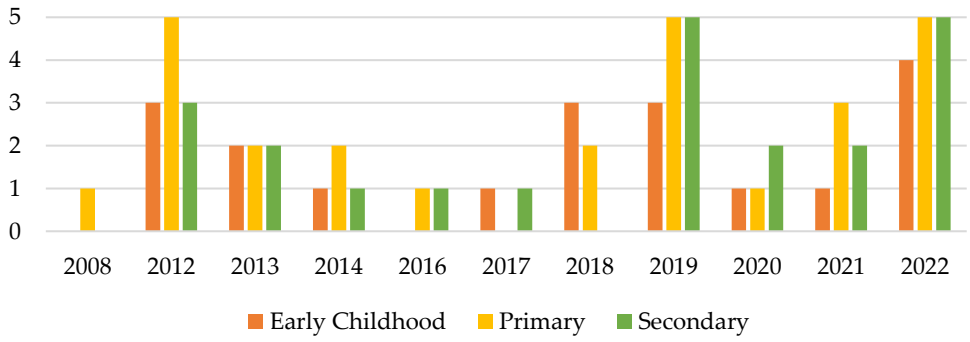
Countries research carried out and year of publication of the 37 studies included in the review



Moreover, attention should be drawn to the fact that in regard to the studies carried out on pre-service teachers (PST), 19 studies were from Early Childhood Education (ECE) (stage between 0-5 years of age), 27 studies from Primary Education (PE) (stage between 6-12 years of age) and 22 studies from Secondary Education (SE) (stage between 13-16 years of age). We analysed studies that focused their research on one, two, or all three educational stages. It can also be appreciated that, in recent years, research has focused more on PE and SE future teachers, which may be due to the lack of interest on the part of students, and above all girls, in science-technology studies at baccalaureate and university level (Figure 4).

Figure 4

Educational stages of the trainee teachers participating in the research and year of publication of the 37 studies included in review



In line with the aim of synthesising the existing literature on gender perspectives in science and technology PST training education and identifying gaps in current research, our results show that the

concentration of studies in certain regions and years could introduce a risk of bias, particularly in terms of geographical and temporal biases. This could limit the generalisability of the findings and may suggest an overrepresentation of studies from specific contexts, such as Spain and Turkey. The underrepresentation of other regions may lead to an incomplete view of the global landscape of gender-sensitive science and technology PST training education. On the other hand, the possible exclusion of publications not in English or Spanish could have limited the diversity of the included studies. There could also be publication bias, as studies showing positive results on the inclusion of a gender perspective in science and technology PST training education are more likely to be published, while those with neutral or negative results may remain unpublished.

Category Classification and Creation

The results of the content analysis show that the studies included in the review revolve around two axes:

1) Results of qualitative and quantitative research on PST attitudes, emotions, perceptions or beliefs influenced by stereotypes in relation to scientific-technological disciplines (31 studies).
2) Design and implementation of proposals for PST education aimed at analysing PST emotions, skills and self-efficacy when faced with different innovating methodologies in scientific-technological disciplines (6 studies).

These findings align with the aim of highlighting key considerations for incorporating a gender perspective into the teacher identity of PST in science and technology fields. Furthermore, they are relevant to the research question: "What strategies and methodologies have been investigated in the context of science and technology teacher training to effectively incorporate a gender perspective and reduce the gender gap in STEM education?" The research shows that there is a clear focus on how gender-related stereotypes impact PST' perceptions and emotions. The studies in the first axis (31 studies) explore how stereotypes shape PST' attitudes and beliefs, with many focusing on how gender biases in STEM impact PST' confidence, interest, and pedagogical approaches. These insights are crucial for identifying effective strategies for incorporating a gender perspective into teacher training programmes. However, the second axis (6 studies), which focuses on the design and implementation of proposals aimed at analysing the emotions and self-efficacy of higher education teachers, highlights the need for more specific and innovative methodologies that actively address gender inequalities in scientific and technological disciplines. Our study highlights existing gaps in the research, particularly regarding innovative methodologies and comprehensive strategies that directly address the gender gap in STEM education. The risks of bias, as mentioned in previous sections -specifically reporting and geographical biases, as well as the potential impact of publication and language biases- should be carefully considered when interpreting these results and acknowledging the limitations of our study. Future research should focus on addressing these gaps by exploring novel strategies and methodologies.

The categorisation process involved constructing a system of emerging categories, which allowed the organization and classification of qualitative data (content of analysed references) based on various thematic criteria (Miles et al., 2014). The process began with a thorough reading of the 37 selected studies, during which initial codes were assigned to key themes and findings that emerged from the data. These codes were then grouped into broader categories. As the analysis progressed, these initial categories were refined and expanded to reflect the recurring patterns and relationships identified across the studies. The emerging categories demonstrated the highest relevance and alignment with the data. As they emerged, their overall generality and significance were consistently refined and validated for relevance. Following the categorisation performed on the content of the studies, the analysis produced five emerging categories. The first includes PST attitudes towards science and technology and the teaching thereof. The second considers perceptions and beliefs on the appropriate student profile for choosing scientific-technological fields. The third category contemplates how different methodologies employed in pre-service science and technology teacher education

influence the attitudes, perceptions and professional competencies of future teachers. The fourth category reflects PST emotions experienced when dealing with the teaching of science and technology disciplines. Lastly, the fifth category shows the lack of female references and PST awareness or ignorance thereof. Each of these categories, which emerge from the content analysis of the studies included in the review, is presented below.

Attitudes Towards Science and Technology and their Teaching

Positive or negative attitudes on the part of teachers towards science and technology and their teaching have a strong bearing on how their students will react to the disciplines (Awofala et al., 2019; Wahyudiati et al., 2019). Having positive attitudes towards scientific-technological subjects and the teaching thereof contributes to the development of related skills and a deeper appreciation of the importance of these in day-to-day life (Vázquez & Manassero, 2004, 2009; Bellová et al., 2021).

Works such as those by Juriševič et al. (2008) and Doğru and Çelik (2019) reveal that female trainee teachers participating in their studies held more negative attitudes than their male counterparts as regards the social image of science and its teaching. However, and in relation to specific curricular content, a number of studies reflect an entirely inverse situation, showing that female teachers in training in fact have more positive attitudes towards concern for the environment and renewable energies (Özerkeskin et al., 2012; Ozsoy, 2012; Madhawa et al., 2013; Doğru & Çelik, 2019; Rivadulla et al., 2021).

Regarding those aspects that could encourage positive attitudes in future teachers, the study by Mazas and Bravo (2018) recognises that the greater the scientific-technological knowledge held by PST, the more awareness they are of its importance in the development of society, and their curiosity and critical attitude towards such knowledge increases.

On the other hand, Steele et al. (2013) and Arabit et al. (2021) underline that future female teachers face barriers to developing the teaching of scientific-technological materials including a lack of resources, specific spaces and in-depth training in the use of new technologies. In this regard, Repenning et al. (2019) conclude that teachers at all educational levels should show considerably positive attitudes towards disciplines such as computers and technology in order to foster interest in their students, especially girls.

The studies taken together highlight a dual narrative: while teachers' attitudes are recognised as influential by various authors (Avolio et al., 2024; Owuondo, 2023; Page, 2024; Shah et al., 2013), gender-based differences and external barriers introduce variability in how these attitudes develop. Discrepancies across studies suggest that broader systemic issues, such as stereotypes and resource constraints, interact with teachers' personal factors such as depth of knowledge and subject-specific preferences. By identifying these trends and differences, it becomes clear that targeted interventions must address both intrinsic and extrinsic factors to promote positive attitudes towards science and technology education.

Perceptions and Beliefs Regarding the Student Profile

As Fernandes and Carim (2018) suggest, there is a persistence of stereotyped beliefs as they are passed down the generations, and incorporated into individuals through the process of socialisation, conditioning their way of thinking and, as a result, their behaviour in the context of the classroom as teachers. In this sense, perceptions and beliefs on the part of teachers in regard to the profile of students who should opt for scientific-technological fields may have an influence on aspects such as their teaching approach, interactions with their students and their interpretations of the academic progress and personal development of these and, in general, their commitment to teaching (Tan & Maeda, 2021).

There are studies that indicate PST tend to connect engineering or technology to physical and thus more male-orientated work (Kuvac & Koc, 2022; Wahyudiati et al., 2019; García-Morís & Alfonso-Cendón, 2022). Other results point to how PST conceive that students who choose scientific-

technological fields should have aptitudes and skills in these disciplines, show interest in science or technology, be logical, curious, hard-working, organised and methodical, assigning these traits mostly to girls (Merayo & Ayuso, 2022).

A number of studies show that women in pre-service technology and physics teacher education consider that male teachers and students perform better in teaching and learning these subjects than they and their female students do (Berber & Oral, 2012; Xu et al., 2021; Kuvac & Koc, 2022). The study by Fernandez and Cardim (2018) also indicates how female teachers in initial early childhood and primary teacher training consider that differences exist as regards aptitudes between men and women, and that these influence professional choices regarding scientific-technological degrees. The study by Ayuso et al. (2022) draws attention to the beliefs of secondary education PST, who perceive that girls possess more skills necessary for continuing with studies in the scientific-technological sphere than boys, finding however that the former do not choose them due to low self-esteem.

The studies reviewed reveal how stereotypes and perceptions influence teachers' beliefs about the profile of students in STEM disciplines. While the association of STEM disciplines with masculine physicality reinforces traditional gender roles, there is growing recognition of girls' intellectual and organizational strengths in these disciplines. However, discrepancies in how these beliefs translate into expectations and outcomes (ranging from self-esteem issues to differential perceptions of performance) highlight the complexity of addressing gender disparities in STEM education. Addressing these biases requires targeted interventions to challenge stereotypes and foster environments where all students, regardless of gender, feel empowered to pursue careers in science and technology.

Educational Methodologies in Pre-Service Teacher Training

The different methodologies employed in pre-service teacher training may have a significant bearing on the perceptions and attitudes of future educators towards science and technology (Sánchez-Martín et al., 2018). Moreover, these methodologies influence the professional skills that teachers may develop in order to teach scientific-technological subjects with a gender perspective. In this regard it is very important for future teachers to be aware of how the methodologies they choose can integrate approaches that promote gender equality.

Thus, diverse studies show how attitudes and perceptions of secondary education trainee teachers are favourable when active innovative methodologies and gamified learning strategies are implemented (Kahraman, 2014; Lay & Khoo, 2012; Akçöltekin, 2016; Çam & Geban, 2017; Bejarajo & García, 2016; Krause et al., 2017; Díaz-Noguera, 2019; Reiman, 2019; Repenning, 2019; Wahyudiati et al., 2020). Furthermore, if their teacher training also includes a collaborative and inclusive peer-to-peer methodology, they become aware of the importance of adopting more inclusive teaching approaches in order to attract female talent and combat gender stereotypes within science and technology (Díaz-Noguera, 2019; Ayuso et al., 2022).

For instance, Kollmayer et al. (2020), via their REFLECT training programme, propose the use of reflexive coeducation to encourage PST to undertake deep critical analysis of gender-related matters in order to overcome the stereotypes and inequalities that may be present in the curriculum, educational materials and classroom interactions. In this programme future teachers reflected on their own gender stereotypes, examined whether or not their idea of teaching was influenced by these and developed teaching competencies in this regard. The REFLECT programme led to an increase in knowledge on gender differences in education and concluded that only those teachers who know how to counteract existing gender stereotypes in their teaching, and who furthermore believe themselves to be capable of resolving inequalities, will promote change.

Similar conclusions are drawn from the studies presented by Díez-Bedmar (2022) and by Acisli et al., (2012), who indicate that asking questions and knowing how to analyse the responses with a gender perspective is key in the training of teachers so they are able to apply it in their professional sphere. In addition, these authors draw attention to the importance of adopting approaches from PST training that enhance knowledge on equality and critical analysis of gender stereotypes. Similar

approaches are proposed by Gullberg et al. (2018) and Kuvac and Koc (2014), who indicate the importance of developing critical thinking on the part of PST from self-reflection on their stereotyped gender patterns, as they will be able to change their future classroom behaviours by being aware of their own actions and thoughts.

Evidence points to the importance of integrating diverse methodologies into initial teacher education (Akhtar et al., 2024; Reinoso et al., 2024) to address gender stereotypes and promote inclusion in science and technology education. Active learning strategies such as gamification and collaboration are widely recognized for their ability to enhance engagement and foster inclusive practices. At the same time, reflective methodologies that focus on self-awareness and critical analysis provide a deeper foundation for addressing stereotypes and promoting long-term change. By combining these approaches, teacher education programmes can equip PST with the tools, awareness, and agency to foster their professional practices with a gender perspective.

Emotions

A holistic perspective of education recognises the interconnection between the emotional, social and cognitive aspect of learning (Garritz, 2010; Kind, 2009; Park & Oliver, 2008; Tobin & Fraser, 1990). The integration of attention to emotions into teaching practice can contribute to the holistic development of students by promoting a more enriching and rewarding learning process. Nevertheless, no studies have been found aimed at raising awareness among future teachers of scientific-technological subjects as regards the considerable impact of the emotions experienced by their students.

Studies that address emotions and initial training of science and technology teachers normally focus on analysing emotions experienced by these future educators as they must deal with the teaching of scientific-technological materials. Along these lines, the study by Bravo-Lucas et al. (2022) shows how their participating teachers expressed negative emotions towards the teaching of physics and, in this case, the women did so more than the men.

Bravo-Lucas et al. (2022) state that emotions have an influence on science teaching and learning, and that teachers' memories of the emotions experienced in the learning of the different science subjects in their time at school are maintained in the subsequent teaching thereof. Thus, half of the PST participating in the study by Steel et al. (2013) admitted to feeling stressed about having to teach primary education science, and stated that their experiences with the subject were largely negative or neutral during their school years.

In this regard, Hernández-Barco et al. (2021) recommend using active methodologies during PST education such as project-based learning in a gamified context, given that they will have positive affective consequences and translate into an improvement in trainee attitudes towards science and a reduction in anxiety. These authors also recognise that these types of methodologies will foster their own curiosity and afford greater confidence in their future teaching practice. López-Banet et al. (2021) likewise recommend that teachers maintain a favourable emotional connection to the sciences that centres not just on knowledge of the content but also procedural and epistemic understanding, along with scientific comprehension of the phenomena with their appropriate interpretation, thus seeking to promote in their students a favourable emotional connection towards science and technology.

All research indicates the fundamental role of emotions in the training of science and technology PST, but they differ in their emphasis on specific aspects. While some focus on the negative emotions experienced by science and technology teachers and their origins in previous schooling, others explore interventions, such as active methodologies, to promote positive emotional outcomes. However, a significant gap persists in the preparation of PST to address emotional dimensions during their pupils' learning. Bridging this gap would require integrating training strategies that stress both teacher and student emotions, thus fostering a more holistic and effective approach to science and technology education.

Invisibility of Female Role Models

The lack of female role models may have consequences with regard to the perception and aspirations of learners related to scientific-technological spheres (Benavent et al., 2020). This may be one of the impediments to overcoming the gender gap in these areas and, with it, contributing to a more equal educational and social environment.

Nevertheless, few studies address this topic and its relationship to the training of future teachers. One such example, by Merayo and Ayuso (2022), shows that pre-service secondary education teachers think that amongst the reasons for pupils not taking subjects in the scientific and technological sphere, as well as preconceived ideas, is the lack of female role models, examples of the contributions of women to the building of scientific-technological knowledge and the history of science and technology. In the same vein, Goreth and Vollmer (2022) reveal that technology PST consider research in this area conducted by women to be strongly under-represented. For these teachers, girls do not have female role models to follow and reach the conclusion that it is not a field for them. For their part, the PST participating in the study by Fernandes and Cardim (2018) consider this situation to be reinforced by textbooks used in the classroom, which seldom allude to the participation of women in science or technology and, when they do, it is still represented in a stereotypical manner, evidencing an androcentric and traditional image of science.

The invisibility of female role models is a widespread problem that perpetuates gender disparities in these fields, as previously reported in their studies by Archer et al. (2010), Avolio et al. (2024), Hoyer (2024) and Rossi and Barajas (2015). The studies reviewed highlight the detrimental effects of this invisibility on girls' aspirations and perceptions of science and technology teachers. However, while there is consensus on causes such as biased educational materials and the absence of female contributions in curricula, there is limited exploration of specific strategies to address these issues in teacher education programmes. Future research should focus on practical approaches to integrate women's achievements in science and technology into teacher education, empowering science and technology teachers to create gender-responsive learning environments.

Conclusion and Didactic Implications

This article presents a systematic review that shows what has been researched so far in science and technology teacher training to help combat the gender gap in STEM studies, identifying aspects that may have didactic implications. Giles et al. (2023) emphasise the importance of teacher identity development for meaningful engagement with teaching and preparing future STEM teachers in their transitions from student to professional, contributing to recruiting students for scientific and technological fields. That is why, with those didactic implications, we try to highlight what to be aware of in order to incorporate a gender perspective to the science and technology teacher identity.

In general terms, it can be seen that this issue has been little addressed since 2008, although in recent years the number of studies found has increased. This seems to indicate that up to now not enough attention has been paid to training teachers in aspects that could help them to address the teaching of scientific-technological disciplines from a gender perspective. Therefore, research in this area should be encouraged to generate more evidence on the need to incorporate a gender perspective into the training of science and technology teachers, as well as, by developing specific training modules focused on teaching strategies with a gender perspective. Furthermore, educational policymakers at the institutional level can draw on this research to design initiatives, the explicit integration of gender perspectives into curricula, and resources aimed at reducing the gender gap in science and technology areas. Future research could explore areas such as longitudinal studies to assess the long-term impact of teaching practices with a gender perspective, thereby helping to evaluate the effectiveness and sustainability of these approaches in narrowing the gender gap in science and technology education.

An analysis of the aims of the studies included in the review makes it possible to state that over half of them are focused on detecting attitudes, perceptions and beliefs, and there are still very few that concentrate on applying training programmes that promote the acquisition of professional

competencies to achieve a gender-responsive identity in the teaching of scientific-technological disciplines. Those that do show that using active methodologies in teacher training such as learning based on gamification, inquiry or problems and challenges helps in this aim, promoting the establishment of favourable affective connections in regard to attitudes and emotions (Hernández-Barco et al., 2021; Sánchez-Martín et al., 2018). We fully agree with them, especially with Kollmayer et al. (2020) in their recommendation to apply methodologies in teacher training that encourage critical reflection on gender issues such as stereotypes, roles, inequalities, etc., which may be present in the curriculum, educational materials and classroom interactions.

Furthermore, it is also important to draw attention to the fact that very few works have been found that endeavour to analyse whether teachers are aware of the lack of female role models in scientific-technological education, and the consequences of this for students, above all girls. We subscribe to the indications of studies that do address this issue, such as that by Fernandes and Cardim (2018), which stresses the need to counteract the shortcomings of textbooks in this regard. To this end, there is a need to boost training of critical-minded teachers able to develop strategies to include familiar and current female role models in order to demystify gender stereotypes associated with scientific-technological professions. Moreover, adopting these approaches would help to change teachers' beliefs on the profile required of students who opt to study STEM subjects. In this regard, we highlight the proposals of Merayo and Ayuso (2022), who warn of the negative influence of teachers with unequal perceptions regarding the engineering performance of men and women, beliefs that must be eradicated to avoid affecting the self-esteem of female students and encourage them to focus their studies on these areas.

Lastly, while we coincide with the approaches of Juriševič et al. (2008), Bisquerra and Pérez (2007), Hernández-Barco et al. (2021) and Bravo et al. (2022), who propose that during pre-service education it is important to provide teachers with both cognitive and emotional knowledge and competencies that enable them to maintain a favourable emotional connection towards the teaching of science and technology, it is interesting to emphasise that no studies have been found that focus on training teachers to take into consideration the emotions they will generate in their future students when teaching scientific-technological subjects. Emotions influence cognition, motivation, interest and learning of science and technology, thus teachers need to be aware of their potential and how they influence the development of work in the classroom. It is therefore necessary for teachers to also be capable of identifying emotions in their students and have at their disposal methodological strategies to promote those that activate their learning.

As recommendations for implementing strategies in PST training to promote a gender perspective in science and technology teacher identity, we propose practical interventions and initiatives based on gender-responsive analysis of educational resources and materials (e.g. textbooks, learning activities, educational games), followed by guided design of teaching proposals. Key aspects to take into account in the analysis and design may be: the image of science shown (collaborative activity beyond academics, with importance for society and current professional perspectives), emotions promoted (e.g., avoid boredom, seek surprise), and the visibility of female references (not only historical models, but also contemporary ones).

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Growth mindset and achievement goal orientation in high-achieving students

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ABSTRACT
The conviction that individuals hold about their own intelligence can significantly affect their motivation and learning outcomes. This study aims to investigate students' growth mindset and personal achievement goal orientation. Data were collected from 10th-grade students, totalling 644 (233 males and 411 females), from 19 schools in the lower northern region of Thailand participating in the Science, Mathematics, Technology, and Environment (SMTE) Programme. Two research instruments adapted for Thai use were utilized: the Growth Mindset Scale and the Personal Achievement Goal Orientation Scale. There was no statistically significant difference in the growth and fixed mindset between boys and girls. The path analysis from growth mindset to mastery goal, performance-approach goal, and performance-avoidance goal were significant. Meanwhile, the analysis from fixed mindset to mastery goal, performance-approach, and performance-avoidance goal were also significant. To predict grade point average (GPA), representing academic achievement, only the regression from mastery goal to GPA was significant. This indicated that mastery goals act as a mediator between growth mindset and GPA. The findings provide insights regarding the relationship between growth mindset and academic achievement, highlighting personal learning goals as a mediator.

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Introduction

Recent research highlights the crucial role of a growth mindset, where individuals believe they can improve their abilities over time and are willing to put in effort, as a key factor in supporting academic achievement across different contexts. For instance, Bai & Wang (2023) highlighted the impact of growth mindset on self-regulated learning strategies, such as monitoring and effort regulation, which contributed to language learning success in primary school students. Similarly, Fathi et al. (2024) found that growth mindset, coupled with self-efficacy, significantly enhanced language achievement through its influence on grit. Combette et al. (2024) further confirmed that growth mindset correlated with the adoption of mastery goals, which prioritised learning and personal improvement, even in adult populations. While growth mindset interventions have shown promise in enhancing children and adolescents' attitudes, motivation, and academic persistence, their direct effects on academic performance remain inconclusive. For instance, a meta-analysis by Burnette et al. (2013) noted that

growth mindset was associated with enhanced self-regulatory processes, such as achievement goal orientation, especially under ego-threatening conditions (e.g., A student asked to solve a difficult math problem on the board, knowing that failure might lead to embarrassment or judgment). Similarly, Wang et al. (2021) reported modest improvements in academic performance through growth mindset interventions in chemistry contexts but noted variability in effectiveness depending on the intervention design and implementation. Conversely, large-scale reviews and meta-analyses suggested that growth mindset interventions often yielded small or negligible effects on academic outcomes, with methodological issues and publication bias complicating the interpretation of results (Li & Bates, 2020; Macnamara & Burgoyne, 2023). The relationship between growth mindset and academic achievement is not straightforward. Some studies show no significant correlation, suggesting that the role of mindset may vary as a cause, mediator, or outcome of achievement (Stohlmann, 2022; Zhang et al., 2017). One of the variables associated with academic achievement and linked to growth mindset is achievement goal. Growth and fixed mindsets are closely connected to the types of achievement goals individuals pursue, whether students aim to improve competence (mastery goals) or to demonstrate competence compared to others (performance goals), especially in academic settings. (Blackwell et al., 2007; Cook et al.,2017; Robin & Pals, 2002).

The enrichment programme of Science, Mathematics, Technology and Environment (SMTE) in Thailand provides an ideal context for exploring the interaction between growth mindset, achievement goal orientation, and academic achievement. This programme has been developed through collaboration among major educational and scientific organisations in Thailand, including The Institute for the Promotion of Teaching Science and Technology (IPST), Office of the Basic Education Commission (OBEC), Office of the Higher Education Commission (OHEC), and National Science and Technology Development Agency (NSTDA). The programme aims to support and nurture high-ability students, in grades 10–12, in science and technology. Students eligible to enrol in this programme must have demonstrated strong academic performance at the lower secondary level and passed a national standardised entrance-to-the-programme examination. This exam assesses knowledge and skills in science, mathematics, and technology. The programme has been in operation since 2007, including 220 schools, and has been taught for the upper secondary levels in separate schools. It is managed through a network structure consisting of 9 networks, which are divided based on the country's geographical regions. This study collected data from the lower northern region network.

The participating schools provide a specialised curriculum emphasising advanced content knowledge in science and mathematics skills. The curriculum includes special activities such as science camps, study trips, research internships, and opportunities for students to conduct advanced STEM projects. The characteristics of such a programme align with research on gifted learners, which suggests implementing differentiated curricula that include challenging and meaningful content to engage their advanced abilities (Gül & Ayık, 2024; Ulger & Çepni, 2020). However, such challenges demand resilience, self-efficacy and adaptive learning strategies—attributes strongly linked to growth mindset (Bandura, 1999, 2023; Dweck & Leggett, 1988; Pintrich, 2000). SMTE students face unique challenges, including high expectations and competitive environments, which necessitate an understanding of how growth mindset and achievement goals interact to influence their academic success. Yang & Gentry (2023) found that underrepresented students (Black, Hispanic, Native American) in STEM fields often face pressures such as impostor syndrome and a "chilly" environment, which can negatively affect their motivation and learning outcomes. Gender differences in mindset and achievement goals further complicate these dynamics. Some studies have found gender differences in specific subjects such as mathematics (Bostwick et al., 2020; Degol et al., 2018; Wang et al., 2021), mathematics and ICT (Sáinz & Eccles, 2012), physics (Kalender et al., 2022; Malespina et al., 2022; Marshman et al., 2018), and STEM (Eccles, 2011). These research findings demonstrated that females exhibited lower levels of mindset and self-concept compared to males, which could influence their future career choices or decisions to pursue higher education.

Despite its importance, research on growth mindset and achievement goal orientation in Thailand remains limited, particularly for high-ability learners in specialised programmes such as

SMTE. Most studies of the individuals' implicit theories were explored within a Western context. In Asian contexts, however, these theories may hold different implications due to diverse cultural values, such as collectivism and the utility of education (Hau & Salili, 1996). For example, in Hong Kong, Chen & Wong (2014) observed that the motivations of Chinese students, influenced by cultural factors such as educational emphasis and competition, differ from Western norms. Specifically, they found a positive association between performance-approach goals and academic achievement but a negative impact from performance-avoidance goals. Similarly, in the Philippines, research found that the growth mindset intervention could improve learners' creativity, habits of mind, and mathematics performance from the "low" to "average" level (Almeria, 2023). In Thailand, efforts have been made to adapt psychological research tools to the local context (Poondej, 2016) and explore the link between lifestyle values and achievement goal orientation (Chantara et al., 2014). Although there have been attempts to investigate implicit theories, specifically in Thailand, the results are still incomplete. Important factors, including the emphasis on students enrolled in specialized science programs and the connections between growth mindsets, achievement goal orientation, and academic success, have not been thoroughly examined. Therefore, this current study aims to explore the relationship between academic achievement, growth mindset, and achievement goal orientation, particularly in the context of Thailand.

Research Questions

1. Do male and female students in the SMTE classroom exhibit different growth and fixed mindsets (RQ1)?
2. What kinds of achievement goal orientation do students in the SMTE classroom exhibit?
3. What is the relationship between academic achievement, growth mindset, and achievement goal orientation among SMTE students (RQ3)?

Literature Review

Implicit Theory

Implicit theories are beliefs about whether personal intelligence is fixed or malleable (Dweck et al., 1995). Research since the 1980s has demonstrated that beliefs, thoughts, and feelings about one's potential significantly influence how learners succeed, fail, or respond to failure (e.g., Dweck & Leggett, 1988; Elliott & Dweck, 1988). Based on the individuals' implicit theories, young people with a 'fixed mindset' tend to believe that their intelligence is limited and inherent and incapable of significant development. Children with a 'growth mindset', on the other hand, believe that their intelligence can be developed through hard work, effective learning strategies, guidance from others, or even persistence in the face of setbacks (Blackwell et al., 2007; Dweck & Leggett, 1988; Haimovitz & Dweck, 2017; Yeager & Dweck, 2012). The implications of the implicit theory influence motivation, learning strategies, judgment of self and others, and responses to failure (Dweck et al. 1995). Moreover, the growth mindset has been associated with positive outcomes, including improved mental health and reduced stress. (Ku & Stager, 2022; Yeager & Dweck, 2012; Zeng et al., 2016). Evidence from Xu et al. (2021) indicated that cultivating a growth mindset could reduce cognitive load and enhance learning retention. These findings suggest that its benefits might be more visible in process-oriented outcomes rather than grades and highlight the need for more nuanced research to understand the conditions under which growth mindset promotes academic achievement.

Achievement Goal Orientation Theory

Dweck & Leggett (1988) linked implicit theories to achievement goal orientations, showing that entity theorists tend to adopt performance goals focused on proving ability, whereas incremental

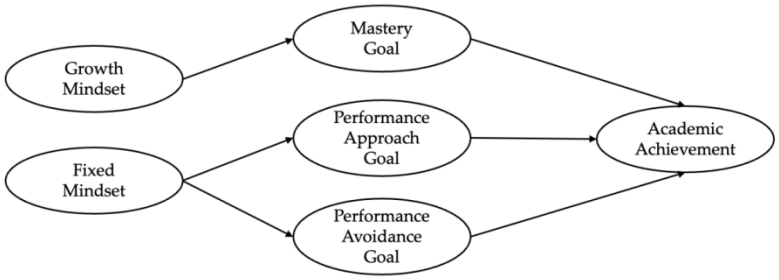
theorists pursue learning goals aimed at growth. These orientations influence how individuals respond to challenges—learning goals promote resilience, while performance goals can lead to helplessness. The achievement goals typically fall into two main categories: mastery and performance (Combette et al., 2024). Mastery goals emphasise the intrinsic desire to gain competence and understanding in tasks, fostering deep engagement and adaptive learning strategies. In contrast, performance goals focus on demonstrating competence compared to others. These include striving for recognition or avoiding negative evaluations (Elliot & Church, 1997; Theis et al., 2020). In achievement motivation research, Elliot & Church (1997) proposed a trichotomous framework that includes mastery, performance-approach, and performance-avoidance goals. Mastery goals, focused on developing competence and task mastery, are characterized by a pure approach orientation, grounded in achievement motivation and high competence expectancies, and are associated with intrinsic motivation. In contrast, performance goals, centred on external evaluations, are bifurcated into approach and avoidance components: performance-approach goals aim at obtaining favourable judgments of competence, while performance-avoidance goals focus on avoiding unfavourable judgments. This partitioning reflects the distinct regulatory processes involved, as performance goals naturally lend themselves to both positive (approach) and negative (avoidance) motivations, whereas mastery goals do not exhibit this dual structure (Elliot & Church, 1997). Mastery goals are often associated with better academic outcomes, as they promote deep learning and intrinsic motivation (Alhadabi & Karpinski, 2020). Learners pursuing mastery goals tend to engage in self-regulated learning strategies, such as goal setting and monitoring, which directly contribute to academic achievement (Bai & Wang, 2023). In contrast, performance goals can have mixed outcomes; performance-approach goals may lead to high achievement when the focus is on outperforming peers, but performance-avoidance goals are generally linked to maladaptive behaviours and lower achievement (Hulleman et al., 2010; Yeager & Dweck, 2020). Furthermore, the adoption of mastery goals mediates the relationship between growth mindset and academic success, emphasising the role of goal orientation as a conduit for mindset effects on learning achievement (Blackwell et al., 2007).

Conceptual Framework

Based on previous studies on the relationships between growth mindset, achievement goal orientation, and academic achievement, a conceptual framework has been developed for this study. In this framework, mastery goals are associated with a growth mindset and serve as a mediator, enabling the positive effects of a growth mindset on academic achievement, such as GPA (Blackwell et al., 2007; Combette et al., 2024). In contrast, performance-approach goal and performance avoidance goal are linked to a fixed mindset, which has a negative impact on academic achievement (Yeager & Dweck, 2020). Figure 1 illustrates the conceptual framework.

Figure 1

Conceptual framework of the study



Methods

This study is survey research that collected data in July 2023. It was conducted as part of an orientation activity for 10th-grade students of the SMTE programme from 19 schools across eight provinces in the lower northern region of Thailand. The data were collected online, with students willingly responding to the questionnaires. Parental consent was obtained for student participation, and the study requires participants to provide personal information, such as their grade point average. Some students may feel uncomfortable disclosing this to others; therefore, all data collected remained anonymous to ensure the students' privacy.

Participants

The participants consist of 10th-grade students studying in the academic year 2023, totalling 644 individuals, including 233 males and 411 females, with an average age of 15-16 years. This group of students has been selected to continue their upper secondary education in the enrichment programme for Science, Mathematics, Technology, and Environment (SMTE). They are eligible to enrol in this programme because they have demonstrated strong academic performance at the lower secondary level (GPA) and passed a national standardised entrance examination.

Data Collection

The survey was part of the orientation activities for students selected for the SMTE program. These activities have three main objectives: to clarify the programme's goals, to inspire students through lectures by well-known scientists in the country, and to explore students' learning goals and background information for further analysis. This study utilises data collected from the third objective of these orientation activities.

The survey process allowed students to provide information by clicking "agree" before answering online questions. Students may choose to respond with 'agree' or 'disagree,' with no impact on their participation in the orientation activities. The survey questions consisted of two main sections: 1) *Demographic Information* inquired about gender, categorised into two options (male coded as 1, female coded as 2), and GPA, the average score in the six semesters of middle school, 2) *Growth & Fixed Mindset* and *Personal Achievement Goal Orientation*. The following section delves deeper into the latter portion of the survey, which serves as the main research instrument.

Research Instrument

The research instruments were as follows: 1) the Growth Mindset Scale (Dweck, 1999) is a 5-point Likert scale comprising 8 questions. Four questions assess the growth mindset (4 items), while the remaining four questions assess the fixed mindset (4 items) 2) the Personal Achievement Goal Orientation Scale, which is one of the dimensions of Patterns of Adaptive Learning Scales (PALS) (Midgley et al., 2000). This study adopted the Personal Achievement Goal Orientation Scale in a 5-point Likert scale consisting of 9 questions that assess aspects of students' perceptions of the classroom environments, which include learning goal orientation (3 items), performance approach (3 items), and performance-avoidance goals (3 items). Both instruments were Thai version. The first author translated all instruments from English to Thai and then verified the translation by face validity with one English language expert. The Thai draft version was revised in some wording to be more appropriate for students. All items were combined into a single survey, resulting in a total of 17 items across 5 dimensions.

According to the *Standards for Educational and Psychological Testing*, one method to verify instrument validity is to conduct a Confirmatory Factor Analysis (CFA). The CFA facilitates the

assessment of construct validity by examining whether the theoretically defined structure adequately explains the relationships between latent variables and observed indicators. Additionally, it evaluates model fit using indices such as CFI, TLI, and RMSEA (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 2014). In addition, the H coefficient, calculated using factor loadings and error variances from structural models like CFA, directly reflects the relationship between observed and latent variables, making it more suitable for evaluating theoretical constructs than Cronbach's alpha. It offers greater precision, flexibility, and the ability to account for error correlations, providing a more accurate assessment of reliability in latent variable research (Komperda et al., 2018). The results of the validity and reliability analysis of the instrument will be presented next in the research findings section.

Data Analysis

The validity of the internal structure was assessed through confirmatory factor analysis (CFA) to evaluate the extent to which the data aligned with the hypothesized domain structure, including growth mindset, fixed mindset, mastery goal, performance-approach goal, and performance-avoidance goal. The criteria from Hu & Bentler (1999) were used to assess the model's fit. The reliability of each factor in confirmatory factor analysis (CFA) is most effectively assessed using Coefficient H, which calculates the variance accounted for by a factor based on standardized regression loadings (Hancock & Mueller, 2001).

To answer RQ1 and RQ2, the analysis involved computing means, standard deviations, and independent *t*-tests. For RQ3, Pearson's correlation and structural equation modelling (SEM) were employed to explore the structural relationships among growth mindset, fixed mindset, mastery goals, performance-approach goals, and performance-avoidance goals. All analyses were conducted with jamovi 2.3.28, utilizing packages from R.

Results and Discussion

Validity and Reliability of the Measure

The CFA result indicated that the model had poor to marginal fit (CFI = 0.86; Gamma hat = 0.93; RMSEA = 0.079 (90%CI = 0.072 - 0.086); SRMR = 0.062). This provided adequate evidence to indicate that revising the questionnaire could yield an acceptable outcome. One item from the growth mindset domain was removed due to having a negative standard estimate. Subsequently, upon reanalysis, it was found that the model had a good fit (CFI = 0.91; Gamma hat = 0.95; RMSEA = 0.067 (90%CI = 0.059 - 0.074); SRMR = 0.047). Table 1 provides items, factors, standardised loadings, and coefficient H for this model.

Table 1

Items, factors, standardized loadings, and coefficient H

Factor/Item	Loading
Fixed Mindset (Coefficient H = 0.76)	
F1 You have a certain amount of intelligence and can't really do much to change it.	0.580
F2 Your intelligence is something about you that you can't change very much.	0.720
F3 To be honest, you can't really change how intelligent you are.	0.671
F4 You can learn new things, but you can't really change your basic intelligence	0.661
Growth Mindset (Coefficient H = 0.71)	
G1 No matter who you are, you can significantly change your intelligence level.	0.724

G2 You can always substantially change how intelligent you are.	0.510
G3 You can change even your basic intelligence level considerably.	0.713
Mastery goal orientation (Coefficient H = 0.73)	
M1 It's important to me that I learn a lot of new concepts this year.	0.702
M2 It's important to me that I thoroughly understand my class work.	0.593
M3 It's important to me that I improve my skills this year.	0.746
Performance approach goal orientation (Coefficient H = 0.73)	
P1 It's important to me that other students in my class think I am good at my class work.	0.643
P2 One of my goals is to show others that classwork is easy for me.	0.760
P3 One of my goals is to look smart in comparison to the other students in my class.	0.631
Performance avoidance goal orientation (Coefficient H= 0.77)	
PA1 It's important to me that I don't look stupid in class.	0.773
PA2 It's important to me that my teacher doesn't think that I know less than others in class.	0.790
PA3 One of my goals in class is to avoid looking like I have trouble doing the work.	0.453

The results of the CFA analysis and coefficient H provide evidence supporting that the validity and reliability of the measurement are acceptable, allowing for further data analysis to address the research questions.

RQ1 : Do Male and Female Students in the SMTE Program Have Different Growth Mindsets?

The results of the analysis are illustrated in Table 2. The analysis results revealed that among the SMTE classroom students who responded to the questionnaire, male students (N=233) had an average growth mindset score of 3.94 (M 3.94, SD 0.725), an average fixed mindset score of 2.41 (M 2.41, SD 0.900) while female students (N=411) had an average growth mindset score of 3.86 (M 3.86, SD 0.728), an average fixed mindset score of 2.39 (M 2.39, SD 0.772).

Table 2

Independent t-test for growth and fixed mindset between groups

Mindset	Group	*N*	*M*	*SD*	*df*	*t*	*p*-value
Growth	Male	233	3.94	0.765	642	1.335	0.182
	Female	411	3.86	0.728			
Fixed	Male	233	2.41	0.900	642	0.326	0.744
	Female	411	2.39	0.772			

The differences in growth and fixed mindset between male and female students in the SMTE classroom were tested by independent *t*-test, and it was found that the *p*-values of 0.182 and 0.744, respectively, were greater than 0.05. It could be summarized that there was no statistically significant difference in growth and fixed mindset between males and females. The finding was similar to the study of the Organisation for Economic Cooperation and Development (OECD). The OECD conducted a survey of students' growth mindset in 2018 involving 600,000 students from 78 countries and found that most students, including Thai students, exhibited a growth mindset. (OECD, 2021).

One possible explanation for this finding may be attributed to the relatively short duration used in data collection for the survey. The data collection primarily captures the general beliefs about belief in their intelligence. For specific subjects, however, some studies found gender related to growth mindset as well as the effect on learning outcomes. For instance, in the Physics course, it was found that male and female undergraduate students who began their studies in physics initially showed no significant variations in their growth mindset; however, over time and by the end of the course, distinctions between the genders in terms of their mindset gradually became noticeable (Kalender et al., 2022; Malespina et al., 2022). Particularly, compared to male students, female students held a more "fixed" view of intelligence in the context of physics (Kalender et al., 2022; Malespina et al., 2022; Marshman et al., 2018), Mathematics (Degol et al., 2018; Wang et al., 2021), Mathematics and ICT (Sáinz & Eccles, 2012), and STEM (Eccles, 2011). Future research based on the findings of this study should include the need to investigate the factors influencing the development of growth mindset and to extend the study duration for a more in-depth analysis. This would involve examining whether male and female students in specialised SMTE classrooms exhibit any notable changes in their overall growth mindset over an extended period. Additionally, researchers should explore how specific subjects such as mathematics, physics, chemistry, biology, or STEM influence mindset development.

RQ2 : What Kinds of Achievement Goal Orientations Do Students in the SMTE Classroom Exhibit?

Among male students (N=233), the predominant goal orientation was mastery goal orientation, accounting for the highest percentage at 57%. Following this, performance avoidance goal orientation was the second most prevalent at 15%. Additionally, students who exhibited a combination of three goal orientations represent 11% of the total. For female students (N = 411), the primary goal orientation was mastery goal orientation, which constituted the highest proportion at 61%. Performance avoidance goal orientation was the second most prevalent, at 15%, with students demonstrating a combination of two goal orientations (mastery goal and performance avoidance goal) accounting for 11% of the total. The research findings indicated that both male and female students shared a common achievement goal orientation, with mastery goal orientation being the most prominent (Table 3).

Table 3

Achievement goal orientation among the SMTE students

	Male		Female	
	Male (*N*=233)	Percentage (100%)	Female (*N* = 411)	Percentage (100%)
Mastery Goal	132	57	250	61
Performance Approach Goal	3	1	9	2
Performance Avoidance Goal	34	15	64	15
Two patterns denoted as 1 and 2	10	4	7	2
Two patterns denoted as 1 and 3	24	10	45	11
Two patterns denoted as 2 and 3	5	2	4	1
Three patterns	25	11	32	8

Note. Two patterns denoted 1and 2 represent students with mastery goal and performance approach goal. Two patterns, denoted 1 and 3, represent students with mastery goal and performance avoidance goal. Two patterns, denoted 2 and 3, represent students with a performance approach goal and a performance avoidance goal.

Initially, researchers conceptualised the intelligence mindset as a single spectrum where students could fall anywhere between a strong growth mindset at one end and a strong fixed mindset at the other. In recent years, researchers have employed both continuum models and models with distinct dimensions, allowing students to embrace both, neither, or even a combination of mindsets concurrently (Yeager & Dweck, 2020). The traditional perspective assumed that as students relinquish

a fixed mindset, they would inevitably adopt a growth mindset. However, in a two-factor model, it became conceivable for a student to neither endorse growth nor fixed beliefs, or to endorse both types of beliefs (Cook et al., 2017). The mindsets that students possess are believed to influence their approach to learning. In the case of a fixed mindset, a student is inclined to withdraw from or evade challenging tasks. Conversely, students with growth mindset perceive difficulties as a chance to acquire knowledge and develop skills, and as a result, they embrace such challenges (Muenks & Miele, 2017; Yeager & Dweck, 2012).

RQ3: What Is the Relationship Between Academic Achievement, Growth Mindset, And Personal Achievement Goal Orientation Among SMTE Students?

Academic Achievement exhibited a low negative correlation with fixed mindset ($r = -.133$, $p < .001$) and a low positive correlation with mastery goal ($r = .158$, $p < .001$). Growth mindset displayed a moderate negative correlation with fixed mindset ($r = .-462$, $p < .001$), a moderate positive correlation with mastery goal ($r = .417$, $p < .001$), a low positive correlation with performance approach goal ($r = .189$, $p < .001$) and performance avoidance goal ($r = .184$, $p < .001$). Mastery goal displayed a low correlation with performance approach goal ($r = .265$, $p < .001$) and performance avoidance goal ($r = .225$, $p < .001$). Performance approach goal exhibited a moderate positive correlation with performance avoidance goal ($r = .528$, $p < .001$). Table 5 presents these correlations among variables.

Table 4

Pearson correlations among psychology test scores

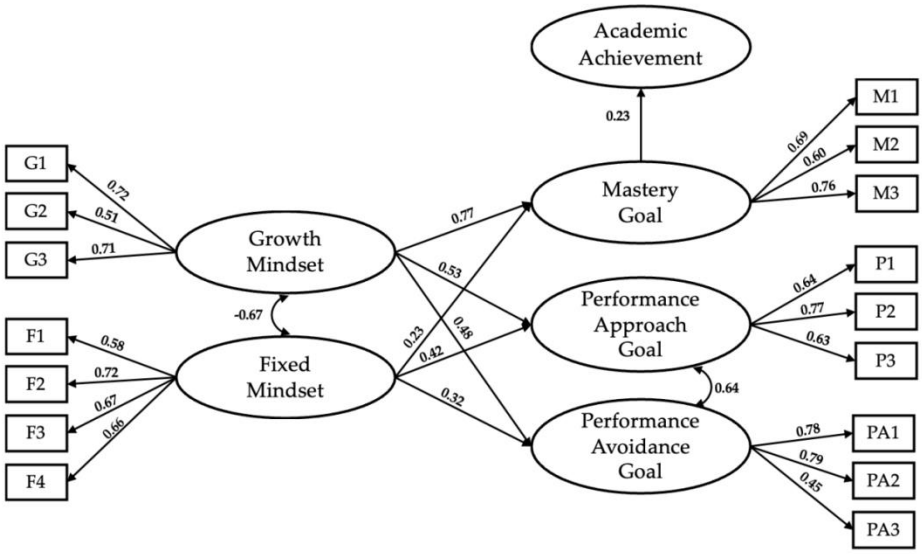
Measures	1	2	3	4	5	6
1. Academic Achievement	-	.090	-.133***	.158***	-.021	.014
2. Growth mindset		-	-.462***	.417***	.189***	.184***
3. Fixed mindset			-	-.198***	.048	.022
4. Mastery goal				-	.265***	.225***
5. Performance approach goal					.-	.528***
6. Performance avoidance goal						-

Note. ***(p <.001)

A structural equation model (SEM) was created in which growth and fixed mindset factors predicted achievement goal factors and the GPA as an academic achievement factor. The model was a good fit (CFI = .901; Gamma hat = .947; RMSEA =.065 (99%CI = .059-.072); SRMR = .047). As shown in Figure 2, the path regressions from growth mindset to mastery goal ($\beta = .77$, $p < .001$), performance approach goal ($\beta = .53$, $p< .001$), and performance avoidance goal ($\beta = .48$, $p< .001$), were significant, which corresponded to the correlations observed for growth mindset and personal goal orientation. Meanwhile, the regressions from fixed mindset to mastery goal ($\beta = .23$, $p = .009$), performance approach goal ($\beta = .42$, $p< .001$), and performance avoidance goal ($\beta = .32$, $p< .001$), were also significant. To predict GPA, only the regression from mastery goal to GPA was significant ($\beta = .23$, $p< .001$. Importantly, the indirect effect results indicated that only the regression path from growth mindset to mastery goal to GPA was significant ($\beta = .18$, $p< .001$). This indicates that mastery goals act as a mediator between growth mindset and GPA, representing academic success.

Figure 2

Results of SEM for growth mindset, achievement goals, and academic achievement



The findings of this study both aligned with and differed from the hypotheses predicted by the conceptual framework of this research. Specifically, the alignment lied in the fact that growth mindset predicted mastery goals, which in turn predicted academic success (GPA) (Chen & Wong, 2014). Midgley et al. (2000) stated that a relationship between mastery learning and growth mindset that when students focused on mastering course content, they were more likely to seek avenues for developing their understanding of the material, where the emphasis was on learning and improvement. However, the differences were that growth mindset also predicted performance approach and performance avoidance goals, and fixed mindset is found to predict both mastery and performance goals. These findings deviated from previous studies (Blackwell et al., 2007; Combette et al., 2024; Yeager & Dweck, 2020). The results might imply that high-ability students tend to have self-expectations, self-confidence, and a desire not to appear unintelligent in the eyes of others. The research findings regarding learning goals were consistent in that the students did not want to appear unintelligent (Yang & Gentry, 2023). The exploration of various cognitive and affective factors that influence school achievement and how cognitive skills instruction could be combined with attempts to create an appropriate affective climate for classroom learning. Research found that most classroom learning occurred in a context involving personal stress, anxiety, and the threat of academic failure (Covington, 2014). In addition, this result could be explained by considering perfectionism. Perfectionism has been associated with a rigid adherence to impossibly high standards, an irrational importance on the attainment of these standards, and a tendency to overgeneralise failures (Fletcher & Speirs Neumeister, 2012). Therefore, this study suggested in the same demeanour as Covington (2014) that teachers of high-ability students should be aware of social cognition and attribution, achievement motivation, fear-of-failure dynamics, and current views of information processing and problem-solving as they apply to actual classroom learning. One of the key findings from the meta-analysis done by Zhang (2022) was the supportive learning environment issue, in which essential tools and resources were necessary for fostering improvement and allowing the transformed mindset messages to interact with student motivation, promoting adaptive behaviours.

Conclusion

This research explored the relationship between mindsets, achievement goal orientation, and academic achievement. The analysis revealed that growth and fixed mindset levels did not significantly differ between male and female students. These students exhibited various goal orientations, including mastery learning, performance-avoidance, and a combination of multiple orientations. This study also suggested key findings regarding the relationship between growth mindset, mastery goals, and academic achievement. Specifically, growth mindset was found to predict mastery goals, which positively influence academic achievement. Additionally, growth mindset also predicted performance-approach and performance-avoidance goals, though these did not directly affect GPA. Interestingly, high-achieving students were found to set both self-improvement goals and comparative learning goals, which differs from previous research that often associates fixed mindset with performance-oriented goals. The results underscore the intricate nature of educational processes, particularly among high-ability students, highlighting the necessity of multifaceted pedagogical strategies to cater to diverse learning requirements. These insights are crucial for developing educational strategies that make students aware of their mindsets and achievement goal orientations, particularly in high-ability student cohorts. They highlight the importance for educators to create environments that do not foster feelings of intellectual inadequacy but instead promote growth mindset and mastery goal, leading to more effective and resilient learning experiences.

Limitations and Recommendations

This study has certain limitations. It relied on the survey data and did not collect data on students' socioeconomic background, family environment, or other contextual factors that might influence their mindsets and learning goals. Furthermore, the study was conducted before students entered a challenging SMTE programme with demanding content and processes. Therefore, future research should consider contextual factors and a longitudinal approach to investigate whether students' mindsets evolve over time and how the passage of time impacts the relationships between mindsets, personal learning goals, and academic achievement. In addition, a controlled experimental study with a manageable sample size could have enabled more detailed of growth mindset development and offered more robust evidence of its impact.

Declaration of Interest

The authors stated that there are no potential conflicts of interest related to this work's research, writing, or publication.

Ethical Statement

The authors acknowledged that the study involved human participants but determined that ethical committee approval was not required, as this survey research was considered low-risk and harmless. Parental consent was obtained for student participation, and participants were informed that their data would be used solely for research purposes, with their identities remaining anonymous in any resulting publications.

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Well-being through digital storytelling: an analysis of young people's stories

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ABSTRACT
The intersection of digital technologies and young people's well-being has become a topic of increasing concern and interest within psychological and educational research. While the advantages of digital engagement for socio-emotional skill development are acknowledged, there is apprehension regarding excessive screen time and its potential impact on mental health. The study's objective was to provide a gender-focused analysis of the main topics related to well-being addressed in young people's videos. Specifically, it addressed the following research question: What issues did boys and girls express in their digital stories, and how can these issues be related to well-being? Drawing upon the positive psychology framework, the study analysed the stories of 31 young participants aged 14 to 20, exploring wellbeing-related themes. Data were collected by transcription of the digital stories and analysis using thematic analysis. The qualitative analysis reveals shared and gender-specific themes, shedding light on the nuanced ways digital engagement intersects with well-being outcomes. Although the study highlights similarities in well-being concerns, it also acknowledges the possibility of subtle differences in how boys and girls express their needs. The findings underscore the importance of understanding the impact of digital technologies on young people's well-being and suggest avenues for future research and intervention. This study contributes to a deeper understanding of the complex relationship between digital technologies, storytelling, and the well-being of young people, offering insights for practitioners and educators striving to support positive developmental outcomes in the digital age.

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Introduction

The implications of digital technologies for young people's well-being are controversial. From one perspective, advantages are recognised for developing socio-emotional skills, primarily through games and videos (Monteiro et al., 2023). However, a significant concern in the literature is young people's excessive time on digital devices, especially mobile technologies, for Internet access (Andersen

& Jiang, 2018). This issue has been linked to poor mental health among at-risk young people, including anxiety, depression, suicidal thoughts, and panic disorder, as reported by George et al. (2018) and UNICEF Innocenti Research Centre et al. (2021).

This paper is based on four digital storytelling (DS) workshops held in the framework of a European project involving young people facing vulnerable situations (Anderson & Mack, 2019). DS can be seen as a research method supported by a video narrative tool created by combining multimedia digital tools, allowing individuals to tell their own stories (Yılmaz et al., 2017, de Jager et al., 2017). According to Lambert (2013a), DS entails short first-person digital video stories that blend voice, images, and sound, organised around seven steps of personal storytelling. Digital stories are potent pedagogical and research tools, fostering exploration, investigation, and creativity (Svoen et al., 2019). These stories cultivate a sense of social belonging and inclusion and promote the development of media and digital literacy, thereby enhancing conditions for social inclusion (Monteiro et al., 2022; Pandian et al., 2020).

Since DS use multimedia tools and social media dissemination, this study aims to provide a gender-focused analysis of the main topics related to well-being addressed in young people's videos. Previous studies highlight varying perspectives, some identifying positive and negative impacts on mental health and media use (Chassiakos et al., 2016), while others suggest no discernible relationship (UNICEF Innocenti Research Centre et al., 2021).

The contribution of this research to the existing field lies in the challenges posed by other studies (e.g. James et al., 2017), which call for the development of studies focused on the individual factors and the mechanisms that support the positive or negative results of digital use, as well as exploring differences between groups of young people who differ in these individual factors, in this case the gender. Moreover, the results of this study will make it possible to discuss the possibilities of DS experiences as a research methodology (Rubio-Hurtado et al., 2022).

Young People's Well-Being and Digital Storytelling: Possible Implications

Although addressing the well-being of young people in the 21st century is becoming increasingly relevant, the relationship between the use/exposure to digital devices and well-being in adolescence remains a gap in the scientific literature (UNICEF Innocenti Research Centre et al., 2021).

Especially in the last decade, the expansion of young people's access to the Internet, particularly through mobile digital devices, has introduced relevant reflection questions within the scope of education (Monteiro et. al., 2024). Excessive exposure to digital devices and the Internet is associated with negative psychological functioning, particularly in emotional and affective development. The COVID-19 pandemic made it more serious. The parents of these children and young people also belong to a generation that cannot do without Internet access, whether for work, leisure, or other reasons. However, it is unclear if this digital engagement compromises normal youth development and well-being.

Some variables must be considered in the analysis of digital engagement and well-being, such as the time of exposure to technology devices, their use (to communicate, to observe others' contents, to get information to improve their academic skills), or other specificities. These variables explain the controversial research results regarding the influence of digital technologies on quality of life, emotional well-being, and levels of self-esteem. Research also reports the constructive benefits of Internet use (Limone & Toto, 2022), although these aspects still need more development (Rosič et al., 2022).

In this context, the positive or negative effects appear to be short-term, such as the experience of a particular emotion, rather than long-term effects, such as life satisfaction. Dienlin and Johannes (2020) argue that young people are more vulnerable than adults to the adverse effects of digital technology use, which are not so evident.

Low and excessive use of digital technologies decreases well-being. In this sense, Baños et al. (2017) refer to the studies that relate digital environment use and behaviour disorders in young people, but also underline the Internet's potential to prevent and promote positive mental health in young

people. Young people's interactions with social media were intricate and deeply personal, and their choice of social media platforms changed quickly. Nevertheless, they are interested in engaging in platforms that provide mental well-being content, and social media is becoming a valuable tool for promoting education and support related to well-being (Jayman et al., 2023).

Regarding gender, girls are more often vulnerable to social comparison and show more concerns about the need for approval on social media (Teixeira & Monteiro, 2024). They invest more in intimate and dyadic interpersonal relationships and popularity searches. Depressive processes are more common in girls (Platt et al., 2021), and well-being negatively correlates with depressive states. The longitudinal study by Liang et al. (2016) showed that addiction to the Internet is more likely to precede depression in girls rather than in boys, which demonstrates girls' possible disadvantage concerning the emergence of depressive states related to Internet use. In addition, girls are more affected by their online identities and behaviours than boys are. In contrast to boys, girls report that their virtual selves and actions play a significant role in shaping their self-perception and desire to feel accepted (Serrate-González, et al., 2023). According to Twenge & Martin (2020), the relationship between low levels of well-being and mental health problems (cyberbullying, sleep disorders, or fear of rejection) in girls is more related to the use of digital media when compared to boys (Konstantopoulou et al., 2019).

Twenge & Martin (2020), using a representative sample of young people between 13 and 18 years old from the United States and the United Kingdom, concluded that gender differences were significant in the relationship between digital use and well-being. According to the results of their study, girls spend more time on the Internet in social interaction activities, preferably using smartphones. Conversely, the boys spend their time gaming on various electronic devices. They prefer group interactions and show higher levels of aggression. Concerning video games, differences between boys and girls were also found. Boys tend to allocate more time to leisure dedicated to video games over time, whereas girls exhibit preferences in selecting their gaming devices (Iglesias-Caride et al., 2022).

Nevertheless, the question remains: what is the role of the virtual world in this relationship? Gender differences are immediately identified in terms of the preferred type of digital devices and the objectives for which they are used (smartphones, social media, texting, general computer use and online, in the case of girls; gaming and electronic devices in general, in the case of the boys). The relationship between low levels of well-being and a high amount of time spent on social media shows much more pronounced disadvantages for girls. Curiously, young people who manage time properly using digital media present higher levels of well-being than those who do not use them at all, and this effect is more evident in boys (Twenge & Martin, 2020).

Boys use more distractions and fun situations to deal with stress in daily life. They are more focused on their dominance in the peer group, but, in return, they receive less emotional support from peers. They are more interested in themselves and their dominant goals. From this perspective, the characteristics of girls' relational processes place them in a position of greater fragility about emotional issues, namely low self-esteem, anxiety, and depression, but do not inhibit antisocial behaviours. For boys, the most common problems are aggression and antisocial behaviour, but they are more protected from emotional issues (Rose & Rudolph, 2006). In sum, some relational processes are protective of some problems and risk factors for others. Facing the above, understanding the impact of numerous variables, including age, life trajectories and the experience of certain events, may be responsible for the inconsistency in the results of studies in this domain.

On the one hand, the same relational processes can have different consequences for boys and girls. On the other hand, young people can integrate the two styles mentioned above, whether they are traditionally associated with boys or girls, leading them to adopt an appropriate pattern of relationships with their peers.

When digital technologies are introduced into adolescent development processes, despite the differences between boys and girls regarding the psychological and emotional outcomes associated with digital technology use, some studies highlight the role of these media in personal and social development (Limone & Toto, 2022). These findings can support the idea that strategies such as DS can bring different benefits for boys and girls regarding their well-being.

Previous studies involving DS and the well-being of young people generally use DS as a means of social activism, intervention, and research in the field (Botfield et al., 2018; Finnegan, 2023). These studies target young people with different characteristics: LGBTQIA+ (Bellamy, 2018), migrants and refugees (Botfield et al., 2018), indigenous (Loebach et al., 2019), young people with cancer (Pereira et al., 2019), out-of-school girls (Buckler et al., 2022) and focus mainly on the implications of technologies and stories for mental health (Granic et al., 2020; Hall et al., 2016). The main findings suggest that intervention through DS can increase the well-being of young people belonging to underrepresented groups if carefully and respectfully planned, since sensitive and personal topics are addressed.

Those studies also conclude that empowering participatory processes can reflect the unique experience of each young person. Regarding the contents covered in the stories, Pereira et al. (2019) state that, although no differences were observed according to sociodemographic characteristics, the young people's struggles and life situations, such as severe illness, are reflected in the stories. Buckler et al. (2022) refer to DS as a capability approach for young people who miss formal schooling.

In the same line of reasoning, Hall et al. (2016) highlight the importance of DS in research to actively engage young people in narrative processes involving themes related to their well-being and mental health, meeting their needs. Botfield et al. (2018), in turn, identify the primary research gaps as the lack of digital stories about sexual health and interculturality and the need to consider ethical issues of using DS and sexual health methods. The authors also mentioned that the possibility of using digital methods as a form of self-representation and autobiographical narrative should be further explored. These arguments justify the relevance of studying themes related to well-being that emerge from young people´s DS as presented in this article.

Methods

Aims/Objectives and Research Question

This paper explores the implications of digital storytelling workshops on the well-being of young people, with particular focus on the themes that emerge in their narratives. The study's objective was to provide a gender-focused analysis of the main topics related to well-being addressed in young people's videos. Specifically, it addressed the following research question: What issues did boys and girls express in their digital stories, and how can these issues be related to well-being?

Rationale

The framework of positive psychology supported the analysis of young people's stories. According to positive psychology, growing up is associated with autonomy, competence, and relatedness, the last understood as a sense of connection with and care for others. These needs could be achieved through digital communication, for example, through which young people can experience different competencies (social comparison, civil participation, and self-presentation, among others) (Barros et al., 2010). Civil participation supports the feeling of engagement and empowerment in a group, the need to struggle for a shared cause, and improves the sense of responsibility and respect for others' differences (e.g., Tynes et al., 2008). Cognitive development also impacts emotion regulation and self-control in virtual environments. Online self-presentation could increase self-esteem and the feeling of well-being, based on New Zealand's Child and Youth Well-being Strategy (n.d.). In contrast, social comparison can lead to depression and anxiety, especially if young people's previous levels of self-esteem are already low. Furthermore, actively engaging with social media is linked to enhanced well-being, while passive use may harm it (Jayman et al., 2023).

Participants

31 individuals aged between 14 and 20 took part in the study, with a modal age of 17 and an average age of 16.87. Of these, 12 were male (39%), and 19 were female (61%). In terms of the level of education, the young people were distributed in: 9th grade (19%), 10th grade (19%), 11th grade (49%), and 12th grade (13%).

As stated, the project involved young people facing vulnerable situations, and most of their parents were employed in sales or other low-skilled occupations, with some experiencing unemployment (29% for mothers, 10% for fathers). Correspondingly, their educational qualifications in the 9th grade suggest a lower level of education, since in Portugal, compulsory education has been set at the 12th grade since 2009 (Law No. 85/2009).

Instruments and Methods

Data were collected during four DS workshops held in Portugal from April to September 2021. The production of the videos followed the steps proposed by Lambert (2010, 2013a, 2013b): owning your insight; owning your emotions; finding the moment; seeing your story; hearing your story; assembling your story; and sharing your story.

The young people were invited to write a personal story with a maximum of 250 words. The stories were shared in the "story circles", as proposed in Lambert's methodology (Lambert, 2013a). The young people recorded the final version in audio and imported it into a video editor. After searching for Creative Commons images or importing their photographs and drawings, the videos were assembled and, when authorised, made public.

Thematic analysis (Braun et al., 2019) was used to identify shared and specific vital themes emerging from participants' digital stories (girls: n = 19; boys: n = 9), focusing on gender regularities and singularities regarding the outcomes and indicators of well-being, based on New Zealand's Child and Youth Well-being Strategy (n.d.).

Research Design

The authors followed the six-step thematic analysis process proposed by Braun et al. (2019), which included familiarisation with the dataset. In fact, besides being the facilitators of the digital storytelling workshops, meaning that they were present during the making of the videos, namely the story circles, the editing and the première, the researchers viewed and listened to the videos to fully transcribe the text, which was then read and re-read. First, observations and comments on each story and the complete data corpus were noted. Subsequently, researchers proceeded to code the material according to the well-being outcomes and their indicators, presented in Table 1.

Table 1

Well-being outcomes and indicators as defined in the New Zealand child and youth well-being strategy

Well-being outcomes	Well-being outcomes indicators
Accepted, respected and connected	Ability to be themselves.
	Sense of belonging.
	Experience of discrimination.
	Experience of bullying.
	Social support.
	Support for cultural identity.
	Languages.

Learning and developing	Early learning participation. Regular school attendance. Literacy, numeracy and science skills. Social skills. Self-management skills. Youth in employment, education or training
Happy and healthy	Prenatal care. Prenatal exposure to toxins. Subjective health status. Preventable admissions to hospital. Mental well-being. Self-harm and suicide.
Loved, safe and nurtured	Feeling loved. Feeling safe. Family well-being. Injury prevalence. Harm against children. Quality time with parents
Involved and empowered	Involvement in community. Representation of youth voice. Making positive choices. Criminal offences
Have what they need	Material well-being. Material hardship (child poverty). Low income (child poverty). Food insecurity. Housing quality. Housing affordability.

Note: Child Well-being and Poverty Reduction Group (2022)

Following this phase, initial themes were generated, and data were collated for each theme. This material was then further developed, reviewed, split, combined, and sometimes discarded.

Researchers were particularly interested in organising the themes according to participants' gender within the scope of the analysis, which focused on gender differences in well-being outcomes present in the digital stories. As a result, the themes that emerged from the coding were redefined and divided into shared and gender-specific categories, which will be presented in the tables related to well-being outcomes in the next section. Given that the analysis of the stories does not always allow for mutually exclusive categorisation due to the intersection of themes, the presentation of results will occasionally reflect this overlap.

The final phase involved writing up the analysis, incorporating data extracts and contextualising them within the relevant literature.

From an ethical standpoint, various considerations were considered at different stages, as StoryCenter (n.d.) outlines. These included measures to safeguard the well-being and emotional support of the young individuals, the acquisition of informed consent from all participants, and the assurance that particularly sensitive stories would not be disclosed to the public.

Findings

How Boys and Girls Expressed Well-Being Issues in the Digital Stories

The thematic analysis results are presented according to the gender variable. The differences mentioned below are not statistically significant. The authors aimed to identify the main topics concerning well-being addressed by boys and girls in their digital stories and the gender-based

differences in the topics addressed. The analysis considered the well-being outcomes indicators based on the Child Well-being and Poverty Reduction Group's proposal (n.d.).

The well-being outcomes most mentioned by both boys and girls were associated with the idea of being accepted, respected and connected (G: 25%; B: 33%) which referred to shared themes related to bullying/cyberbullying, online benefits and disadvantages/dangers, the need for respect and recognition, loneliness, mental health concerns, and integration in a new country (migration).

Table 2

Thematic analysis of young people's stories related to the well-being outcome 'accepted, respected, and connected´

Well-being outcome indicators	References	Thematic analysis	
Ability to be themselves. Sense of belonging. Experience of discrimination. Experience of bullying. Social support. Support for cultural identity. Languages.	Girls (19 digital stories) 14 references (25%) Boys (9 digital stories) 15 references (33%)	Specific themes Girls: Coming out as gay Homophobia Seeking psychological help Importance of socialising with other young people and leisure (music, dancing) to express emotions and to relax Leisure, holidays, travelling Getting to know new cultures Abusive love relationships (disclosing or sharing intimate content without consent, revenge porn, manipulation) School disengagement Boys: Greater ability to understand others - empathy Gratitude Recognising the need for an attachment figure – (in)security	Shared themes Bullying/cyberbullying Online benefits and disadvantages/dangers Need for respect and recognition Loneliness Concerns about mental health Integration in a new country (migration)

As presented in Table 2, the well-being outcome related to being accepted, respected, and connected had many male and female references. Regarding shared aspects, both groups mentioned situations related to peer violence, both online and offline, highlighting some benefits and dangers of the Internet. They also expressed concerns about mental health. Their stories conveyed feelings such as loneliness and the desire for integration, respect, recognition, and social inclusion.

Why don't people and society think before criticising someone?

We are in the 21st century, and there is still the prejudice of image and how people look.

(...) Why must our society criticise people with coldness, arrogance, and negative points?

Why do they only see this side? And why don't they see the good side of people? (Rita, girl, 18 y.o.)

I have been here in Portugal for seven months, fulfilling my goal of studying. (...) I am here, in Porto, because I had a scholarship from São Tomé to study in Portugal, and I obviously did not let the opportunity go by because where I was studying, I had a hard time learning. (Artur, boy, 17 y.o.)

Regarding specific references, girls mentioned a broader range of topics, such as leisure, cultural identity, sexual identity, emotional/psychological issues, abusive intimate relationships, and even school disengagement. The boys focused on empathy, gratitude, and needing an attachment figure.

Table 3 presents themes related to the learning and developing outcome were frequently mentioned by girls (25% of references in the videos), with similar results as the previous outcome, and by boys (31%).

Table 3

Thematic analysis of young people's stories related to the well-being outcome ´learning and developing´

Well-being outcome indicators	References	Thematic analysis	
Early learning participation. Regular school attendance. Literacy, numeracy and science skills. Social skills. Self-management skills. Youth in employment, education or training.	Girls (19 digital stories) 14 references (25%) Boys (9 digital stories) 14 references (31%)	Specific themes Girls: Social learning Respect Helping others who may be going through similar situations Giving meaning to adversity Learning about preserving intimacy online Boys: Self-recovery	Shared themes Emotional learning and self-improvement: not giving in to threats and pressure; self-acceptance; self-esteem; self-care; self-confidence; self-control; self-acceptance; breaking with patterns of comparative thinking; internal locus of control, perseverance Areas of vocational interest and choice of future profession Encouragement to follow dreams

As can be seen in Table 3, the shared themes for both genders were emotional learning and self-improvement: not giving in to threats and pressures, self-acceptance, self-esteem, self-care, self-confidence, self-control, self-acceptance, breaking with patterns of comparative thinking, internal locus of control and perseverance, areas of vocational interest and choosing a future profession, and encouragement to follow dreams. As for the most distinctive aspects, girls focus on social learning and respect, helping others in similar situations, finding meaning in adversity, and learning about preserving intimacy online. On the other hand, boys emphasise self-recovery with the help of other people:

In the Association, I learnt to respect others, to improve my skills, such as my self-esteem and confidence, to control my emotions, to control my impulsiveness. I have also managed to change several

things about myself, to have more goals, to express myself more, but above all, I have grown, and I am beginning to see life differently. (Paula, girl, 15 y.o.)

I think using technology was very important, especially to talk to our families or with homeschooling. We gained another achievement: teachers so far away, always helping us, which we know was difficult. (Luís, boy, 16 y.o.)

A similar number of boys and girls reported stories related to the outcome of being happy and healthy, comprising 23% for girls and 18% for boys. This category involves mental health issues, concerns related to anorexia and body image, worries about illness, experiences of grief, like the loss of a close family member or pet, and occurrences of physical violence.

Table 4

Thematic analysis of young people's stories related to the well-being outcome ´ happy and healthy´

Well-being outcome indicators	References	Thematic analysis	
Prenatal care. Prenatal exposure to toxins. Subjective health status. Preventable admissions to the hospital. Mental well-being. Self-harm and suicide.	Girls (19 digital stories) 13 references (23%) Boys (9 digital stories) 8 references (18%)	Specific themes Girls: Seeking psychological help ITD Dealing with parents' divorce Psychological violence Suicidal thoughts or suicide attempt Boys: Domestic violence Regret and culpability	Shared themes Mental health concerns Anorexia/body image concerns Illnesses Grief (loss of close family member; pet) Physical violence

Table 4 indicates that both genders depicted health-related concerns in their stories. These situations encompassed illness, grief, and matters associated with body image. Delving into more specific details, girls addressed risk behaviours, sexually transmitted diseases, psychological violence, and attempted suicide. In contrast, boys mentioned situations involving domestic violence, remorse, and feelings of guilt.

In 2021, I got sick from a mistake, and that mistake resulted in two STDs [sexually transmitted diseases] that led to me going to the health centre every week and often to the ER. I was having treatments until one night I got ill and had, I can say, the greatest pain of my life. In the morning, I woke up and was frightened by what I saw, so I went straight to the emergency room. (...) The things that STDs can cause! (Teresa, girl, 18 y.o.)

Suddenly, I started to reduce my meals to the point I stopped eating. All because I wanted to be thin. (...) That morning, I could not get out of bed. I didn't have the strength. I requested an ambulance to take me to the hospital. During the ride, I passed out and lost consciousness of everything. For 15 days, I was intubated, and my life was at risk, weighing just 47 kilos. (Filipe, boy, 17 y.o.)

With fewer references from boys and girls, the outcome loved, safe, and nurtured had 18% references in girls' stories and 11% in boys' stories, as presented in Table 5.

Table 5

Thematic analysis of young people's stories related to the well-being outcome ´loved, safe and nurtured´

Well-being outcome indicators	References	Thematic analysis	
Feeling loved. Feeling safe. Family well-being. Injury prevalence. Harm against children. Quality time with parents.	Girls (19 digital stories) 10 references (18%) Boys (9 digital stories) 5 references (11%)	Specific themes Girls: Family problems (break-ups; divorce; alcoholism; road accidents) Boys: Recognition of teachers' work and effort Support from the social network (friends and teachers) Social and family support School support	Shared themes Family emotional support; parents' emotional support

As seen in Table 5, boys and girls told stories that valued emotional support from parents and their extended family. In fact, girls mentioned topics related to family problems, such as break-ups, divorce, alcoholism and road accidents. On the other hand, boys emphasised the recognition of teachers' work and effort, support from the social network, including friends and teachers, as well as social and family support, and school support:

It was spread through the Internet, which made the whole school, colleagues and friends of Mariana see the photos. (...) She suffered from much bullying. (...) She was alone, scared, ashamed and sad. She felt humiliated. She had the onset of depression and suicidal thoughts. Distressed, she spoke calmly to her parents and asked for help. They decided to change her school to have a fresh start. Mariana went to a psychologist to get her mental health as good as before. She made new friends and learned from the past that she should never give in to threats and do what she does not want to; be careful what she posts online and does. She is becoming a new Mariana. (Helga, girl, 15 y.o.)

She was abused by her father when she was little, and it got him arrested. The girl is not good at her studies and is bullied at school. She still has social anxiety and getting her out of the house is impossible. All these personal problems ended up giving her depression and anxiety. (Fernando, boy, 15 y.o.)

With a lesser degree of prominence, there were only six references from girls and two from boys to the outcome involved and empowered.

Table 6

Thematic analysis of young people's stories related to the well-being outcome ´involved and empowered´

Well-being outcome indicators	References	Thematic analysis	
Community involvement. Representation of youth voice. Making positive choices. Criminal offences.	Girls (19 digital stories) 6 references (5%) Boys (9 digital stories) 2 references (4%)	Specific themes Girls: Online risks and on social media: unrealistic beauty standards (impact of influencers and YouTubers on young people); cyber-bullying Recommendations for other young people about the dangers of the Internet Surviving hardship: coping The importance of reporting bullying Boys: Knowing how to take advantage of life's opportunities	Shared themes Online opportunities: overcome isolation and promote communication and school learning Using social media to communicate with family members who are living abroad, claiming their sexual identity

As depicted in Table 6, regarding the outcome involved and empowered, shared concerns revolve around online opportunities, including overcoming isolation, fostering communication and learning in school, using social networks to connect with relatives abroad, and asserting their sexual identity. In terms of gender-specific themes, girls delved into discussions about online risks and social media, addressing issues such as unrealistic beauty standards promoted by influencers and YouTubers, as well as cyberbullying. They also provided recommendations for other young people regarding Internet dangers, shared experiences of overcoming challenges and coping, and emphasised the importance of reporting bullying. Conversely, boys concentrated on understanding how to make the most of life's opportunities:

Today, on this channel, she talks about her experience and shows people going through the same thing that they are not alone. Always remember to be careful about the comments you make online, because they can ruin a person's life, and never forget to love yourself the way you are, and forget about silly Internet standards. (Sofia, girl, 14 y.o.)

Since I was a little boy, I have loved soccer. I played at school and at home with friends until I joined a soccer school and became the team captain. (Eduardo, boy, 15 y.o.)

Table 7

Thematic analysis of young people's stories related to the well-being outcome ´have what they need´

Well-being outcome indicators	References	Thematic analysis	
Material well-being. Material hardship (child poverty). Low income (child poverty). Food insecurity. Housing quality. Housing affordability.	Girls (19 digital stories) 2 references (4%) Boys (9 digital stories) 1 reference (2%)	Specific themes Girls: Migration in search of new opportunities Boys: Migration to solve health problems	Shared themes Family's financial difficulties

As Table 7 shows, the girl's story focused on migration in search of new opportunities, while the boy referred to the need for migration to solve health problems:

With the bit of [money] we had, we were very happy. However, one day my parents decided that I should come and study here in Portugal, because it is a significantly developed country, compared to our country, São Tomé, and I would have new opportunities. Seeing my parents' concern for me, I did not want to disappoint them by refusing, so I accepted. It was a good idea for everyone, but it was also a huge shock, especially for my brothers, who had great affection for me. I felt terrible about it, but I was discreet so as not to make things worse, and today I am in Portugal. (Maria, girl, 21 y.o.)

I was born in the south of Africa, in Angola. I was a boy who did not always go to school because I was always sick. Moreover, in 2016, everything changed in my life. I was diagnosed with spinal cord insufficiency. Due to a lack of resources, my parents decided to move to another country. We chose Portugal. (André, boy, 18 y.o.)

Discussion: Differences in Well-Being Outcomes Based on Gender

Gender refers to psychosocial and cultural features that society attributes to masculinity and femininity. This means gender stereotypes and gender-related norms result from social and cultural production (Rubegni et al., 2019). It is applied to several areas, such as marketing and targeting messages to men and women using gender stereotypes. Our discussion about the topics presented by boys and girls regarding well-being (or lack of it) will be sustained on these gender stereotypes, because less attention is paid to the similarities found (McLean et al., 2007; Hyde, 2014). In contrast, some studies (e.g., Masanet et al., 2021) continue to highlight the gender gap in digital environments and the differences in how boys and girls relate to them, associating this gap with stereotypes and male and female roles.

As previously mentioned, accepted, respected and connected and learning and developing were the outcomes with the most references, both by boys (33% and 31%) and girls (25% for both). However, there were gender differences, as girls chose to address broader concerns within each outcome, except for the outcome loved, safe and nurtured. This is in line with a systematic literature analysis presented by Mutlu & Dağ (2022), whose results point to the diversity of themes presented by women, the most relevant of which were grouped by the authors into themes related to self-efficacy, social responsibility, catharsis and socialisation.

Issues related to cyberbullying have increased over the past 20 years, and according to Platt et al. (2021), it is more frequently experienced by girls. The more evident relationship between low levels of well-being and cyberbullying in girls, as noted by Twenge and Martin (2020), is not confirmed in our analysis. The stories of our participants include this theme, but do not differentiate between boys and

girls. Cosma et al. (2002) concluded that higher levels of gender inequality were linked to greater gender disparities in traditional bullying. However, lower gender inequality was related to more pronounced gender differences in cyber victimisation. Besides gender, the effect of cyberbullying on well-being is also shaped by elements such as the quality of friendships and the availability of social support. While strong peer connections can serve as a protective factor, differences in social networks based on gender may affect how adolescents handle and respond to cyberbullying. The importance of reporting bullying/cyberbullying is included in the outcome involved and empowered, and this report is what differentiates girls and boys. This leads us to think that the current generation of young girls is more aware of having their voice heard and that a criminal offence can have repercussions due to the social echo it acquires in some countries. This idea is reinforced in the involved and empowered outcome, in which the girls emphasise the importance of raising the awareness of other young people to the dangers of the Internet and to cope with hardship situations.

Returning to the accepted, respected and connected outcome, both boys and girls presented stories about the need for respect and recognition, loneliness, and integration in a new country (migration). These concerns align with the indicators of a sense of belonging, social support, and support for cultural identity.

Regarding the learning and developing outcome, the results also put in evidence that there is no differentiation between girls and boys regarding youth employment, education or training; their digital stories focus on areas of vocational interest, choice of future profession, and the encouragement to follow their dreams. Boys only explore the topic of self-recovery in specific themes. It could be related to males' tendency to express more hope, which is protective for depression symptoms (Goh et al., 2023), and more likely to use humour to cope with stress (Rose & Rudolph, 2006). Nevertheless, girls mentioned the relevance of giving meaning to adversity. Girls also mentioned helping others in the same situation, but boys point out a greater ability to understand others – empathy, when the well-being outcome accepted, respected and connected is analysed. Considering these results, gender differentiation does not stand out. Rose and Rudolph also found no gender differences in young people's reports of helping their friends' behaviour. We agree with them when they state that the question is not addressed to empathy itself, but how it is operationalised, and also because empathy is experienced internally.

The issue of intimacy only becomes evident in girls. Preserving online intimacy appears not only in the learning and developing outcome but also in accepted, respected and connected outcome, namely regarding abusive love relationships (disclosing or sharing intimate content without consent, revenge porn, manipulation). Highly emotional stories with sentimental topics related to relationships and love are aimed at women (Källström et al., 2018). Girls are viewed as vulnerable to risks from sharing personal information, reflecting the idea of femininity as giving and passively exposed to potential predators (Steinfeld, 2022). McLean & Breen (2009) also highlight the reporting of more intimate processes in girls. Concerns about intimacy issues may be associated with girls' greater permeability to opinions and evaluations from peers (Rose & Rudolph, 2006). Connected with this content, online risks and social media addressing unrealistic beauty standards are found particularly in girls' digital stories.

Body image concerns are shared in the happy and healthy outcome in both genders. These results contrast those found by Aran-Ramspott et al. (2024), who emphasise the concern with body image and the influence of social media on girls. Again, while body image is more connected with female stereotypes, it may be that this stereotype is beginning to dissipate in today's society. Nowadays, body image issues seem to address both boys' and girls' concerns in digital settings (Revranche et al., 2022).

We find that in the happy and healthy outcome, boys indicate concerns about domestic violence, regret and culpability, while the girls specifically present other topics in their digital stories. It could be suggested that girls mentioned psychological help, psychological violence, parents' divorce and suicidal thoughts or attempts because they are more vulnerable to depressive symptoms (Platt et al., 2019) and because social media use was only associated with internalising symptoms for girls (Svensson, 2022).

Despite the increase in depressive symptoms among young people since 2012, particularly in girls (Keyes et al., 2019), we did not find gender differences in the digital narrative of our participants. The prevalence of shared topics related to mental health concerns, anorexia/body image concerns, illnesses, grief (loss of a close family member or pet) and physical violence are more evident.

Concerning the loved, safe and nurtured outcome, both genders mentioned themes about the importance of the family as a support network. In contrast, Källström et al. (2018) mention stories centred around deep emotions and sentimental themes like family are generally directed towards women. According to our results, boys mentioned other types of networks, such as support at school, especially but not exclusively from teachers, support from friends and society in general, while girls focused more on the family as a safe haven and the main emotional assistance, especially from parents. In this respect, the girls' stories show concerns for family problems (break-ups, divorce, alcoholism, road accidents), which can jeopardise their main source of support. In addition, within the accepted, respected and connected outcome, girls evidence school disengagement, which can be seen as a threat, so their stories place the family context as the most protective.

Regarding the outcome involved and empowered, and in the specific themes, boys essentially mentioned knowing how to take advantage of life's opportunities, while girls delve more deeply into issues linked to online risks and social media, namely unrealistic beauty standards promoted by influencers and YouTubers, and cyberbullying; making recommendations for other young people about how to deal with these dangers; coping and surviving hardships. In short, while girls established a link between empowerment and fighting against discrimination and self-protection (a defence against something negative), boys related it with advantage (as an opportunity), which aligns with their sense of agency.

The relevance of narrative identity development is crucial in adolescence, and according to McLean & Breen (2009), narrative-making-meaning processes result from a reflection on personal past events and how individuals interpret their own changes over time. Their study, supported by storytelling mechanisms, points out boys' higher self-esteem but also highlights girls' reports about relational topics, namely those relationships that involve intimacy, the concern with making others feel better, getting closer to others, and, finally, sharing the self. Positive emotionality in stories predicts self-esteem for both genders. However, reconstructing negative past experiences into more positive experiences is particularly a better predictor of self-esteem for boys. The positive narrative-making-meaning addresses different aspects of well-being (including making positive choices), depending on gender. Girls' well-being is more focused on relationships, and boys' well-being is on agency, the ability to influence one's functioning and the course of events through one's actions. It is curious to find this trend with pre-young people (11–12 years old), as Rubegni et al. (2019) reported. They stated that the mean agency of male protagonists was significantly higher than that of females. According to Källström et al. (2018), a story with information conveyed clearly and directly works better for men. In part, our results are in line with these studies. In fact, knowing how to take advantage of life's opportunities became evident in boys' digital stories. However, topics related to online opportunities, such as overcoming isolation and promoting communication and school learning, are shared by boys and girls, as well as issues addressed to the self (self-acceptance, self-esteem, self-care, self-confidence, self-control, self-improvement) and emotional learning.

Finally, regarding the outcome of having what they need, the two young African immigrants who mentioned it referenced the difficulties they suffered in their home country and their search for better living conditions and new opportunities, such as education (girl) and medical treatment (boy). The two youngsters also mentioned adaptation and difficulty integrating into a new country. In sum, the most relevant variable in this outcome is undoubtedly the social condition of socioeconomic vulnerability. Although this outcome is the least representative considering all the DS, it is interesting that the lack of material well-being is addressed in migratory movements. According to Shishko (2022), migration is a topic in DS for men. In our case, boys and girls are both aware of the material difficulties that arise from migratory processes.

Conclusions

Well-being is one of the central constructs explored in positive psychology, and it has been transported to the educational context due to its humanistic and developmental perspective. This line of thinking justifies those DS and other educational interventions can be analysed in the light of positive psychology as they work on children and young people's emotions, identifying their potential and resilience issues.

In our case, the participants had the opportunity to interact, share, and produce audiovisual content on topics that concerned their lives, carrying out activities in a project whose intervention occurred immediately following the social confinement due to the COVID-19 pandemic. The contents of the digital stories can be considered evidence that the collaborative production of DS can contribute to the promotion of mental health. Developing and creating stories in the participant group about concerns over (well) being online created conditions for sharing overcoming strategies, emotional support among peers, and personal and social well-being.

This study, supported by DS, enables adolescents to express their perceptions, beliefs, experiences and insights through digital media authentically and genuinely. Exploring their narratives allows us to interpret more deeply those experiences concerning well-being. The contribution of this study to the previous research is to emphasise a different way of researching the problem of well-being in adolescents, through options that are more in line with their generation features, such as the use of digital technologies. The richness of the contents presented by them and the qualitative analysis carried out have put into question the traditional gender beliefs and stereotypes, namely in the scope of well-being. The literature focused on gender differences tends to emphasise the differences between boys and girls.

According to gender stereotypes, stories that focus on strong emotions and sentimental themes like family, relationships, and love are typically targeted at women. In contrast, men tend to respond better to narratives featuring relatable characters and presenting information clearly and straightforwardly.

Indeed, most theories on gender seek to find and explain differences. Evolutionary theories, cognitive social learning, sociocultural, and expectancy-value theories are good examples. To point out the similarities between boys' and girls' challenges is to disrupt conventional gender stereotypes that advance females' socialisation into prescribed behaviours, disrupting conventional gender socialisation practices. This leads us to highlight social constructionist theory because it focuses on processes which express self-movement and ongoing self-organisation and, at the same time, explains how DS shapes people's social identities based on their gender.

Regarding the research question "What issues did boys and girls express in their digital stories, and how can these issues be related to well-being?", our results show that they expressed well-being issues in similar ways, addressing similar topics. Our results also show that the main topics concerning well-being are related to the need to be accepted, respected and connected, followed by recognising the opportunity to learn and develop themselves. The differences between girls and boys are not highly evident, and they are limited to particular topics, such as intimate relationships, which appear in the girls' stories and not in the boys. In addition, boys' positive meaning in DS provides them with an experience of well-being when focused on agentic personal storytelling.

To assume that gender differences observed in real-life social behaviour are reproduced similarly in virtual contexts is questionable. Although this argument makes some sense to us, today's young people, who were born into the digital world, have developed with digital technologies and have also shaped them. The speed and permanence of communication, the contact with sociocultural differences and the sharing of the problems of adolescence itself may have attenuated the expected impact of gender. This can be deduced from the contents of digital stories, which analysed the different outcomes based on well-being experiences.

We suggest further studies supported by DS to address the challenges girls confront today's culture, particularly concerning gender stereotypes (Hlalele & Brexa, 2015). It is also important, in the

future, to examine how other forms of digital engagement compare with digital storytelling in influencing and expressing well-being. Furthermore, the present study sheds light on the need to deepen the research, from a multicultural perspective, on how different theoretical frameworks, technical and methodological procedures can influence the understanding of how young people express well-being issues through digital means. Regardless of the approach adopted, we recommend that teachers and practitioners provide tailored support strategies to individual preferences and experiences, always mediated by an environment where both boys and girls feel equally comfortable discussing well-being topics. In the digital age, can boys and girls emerge as leaders in gender transformation, challenging traditional gender socialisation norms through online activities? Finally, in most of the stories created in the workshops, there was a special closing with a message of hope. In these cases, friends, family, and other professionals were given a fundamental role in overcoming situations that threatened young people's well-being.

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External mediation educational resources for teaching General Relativity: a systematic review

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ABSTRACT
Modern and Contemporary Physics is an important component of civic education for senior high school students, as topics such as Relativity and Quantum Physics connect with everyday life and foster abstract thinking and critical skills. Yet, these themes are often absent from high school curricula. Among them, Einstein's General Relativity Theory (GR) stands out: when presented, it usually sparks strong student interest. This paper aims to support GR teaching through a systematic literature review that identifies accessible resources for high school classrooms. The review is framed by the Cognitive Mediation Networks Theory (CMNT), focusing on its external mediation levels. Searches were conducted in ERIC, Scopus, Google Scholar, and SciELO, targeting studies reporting resources that are both accessible and manipulatable, enabling students' external information processing. Thirty studies met the criteria, comprising resources across psychophysical (14), social (2), cultural (4), hypercultural (10), and sophotechnic (2) mediations. These ranged from physical models, analogies, and collaborative discussions to cultural artifacts, simulations, and AI chatbots. Some gaps were identified: several studies described GR resources without robust empirical testing, while others offered limited evaluation. This suggests that GR teaching at the high school level is still at an early stage. The review highlights the diversity of educational technologies available and their potential to expand students' cognitive capacity through CMNT mediations. Although centred on a specific topic, the mediation-focused analysis proposed here offers a model for identifying effective instructional technologies applicable to teaching other complex theoretical concepts.

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Introduction

Developing informed citizens with critical thinking skills is a key educational goal for full participation in a modern and complex society (Muhfahroyin et al., 2024). Scientific literacy is crucial, and certain science topics, like Modern and Contemporary Physics (MCP), can facilitate this by providing new perspectives and understanding of everyday technologies (Boublil et al., 2023). MCP

topics engage student interest (Emrahoğlu & Yalçın, 2025; Henriksen et al., 2014), especially Einstein's Relativity Theory, which is further motivated by its astronomy links (Kersting, 2019).

The development of relativity has led to the emergence of widely used technologies such as the Global Positioning System (GPS) and events such as the detection of gravitational waves (Abbott et al., 2016). The first image of a black hole increased the presence of General Relativity (GR) in social media (Bower & Van Langlevende, 2022), bringing GR closer to students' daily lives. Therefore, including GR in the school curriculum can help 'overcome negative attitudes towards science' (Aristeidou et al., 2023).

However, the abstract reasoning required to understand the complexity of GR most often excludes it from the secondary science curricula worldwide (Kaur et al., 2017), largely because the relativistic effects are not observed in daily life and conflict with various common-sense ideas (Kraus, 2008). In this sense, the main student difficulty is related to visualization of relativistic phenomena. For example, students often struggle in their imaginative processes due to tensions between their understanding of previously learnt Newtonian conceptions of gravity and their more recent understanding of gravity from an Einsteinian perspective (Steier & Kersting, 2019). Not surprisingly, this difficulty in the abstraction process that requires students to learn about GR was also observed when primary grade students were introduced to this concept (Ruggiero et al., 2021).

Even undergraduate physics students have difficulties understanding GR concepts. Classical conceptions from other conceptual domains, such as Galileo's Relativity, challenge students' understanding of GR (Bandyopadhyay & Kumar, 2010). Students also have difficulties comprehending inertial reference frames and confusions between Special and General Relativity are common (Gousopoulos et al., 2015). Therefore, to help make GR more easily understood by students, we highlight the importance of activities that stimulate students` imaginative process to overcome these obstacles from previous daily experiences.

Considering this scenario, enriching the learning experience with visualizations of studied phenomena will be highly beneficial. Using various educational technologies based on the Cognitive Networks Mediation Theory's (CNMT) external mediation levels (Souza et al., 2012) has the potential to facilitate students' learning (Authors, 2020).

Therefore, the purpose of this review is to identify educational resources for teaching GR that are supported by the four mediation levels of the CNMT. Consequently, we address the following questions:

- Q1. What are the target levels of instruction in the studies investigating educational resources for teaching General Relativity?
- Q2. What types of educational resources and interventions are used/proposed to teach General Relativity based on different levels of mediation?
- Q3. How can the educational resources using different levels of mediation facilitate students' understanding of General Relativity?

We provide insights into these technologies and approaches, discussing their efficacy in demonstrating GR's complex phenomena, to help teachers engage students more effectively. While topic-specific, this resource analysis has multidisciplinary potential for various school subjects, since it can be replicated for other complex topics.

Cognitive Mediation Networks Theory (CMNT)

The Mediation Cognitive Networks Theory (CMNT) posits that the incorporation of Information and Communication Technologies (ICT) in society has changed individuals' cognitive structure. People develop knowledge by processing information in their brains. However, for complex tasks, engaging with external structures is necessary to enhance brain's capacity through external information (Souza et al., 2012).

This interaction with external structures is enabled through four different mediations: psychophysical (interaction with objects), social (interaction among individuals), cultural (use of

language and communication), and hypercultural (using computer and digital tools) (Souza et al. 2012).

Interacting with these external structures, or educational resources, the individual develops internal mechanisms to understand the operations and information provided. Engaging in these mediations is a learning process (Souza et al., 2012), necessitating the development of strategies to optimize their use.

For GR, external processing tools are crucial as it deals with an inaccessible four-dimensional spacetime (Kaur et al., 2017). Therefore, the need arises within the education community to create and disseminate cognitive techniques and tools that can assist the teaching process at different levels and enhance the learning opportunities.

Method

The literature review was developed in November of 2023, through the platforms ERIC, Scopus, Google Scholar and SciELO, widely used sources in science education. On ERIC, a database focused on science education, only the term 'general relativity' was used. We selected these databases for their broad coverage of educational research (ERIC), diverse scientific literature (Scopus), accessibility to a range of materials (Google Scholar), and focus on Ibero-American contexts (SciELO), thus ensuring a comprehensive and culturally diverse dataset.

On Scopus the words in the title, abstract, and/or keywords were searched using the terms and operators 'general relativity' AND ('teaching' OR 'learning' OR 'education'). For Google Scholar, we applied the same terms and operators used at Scopus, both in English and Portuguese. As the most accessed and cited papers are presented in the first pages of Google Scholar, the first 20 pages were analysed. On SciELO the same terms and operators of Google Scholar were used, for both English and Portuguese.

As the aim of the review was to identify teaching resources, we considered papers published from 2000, as older approaches might be outdated. This criterion was established to ensure relevance to contemporary educational technologies, acknowledging that significant growth in digital and external mediation tools occurred after the turn of the century. This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Dewi & Rahayu, 2024; Moher et al., 2015). The first selection of the papers was conducted through the reading of the titles and abstracts. The complete selection process is summarized in Figure 1.

In the screening and reading process, we looked for easy to manipulate resources that could be used with easy-access materials, both for teachers and students, to facilitate GR's comprehension. Considering the CMNT, only papers presenting resources that provided students with an opportunity to engage in external processing of information were considered. Moreover, we considered papers only written in English, Portuguese, and Spanish. Table 1 summarizes the inclusion and exclusion criteria.

Four Mediations Levels' Use

After the selection process, the 30 papers were read in full by the first author to extract the relevant information: the educational technology used/proposed with its external mediation level, the target audience, and, for tested resources, the main research outcomes. To ensure validity and reliability in the article selection and categorization, we implemented a two-stage consensus approach. Any discrepancies in the categorization of this extracted information were discussed between the first two authors until a consensus could be established. We focused on systematically synthesizing qualitative patterns to ensure trustworthiness and transparency of the analysis

The selection and categorization of the papers followed the CMNT premises, considering the external mediation resources that can allow information processing outside the brain. Considering this theory-based analysis and the consensus between the authors, it was possible to increase the validity

and reliability of the analysis. This approach helped minimize subjective bias in classification. The categorization process is summarized in Figure 2.

Figure 1

Flowchart of the search and selection process

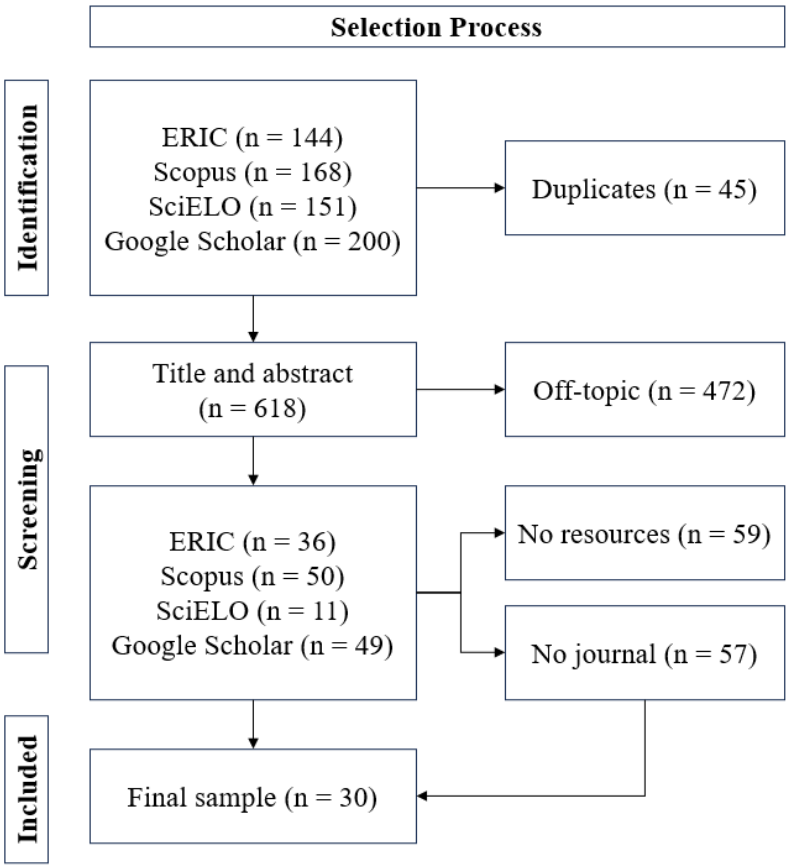


Table 1

Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Journal papers	Conference papers, theses, chapters, books
Papers in English, Portuguese, or Spanish	Paper in other languages
Accessible materials and resources	Difficult to access resources
Teaching resources using at least one level of mediation	No specific teaching resources using one of the four mediation levels

Consequently, it was possible to identify studies that reported or proposed the use of each of the four mediations levels (Table 2). Studies were classified according to the most relevant mediation identified, although in some studies more than one mediation level was used. It is possible to note that there is an emphasis on the usage of psychophysical and hypercultural mediations. In contrast, concerning the social mediation only two correlated works were found.

Figure 2

Flowchart of categorization process

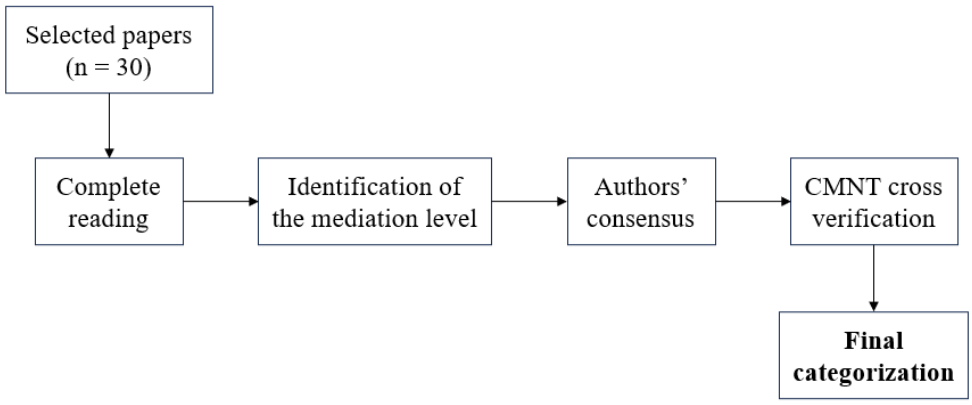


Table 2

Synthesis of selected papers

Source	Psychophysical	Social	Cultural	Hypercultural
ERIC (n = 16)	7	2	0	7
Scopus (n = 9)	6	0	1	2
SciELO (n = 2)	0	0	1	1
Google Scholar (n = 3)	1	0	2	0
Total (n = 30)	14	2	4	10

Results

To present and discuss our results in a logical manner, they were classified according to the external mediation and resource used or proposed.

Psychophysical Mediation

This section focuses on the identified educational resources that enable psychophysical mediation stimulating individuals' sensorimotor schemes.

Sector Models

Zahn and Kraus (2014) presented 'sector models' as a psychophysical resource to visualize curved spacetime in GR (Kraus & Zahn, 2015). The models represent curved surfaces in two and in three dimensions through extrinsic visualization – from one outside observer.

The two-dimensional sector models can be used to identify curvature as positive (spherical space) or negative (hyperbolic space) (Figure 3) by comparing gaps between pieces; for a plane space there are no gaps, a spherical space shows 'open' gaps, and a hyperbolic space shows 'closed' gaps. Three-dimensional sector models represent a three-dimensional plane (Euclidean) and curved spaces (black hole's surroundings) (Figure 4) also with gaps indicating curvature. Therefore, this model allows an extrinsic visualization of a curved three-dimensional space.

Extrinsic visualization of surfaces containing more than two dimensions is challenging. Humans have an intrinsic understanding of three-dimensional space but struggle to visualize it extrinsically, as an additional dimension would be required. Regarding GR, it uses a four-dimensional spacetime universe, and humans cannot perceive the fourth dimension (time) even intrinsically.

Figure 3

Representative scheme of two-dimensional sector models representing the spherical (A) and hyperbolic space (B)

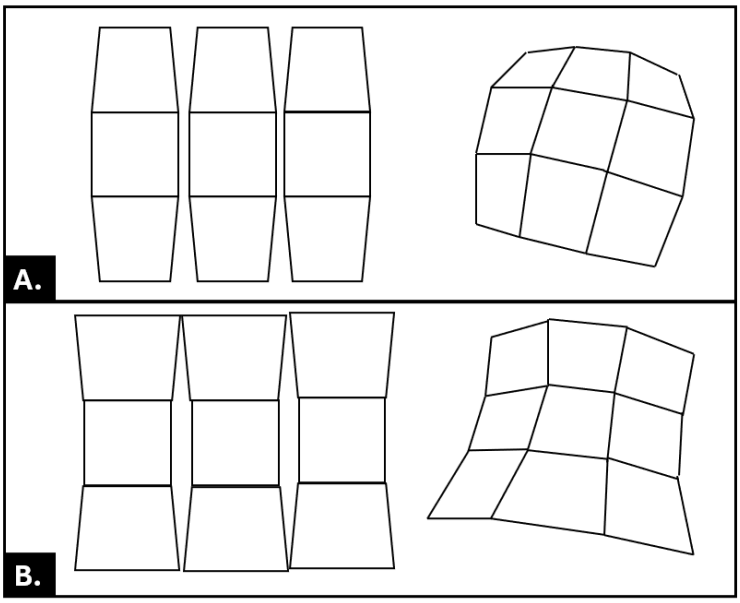
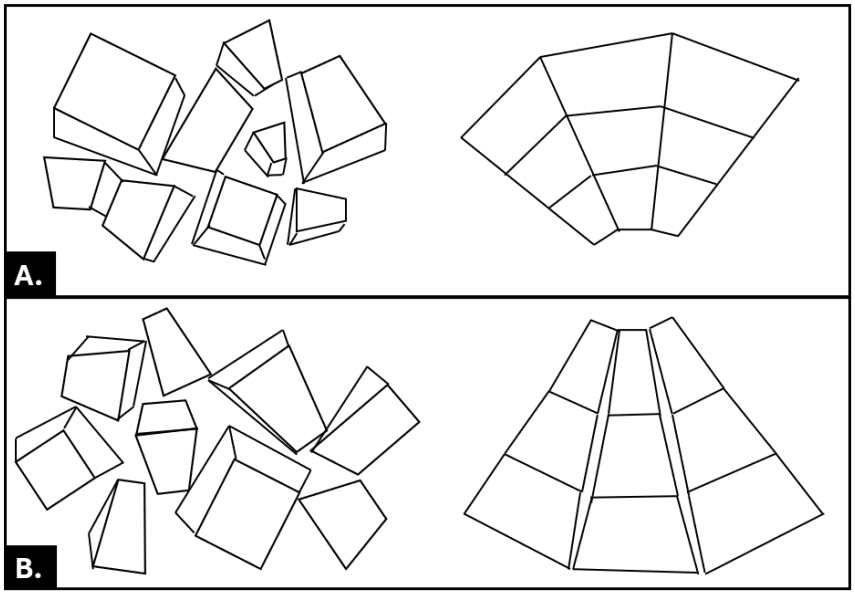


Figure 4

Representative scheme of three-dimensional sector models, separated (left) and assembled (right), representing plane (A) and curved space (B)



Therefore, the human brain is unable to process this kind of information alone and external mediation resources are necessary for students to visualize and comprehend curved spacetime (Souza et al. 2012). Sector models enable the extrinsic view for three dimensions through psychophysical external mediation, aiding students' understanding of four-dimensional curved spacetime.

The authors used these models in subsequent works to represent geodesics and gravitational time dilation (Zahn and Kraus 2019; Kraus and Zahn 2019) and in workshops with pre-service physics teachers and high school students.

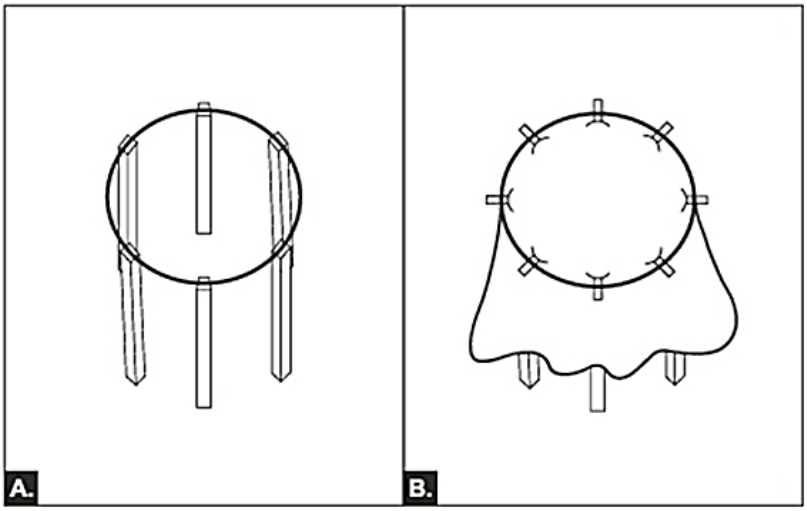
Rubber-sheet Model

The rubber-sheet model is a well-known psychophysical resource used to visualize relativistic phenomena. The Einstein-First project (Einstein-First Project, n.d.) extensively used this model, calling it 'spacetime simulator', proposing various activities to teach Einsteinian physics in schools (Kaur et al., 2017). These activities include measuring spacetime distortion caused by masses (marking two dots on the Lycra-sheet and measuring the distance between them), observing small balls' and toy cars' movements around a central mass, exploring gravitational lensing and precession, measuring gravitational 'force' (using a spring balance with a test mass), and discussing non-Euclidian geometry using triangles on curved surfaces.

Ruggiero et al. (2021) also used the rubber-sheet model and triangles in curved ballon surfaces with elementary school students (10 and 11 years-old). Postiglione and De Angelis (2021a, 2021b) provided a step-by-step guide for constructing a Lycra-sheet structure (Figure 5) and proposed activities through a free-access e-book and activity cards. However, they observed some misconceptions among high school students, such as the belief that only large masses deform spacetime and that gravity acts 'downwards'. Interestingly, the use of this analogy is also reported by Baldy (2007) with Grade-9 students using a soft pillow. The analogy was compared to the traditional teaching methods for teaching falling bodies.

Figure 5

Representative scheme of the proposed structure without (A) and with Lycra-sheet (B)



Despite its limitations, the rubber-sheet analogy is a simple and adaptable resource that can assist students in visualizing GR consequences. It enables the visualization of an effect that students cannot experience in everyday life, serving as an external psychophysical tool that helps students' brains process information (Souza et al., 2012). However, to avoid the development of students' misconceptions, teachers must explicitly discuss the analogy's limitations, such as the visualization of deformation in two spatial dimensions and the need of Earth's gravity for the demonstrations.

Falling Objects

Boublil et al. (2023) from the Einstein-First research group, reported activities with falling objects to explain the Equivalence Principle to Grade-7 students. This principle states that a gravitational field is indistinguishable from an accelerated reference frame, and an inertial reference frame is equivalent to free-fall.

The activities included observing a suspended slinky spring being dropped (its bottom only starts moving downwards when the section above is relaxed), a filled cup of water with a hole in the side (when the cup is dropped, the water stops leaking), a flexible dumbbell (metal measuring tape with a piece of wood on each end), and repelling magnets (toroidal magnets fitted to a wooden dowel rod). In free-fall, the objects behave as if there was no gravity.

These activities help students understand the fundamental concepts of Einsteinian gravity and free-fall. However, students often struggle with reference frame changes and may hold ideas of an absolute and privileged reference frame. These difficulties can hinder students' understanding of the experiments, so it is important to analyse them in different ways.

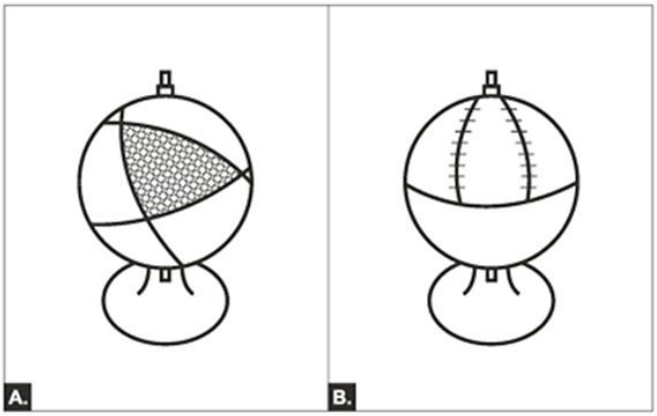
The activities presented used simple psychophysical tools to address the Equivalence Principle, the starting point for GR. The abstract idea of free-fall being equivalent to the absence of a gravitational field involves reference frame changes and can be observed using these external resources, helping the brain's information processing (Souza et al., 2012). The variety of experiments allows teachers to choose the most suitable ones for their context.

Metallic Globe

Andersen (2020) proposed using a metallic globe to convey physical and mathematical concepts to introduce GR. The first activity involves measuring the curvature of the globe using small magnets to form a triangle (Figure 6, left) and calculating the two-dimensional curvature using geometry. The second activity involves drawing six triangles of decreasing sizes inside the marked triangle and comparing their hypotenuse measurements to the calculated values using Euclidian geometry for flat and spherical forms, demonstrating the need for a different geometry on curved surfaces.

Figure 6

Representative scheme of the first activity, with the magnets and strings positioned at the globe (A); and of the third activity, with the geodesic drawn in the globe (B)



The third activity demonstrated the connection between spacetime curvature and tidal acceleration using the 'flatlanders' thought experiment (Thorne, 1994). Two points are marked on the equator of the globe and geodesic lines are drawn towards the pole (Figure 6, right), showing how the lines converge. This demonstrates, in a two-dimensional form, how gravity can be interpreted as a consequence of spacetime geometry (extrinsic view), rather than as a force (intrinsic view). The resources used are accessible and suitable to be used both with high school and undergraduate students.

As the universe is approximately flat in small pieces, the Euclidean geometry works well in everyday life, but the universe is curved on a large scale, requiring a curved geometry. The globe

helps visualize abstract and unfamiliar concepts of non-Euclidian geometry, acting as an external psychophysical resource that aids students' information processing (Souza et al., 2012).

Swirling Water Vortices

Barr et al. (2016) compared black holes to swirling vortices in water, an analogy that can be easily used with high school students. Light beams directed to the vortex bend around it due to refraction, forming a shadow, illustrating how light bends around a black hole due to gravity.

As we do not deal with objects as massive as black holes in daily life, it is not possible to easily observe light bending. This simple and accessible resource helps students process information related to light-bending phenomenon through psychophysical mediation (Souza et al., 2012). However, it is important to highlight that this resource is a 'visual metaphor' and does not represent the explanation for light bending.

Seatbelts

Oliveira et al. (2019) proposed activities that establish a relationship with students' daily life experiences, allowing psychophysical mediation. They used traffic education to introduce GR by linking the Equivalence Principle to the need of seat belts. Using an external reference, the passengers' bodies move forward due to inertia when the vehicle stops. However, using the moving vehicle's reference frame, an 'Einstein's force' emerges as a local gravity pulling the passengers' bodies forward. By changing the reference frame, it is possible to demonstrate the equivalence between gravity and acceleration.

Students often face difficulties with reference frame changes when analysing physical situations (Di Casola et al., 2015), which can be an obstacle that teachers need to be aware of when using this comparison between inertia principle and Equivalence Principle. The authors argue that the relevance of this approach is because it covers two important themes: traffic education and Modern and Contemporary Physics. Moreover, the activities can be conducted with students from the final years of elementary school. The strategy uses students' everyday experiences, such as being inside a vehicle, to assist students in information processing (Souza et al., 2012). This is an excellent and simple psychophysical approach for teaching GR.

Wineglass Base

Huwe and Field (2015) presented a simple resource, a broken-off wineglass base with the centre covered with black tape, to allow the visualization of gravitational lensing effects. The activities, suitable for high school students, involve using the wineglass base and graph papers to understand gravitational lensing via an optical lens model.

The resources are easily accessible and simple to use, making this wineglass base a good psychophysical resource enabling external processing to visualize a phenomenon not seen in daily life. However, as the water vortices, it is a visual metaphor for understanding the concept but does not provide the explanation of gravitational lensing.

Experimental Eclipses' Data

Finally, Goldoni and Stefanini (2020) experimental astronomical data about solar eclipses for explaining light-bending. The first substantial confirmation of GR was the light-bending observation during the Sobral Eclipse in 1919. In the following years, more eclipses were observed with the same purpose. The authors collected measurements from eight solar eclipses between 1919 and 2017 and proposed an activity for high school students to compare the data to two different theories, without referring to them as Newtonian or Einsteinian theories.

Students usually present some difficulties in doing calculations (Machado & Santos, 2004) and, considering the small values involved, they can struggle with it. However, using these data can help students comprehend the broader application of Einstein's theory compared to Newtonian gravity. Although it is a group activity (social mediation), the primary emphasis is on psychophysical mediation.

Social Mediation

Even though individuals' interactions can be present in the use of other mediations, in this section we present the activities focusing on the social interaction.

Conceptual Group Discussions

Steier and Kersting (2019), as part of the ReleQuant project (University of Oslo, Department of Physics, 2016), emphasized the role of imagination as a social process that helps students understand abstract complex themes in science education. They analysed the dialogue and gestures of two high school students performing activities related to the rubber-sheet analogy, focusing on the forms of imagination that emerged from collaborative engagement, with words and gestures mediating the imaginative process.

The main students' challenges highlighted are that GR's effects are hardly noticeable in everyday life and the need to learn how to use three-dimensional representation systems. As students faced challenges that their brains were not able to process alone, interaction with external resources, such as the classmates, was necessary to expand their cognitive capacity (Souza et al., 2012). The communication through dialogues and gestures assisted in information processing, highlighting the importance of social mediation during learning.

In another study as part of the ReleQuant project, Kersting and Steier (2018) investigated students' interactions through a metaphor and thematic analysis of written answers from students' groups discussions about the rubber-sheet analogy. They concluded that the social interaction was crucial for students to make sense of abstract concepts and highlighted the importance of providing opportunities for collaborative and creative activities that foster their understanding of curved spacetime.

Hence, we have highlighted the importance of activities that encourage discussions and interaction among students about GR's main concepts. Through social mediation among themselves and with the teacher, students can expand their cognitive processes and better understand GR (Souza et al., 2012).

Cultural Mediation

Cultural mediation is established using symbolic systems that are socially constructed. Incorporating cultural artifacts, like movies and books, into the teaching can aid students processing information.

Science Movies

Moura and Vianna (2019) and Almeida and Soltau (2022) used the film Interstellar (Nolan, 2014) to address modern physics in high school, using the power of movie scenes to capture students' attention, promote engagement, and facilitate the visualization of phenomena. Such cultural artifacts can broaden students' cognitive capacities and facilitate their understanding of GR.

Moura and Vianna (2019) began with a diagnosis of students' prior knowledge identifying difficulties with GR and Modern Physics concepts and feelings of incapability to comprehend them.

The film was used alongside conceptual discussions, to address the topics from a new perspective, promoting students' confidence and engagement to learn Physics.

Some remarkable scenes, such as the Miller's planet mission that illustrates gravitational time dilation, were the primary focus of the discussions. While this scene provides a helpful yet complex external processing, it may lead to the misconception that relativistic effects happen only in 'outer space' (de Souza et al., 2025).

From another perspective, Almeida and Soltau (2022) employed the flipped classroom methodology, with students first watching Interstellar to motivate participation and generate initial questions. Subsequent classes focused on discussions, exercises and experiments. Finally, students created videos or posters explaining the topics discussed and linked them to the movie scenes.

By interacting with the movie, selected YouTube videos, texts and producing their own videos and posters, students engaged with different cultural external resources to aid their comprehension of the theory, facilitating their information processing. The use of cultural artefacts as external processing tools can expand students' cognitive capacities (Souza et al., 2012). Films, being readily available and well-received by students, can stimulate curiosity and make GR more accessible when they draw upon familiar cultural experiences.

Science-art Festival

Grimberg et al. (2019) used a science-art festival to promote scientific engagement, merging physics, dance, and music for both students and general audience about gravitational waves and black holes. Collaborating with physicists and choreographers, a danced lecture choreography was produced inspired by the TED Talk Dance vs. Powerpoint a modest proposal (Bohannon, 2011) The dancers' movements, sounds echoing and the narrator words, artistically represented and explained the ripples in spacetime. A live interview with a physicists followed the danced lecture. Pre-test and post-test surveys and interviews revealed that participants' knowledge and interest in GR increased, and that many previously had a limited view of science, that was slightly developed after the festival.

Famous Paintings

Guerra et al. (2007) developed a sequence of activities connecting GR with famous artistic paintings. Working in groups, high school students analysed paintings identifying patterns of representations used and comparing them with the accepted scientific theories of that time. For example, in Picasso's Les Demoiselles d'Avignon, they identified revolutionary conceptions about time and changes in ideas of space perception. Then they discussed the influence of Relativity Theory on this change of the conceptions of space and time.

Subsequently, students organized the relationships between GR concepts and the historical and cultural context, presenting their findings creatively through plays, videos, or poetry. The authors highlighted students' great interest during the activities and the challenges posited by students' previous commonsense conceptions.

Using specifically identified art, such as Picasso's work, provides students with cultural external resources that can aid their comprehension of the main concepts of GR. Representing GR artistically and observing its influence on 20th century cultural development can establish connections that foster and broaden the information processing of students' brains (Souza et al., 2012).

Hypercultural Mediation

The hypercultural mediation happens by the interaction with digital tools used to perform programmed and logical actions, for example, by using virtual environments or computer simulations.

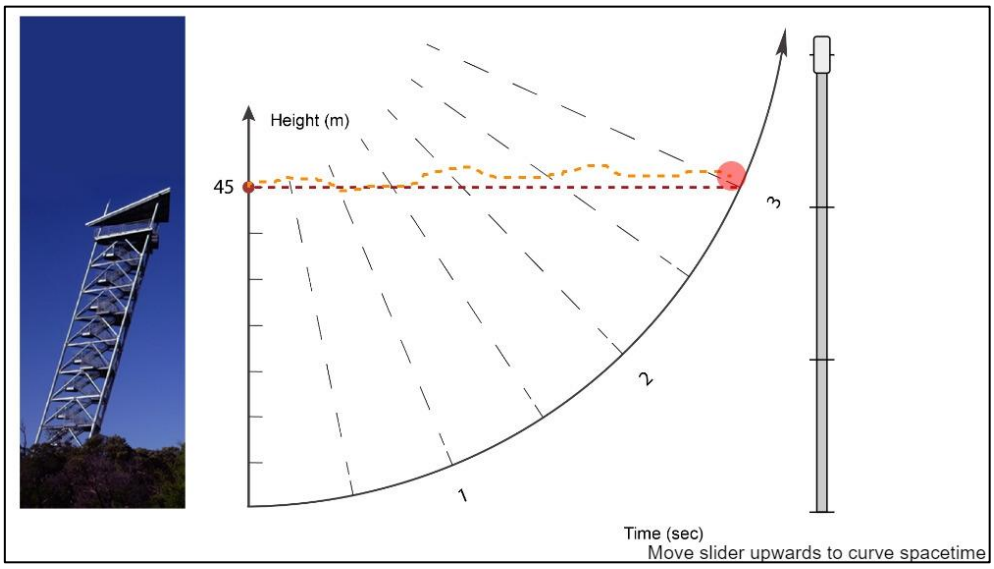
GR Virtual Environment

Machado and Santos (2004) developed and evaluated a course about gravitation where high school students could explore the environment by accessing available computer links. The authors noted that students struggled to solve the proposed problems involving calculations. Although this specific resource is now outdated due to technological advancements over the past two decades, the study reported the early use of hypercultural mediation for GR.

Nowadays, the hypercultural mediation for addressing GR is widely used. The ReleQuant virtual environment, which was presented and explained in various works of the research group (Henriksen et al., 2014; Kersting, 2019; Kersting et al., 2018; Kersting et al., 2020) includes a freely accessible virtual model constructed in the relativistic perspective of Newton's first law, referred to as 'Einstein's first law': 'objects free from the influence of forces move along geodesics in spacetime' (Kersting 2019, 2). The model represents free-fall in a diagram where time curves, according to Einstein's interpretation of gravity (Figure 7).

Figure 7

Time-distortion model where students should draw the trajectory of a free-falling object in a curved spacetime



Note. Kersting (2019).

The authors presented the model's functionalities and how it can complement the rubber-sheet analogy, where time is not represented. Kersting (2019) emphasized that the material was used by high school students, but some learning difficulties were still evident, such as time dilation visualization and conflicts between Newtonian and Einsteinian conceptions. Therefore, the author highlights the importance of using different resources that complement each other to overcome learning gaps.

This interactive diagram allows for external information processing by visualizing time distortion caused by gravity. By interacting with this resource, students can broaden their cognitive capacity. The model is simple and freely accessible online (Kersting, n.d.), making it an excellent hypercultural tool (Souza et al., 2012) for teaching GR.

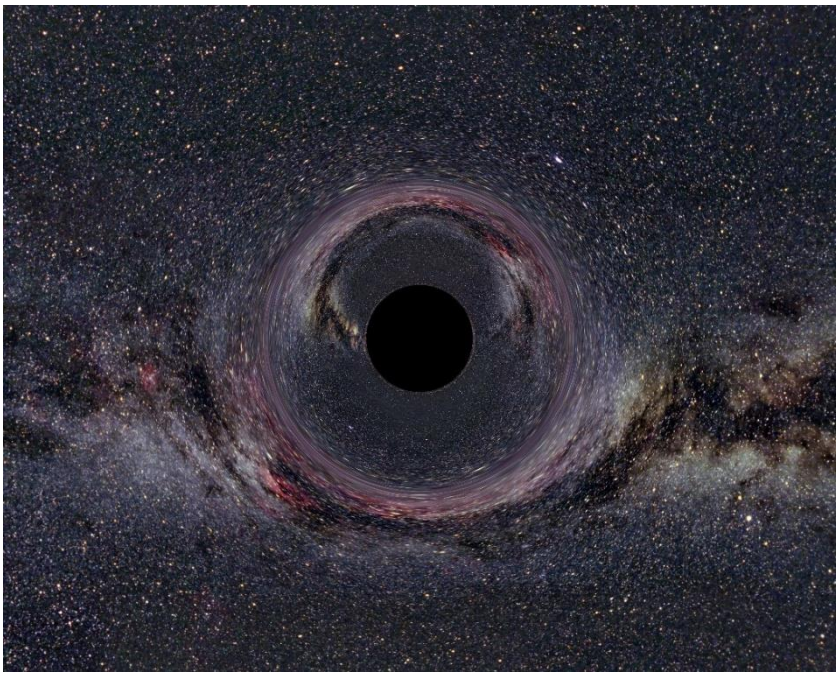
Computer Simulations

Kraus (2008) presented first-person simulations for both Special and General Relativity to facilitate students' visualization of relativistic effects. The GR simulation consists of visualizing a black

hole's surroundings and observe the deflection of light. In this simulation, a black hole was positioned in front of the Milky Way, and the deflection of light emitted by the galaxy behind the black hole can be perceived as the observer approaches the black hole (Figure 8). Kraus (2008) discussed the use of these visualizations in exhibitions at German schools and proposed their use in secondary school physics education.

Figure 8

Simulation of a black hole of ten solar masses at 600 km



Note. Kraus (2008).

The simulation, freely available online (Kraus & Zahn, 2015), constitutes an interesting hypercultural tool that facilitates the visualization of light deflection, a phenomenon not observable in students' everyday life. Considering students' difficulties to imagine visual observations in the surroundings of extremely massive bodies, the simulation serves as an external resource for information processing, helping students better comprehend relativistic phenomena expanding their cognitive capacities (Souza et al., 2012).

More recently, Ferreira et al. (2021) reported using the interactive computer simulation Universe Sandbox to demonstrate collisions between two stars of equal masses, and two with different masses; and then between five stars, one massive central and four smaller stars at different distances. They also used the simulation to discuss the stars' velocity during the collision processes. Universe Sandbox is an interesting educational tool to visualize gravity effects in different situations helping students' information processing about the gravitational behaviour of different objects (Souza et al., 2012).

However, even though this is an interesting resource, using the Universe Sandbox requires purchasing a license, limiting its accessibility, particularly for many public schools. Moreover, it is important to consider the contradictions between students' everyday experiences and relativity concepts during the activities, such as the idea of 'gravity as a force' (Steier & Kersting, 2019), to achieve the expected outcome in GR understanding.

The computer simulations presented can be used with students through direct or indirect interaction. Direct interaction involves students manipulating the simulations in small groups using a computer under the teacher's guidance. Alternatively, indirect interaction is enabled by the teacher manipulating and demonstrating the simulations using a media projector.

Video-analysis Software

Marzari et al. (2023) reported activities developed using video recording and the software Tracker to investigate the Principle of Relativity and the Principle of Equivalence in classical mechanics taught in high school. These principles are crucial for understanding GR and the activities can be used to introduce them, even with a classical focus.

The students used Tracker to analyse videos of moving objects, for example, someone throwing balls and observing their trajectories from different reference frames. Marzari et al. (2023) also used cases with non-inertial reference frames, for example, an experimental car in an accelerated motion throwing a ball upwards. Addressing these principles in a classic view before introducing Relativity Theory is a good way to develop students' abilities to work with reference frame changes, a common difficulty among them (Di Casola, Liberati, and Sonegoc 2015).

The resources used are freely available online (Brown, Hanson, & Christian, 2025), making them accessible tools for different contexts. The videos and their analysis with Tracker can help students develop their information processing skills because the software can highlight different views of the movements that students may not perceive on their own. Moreover, using videos produced by students, such as throwing a ball, it is also possible to make a connection with the psychophysical mediation.

Sophotechnic Mediation

With the advent of Generative Artificial Intelligence (GenAI) in 2023, its usage in educational settings started to be explored. However, as a novel approach, no papers proposing activities using these resources for GR teaching were found. Considering the huge impact that the interaction with these new tools can cause in cognition, the Cognitive Networks Mediation Theory was recently updated to include Sophotechnic mediation (Souza et al., 2024). As a complete new set of competences are required to interact with GenAI, there is the possibility of relevant structural changes in individuals' cognition due to direct interaction with these tools.

Therefore, from the CNMT perspective, it becomes a new form of external cognitive mediation, due to its distinctive operational possibilities. According to Souza et al. (2024), the Sophotechnic mechanisms have 'the capacity to process natural-language queries so as to translate them into commands . . . producing desired content outputs' (p. 9). Considering this premise, we have already developed some activities using two different GenAI tools to approach GR. These activities are discussed below.

ChatPDF

This chatbot uses the Large Language Model (LLM) GPT 3.5 where it is possible to upload PDF files. The AI reads the files, and it is possible to ask questions about the document interacting with the GenAI. This tool is available online and can be freely accessed. Working with the main confirmations of GR (de Souza et al., unpublished), the students were divided into small groups with specific topics: Mercury perihelion precession, Sobral eclipse (1919), GPS, Large Hadron Collider, LIGO's first detection of gravitational waves, and first pictures of black holes (2019 and 2022).

Each group received a scientific communication paper about their topic and were instructed to upload it into ChatPDF. The students interacted with the GenAI asking questions about the topic of the paper uploaded. The objective was that the students became familiar with that specific confirmation of GR. The data collected with this activity was already analysed and will be included in a future paper.

When interacting with ChatPDF, students can ask specific questions concerning their doubts and obtain immediate answers. Therefore, this tool acts as an external resource helping students' brains process information. However, the quality of the outputs obtained depends on the quality of

the inputs, that is, the quality of the prompts. In this sense, it is important to highlight that the students presented some difficulties to elaborate the questions about the papers' subjects to insert in the chatbot. Hence, students need to generate good prompts and interact efficiently with the GenAI (Souza et al., 2024).

AI Image-generator

Interesting tools that can help students communicate their understanding of scientific topics are the AI image-generators. In this context, we developed an activity using the BingAI image-generator. The students were instructed to think about what they imagine for the word 'relativity' and then describe this image to the AI generate it (de Souza et al., 2024).

This activity occurred before and after classes that consisted of learning about GR. The details of the activity and the main results are discussed in de Souza et al. (2024). This GenAI tool can help students to represent their mental imagery in a way different to traditional representations, like diagrammatic sketches. Moreover, the visualization of the results obtained from the AI can help students grasp the concepts and even enable them to perceive their own limitations on images which they have generated.

Therefore, the GenAI acts as an external agent performing tasks and helping the information processing in students' brains. Nonetheless, as well as with ChatPDF, the output obtained, that is, the image generated, depends on the prompt's quality. Some students analysed their difficulties in externalizing what they imagined: other students even presented their thoughts that showed their difficulties in forming clear mental images related to 'relativity'. Based on this study, it is very clear that students need the ability to translate their mental imagery process into prompts using natural language.

Discussion

From the analysis of selected studies, we identified the availability of varied materials and accessible resources for use in the classroom. These studies used simulations and software, analogies with experimental construction, films, and interactive activities among students, thus covering the five mediation levels of CMNT (Table 3). These resources can be used in different social contexts because many of them can be adapted to different situations.

Evidently, some educational technologies presented a higher potential to promote external processing of information than did others. Among them, we highlighted the approaches of GR topics that are crucial to its understanding and with which students usually struggle. These external resources can expand students' cognitive capacities (Souza et al., 2012).

As spacetime curvature is one of the main concepts of GR (McInerney & Sutton, 2024), the psychophysical resources of the rubber-sheet model (Postiglione & De Angelis, 2021a) and the sector models (Zahn & Kraus, 2014) are interactive tools that enable students to visualize this curvature, even with the limitations already presented. The resources are easily accessible and, besides providing external processing of information, they also promote social interactions among students.

The use of the movie Interstellar is also a powerful tool. As many students are familiar with the movie, it can promote their engagement in the learning process (Moura & Vianna, 2019). The scene of the Miller's planet mission, about gravitational time dilation, provides a helpful external processing. As students struggle to understand this phenomenon as real, due to the conflict with everyday experiences (Kraus, 2008), watching the scene and seeing time dilation effects can help them in information processing.

Also dealing with time dilation, the ReleQuant virtual environment has potential to promote external processing (Kersting, 2019). This resource can complement the rubber-sheet model providing the visualization of warped time. Moreover, it is an interactive tool freely available online. As the resource involves free-fall it can be used combined with the graphical representations presented

(Stannard, 2018), enriching the mediation process. This approach might help to integrate the Einsteinian interpretation of free-fall to students' previous conceptual domains, which often become a challenge for their understanding (Bandyopadhyay & Kumar, 2010).

Dealing with the Equivalence Principle, the seatbelt analogy can be easily used and provides powerful insights for students in their learning process (Oliveira et al., 2019). Moreover, the free-fall experiments also can be effective tools to teach this principle (Boublil et al., 2023). As students have difficulties with reference frame changes, they face challenges understanding the meaning of these changes (Gousopoulos et al., 2015). Therefore, using the experiments described in this review paper it is possible to promote external information processing, thereby helping overcome these difficulties.

Finally, we highlight GenAI tools and proposed activities described here using them. The use of the GenAI in the educational setting only started recently but already shows promising potential. Even though we could not find any reports of its use in the classroom, we expect the number of works using GenAI tools to increase soon.

Table 3

Synthesis about the educational technology used in the reviewed studies

Mediation	Resource	Year Level	Researchers	Activity and GR Concepts	Common difficulties
Psychophysical	Sector models	High school	Zahn and Kraus 2014, 2019; Kraus and Zahn 2019	Extrinsic visualisation of curved 3D space using cardboard blocks	Idea of 2D curvature
	Rubber-sheet model	Elementary to high school	Baldy 2007; Kaur et al. 2017; Ruggiero et al. 2021; Postiglione and De Angelis 2021a, b	Understanding that a large mass distorts spacetime and influence the movement of other bodies using a Lycra sheet and different size spheres	Gravity has a downward pull; 2D curvature only on space
	Falling objects	Elementary to high school	Boublil et al. 2023	Recognising that free fall is equivalent to an inertial reference frame using falling objects, such as leaking cup of water	Reference frame changes; ideas of an absolute reference frame
	Metallic globe	High school; Lower undergraduate	*Andersen 2020	Measurements on the globe's curved surface show need for non-Euclidean geometry	Everyday flat space conceptions
	Water swirling vortices	High school	*Barr et al. 2016	Shadows in vortexes of water simulate behaviour of light around black holes	Visual metaphor, not the explanation for light bending
	Seatbelts	Elementary to high school	*Oliviera et al. 2016	Comparing inertia principle to gravitational field effects to explain the Equivalence Principle	Reference frame changes to understand 'inertia as a local gravity'
	Wineglass base	High school	*Huwe & Field 2015	Laser projection in wineglass base simulates visualisation of gravitational lensing	Visual metaphor, not the explanation for gravitational lensing
	Experimental solar eclipses data	High school	*Goldoni and Stefanini 2020	Light deflection measurements in eclipses used to compare Newtonian and Einsteinian theories	Small deflections measured to use for calculating
Social	Conceptual group discussions	High school	Kersting and Steier 2018; Steier and Kersting 2019	Discussions in pairs about the rubber sheet analogy to explain gravity and free-fall	Imagination and expression of ideas; imperceptibility if GR effects in everyday life
Cultural	Science movies	High school	Moura and Vianna 2019; *Almeida and Soltau 2022	Use of *Interstellar* movie to illustrate GR effects and engage students	Idea that relativistic effects happen only at 'outer space'; students feel incapable to comprehend GR concepts
	Science-art festival	Elementary to high school	Grimberg et al. 2019	'Celebrate Einstein Festival' with danced lecture representing black holes and	Previous limited view of science

				gravitational waves, and interviews with physicists	
	Famous paintings interpretations	High school	Guerra et al. 2007	Analysis of the relativity influence in the representation of space and time on paintings	Previous commonsense conceptions
Hypercultural	GR virtual environment	High school	Machado and Santos 2004	Courseware about gravitation where students can explore and access available links	Struggle to solve proposed problems involving calculus
		High school	Henriksen et al. 2014; Kersting et al. 2018; Kersting 2019; Kersting et al. 2020	Virtual environment addressing GR topics where students can interact and access different resources, such as the 'time distortion model'	Difficulty in visualization of gravitational time dilation; conflict of Newtonian and Einsteinian conceptions
	Visual graphic diagrams	High school	*Stannard 2018; *Stannard et al. 2017	Graphic diagrams representing free-fall using Einsteinian interpretation	Difficulty in visualization of gravitational time dilation; difficulty to interpret free-fall in Einsteinian view
	Computer simulations	High school	Kraus 2008	First-person visualization of a black hole in front of Milky Way showing light deflection	Difficulty in imagine visual observations in high-gravity surroundings
		High school	Ferreira et al. 2021	'Universe Sandbox' simulation of stars' collision	Ideas of gravity as a 'force'; contradiction between everyday experiences and relativity
	Video-analysis software	High school; Undergraduate	Marzari et al. 2023	Use of 'Tracker' software to analyse videos of inertial and non-inertial movements and address Relativity Principle and Equivalence Principle	Difficulty in analysing movement from different reference frames
Sophotechnic	ChatPDF	High school	de Souza et al. not published	Upload on ChatPDF of science communication papers about relativity corroborations, asking questions and elaborating posters	Limited interaction with the chat and difficulty to elaborate questions regarding the papers
	AI-image generator	High school	de Souza et al. 2024	Use of Bing AI image generator to create images that represents what students imagine for 'relativity'	Difficulty in forming clear images related to 'relativity'; difficulty in externalising what was imagined

Note. *Without reporting the test of the resource, some of these findings are from other papers dealing with the same topic but not necessarily the same resource

Conclusion

The concept of General Relativity uses an interpretation of nature that contradicts common-sense. Consequently, GR involves highly abstract and hardly perceptible concepts in everyday life, creating great difficulties in the imaginative process of the phenomena involved (Steier & Kersting, 2019). Therefore, the importance of using different mediations and educational technologies that allow such visualization to occur is highlighted, contributing to an understanding of GR.

Using the background of the Cognitive Mediation Networks Theory (Souza et al., 2012; Souza et al., 2024) we presented a literature review aiming to identify these available educational technology resources. Through the research conducted, it was possible to find a range of different resources using the five external mediation levels of CMNT. Many of these resources have great potential to be used in GR teaching because they are developed with easily accessible materials that teachers can use with their students.

Through the results obtained it was possible to answer the three initial research questions. For each work selected, the target level of instruction was identified, answering the Q1. Moreover, each educational resource identified was classified according to the different mediation levels, answering the Q2. Finally, we discussed how these educational resources might help students to overcome the main difficulties reported in the literature, answering Q3. These results answering the research questions were summarized in Table 3.

We acknowledge the limitations of this systematic literature review that should be considered when interpreting the results. Firstly, the search strategy was limited to sources indexed in the databases used (ERIC, Scopus, SciELO and Google Scholar). Therefore, some eligible studies may not have been included in our analysis. Moreover, the eligibility criteria and search strategy focusing specifically on resources for teaching General Relativity may have led to the omission of some relevant studies exploring educational technologies for other complex physics topics that could potentially be adapted for GR.

The quality and risk of bias of the included studies was not formally assessed, as some of them described proposed teaching resources without robust empirical testing. Considering the studies that did test the presented resources, most did so in a limited educational context, so the generalizability of the results to other student populations is unknown. More rigorous empirical studies across diverse contexts are needed to establish the efficacy of the identified resources for supporting student understanding. However, the present review aims to present potential educational technologies to be used, and not to evaluate their effectiveness.

Despite the limitations mentioned above, this review provides a valuable synthesis of available resources leveraging different external mediation levels and highlights promising tools and strategies that can serve as a starting point for educators seeking to incorporate these topics into physics curricula. Considering the limited number of empirical studies that we identified from 2000 to 2024, the findings also underscore the need for further research to develop evidence-based recommendations for the optimal use and combination of educational technologies to teach General Relativity and other challenging scientific theories.

The identified gaps, such as the lack of fully validated instructional tools or insufficient alignment with systematic curricular standards, suggest opportunities for future studies to integrate robust assessment frameworks and cross-cultural comparisons. By mapping the identified resources on to theoretical perspectives, we highlight not only their instructional potential but also the need for evidence-based refinement and rigorous empirical testing

As Modern and Contemporary Physics topics are, up until recent times, rarely present in the school environment (Kaur et al., 2017), we anticipate that this review will facilitate the use of and accessibility to educational technology resources for teachers, thereby encouraging the teaching of GR and assessments of students' learning. Finally, this analysis to identify available resources for teaching GR can be replicated for all other teaching fields, not only science education. This strategy can also be used to identify assistive technology for inclusive education using the external mediations (Picanço et

al., 2022). The approach described in this paper, guided by the CMNT, can help the teaching of complex concepts that rely heavily on information-processing, knowledge acquisition, abstraction, and other cognitive mechanisms.

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Declaration of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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Effect of guided inquiry on junior high school learners' experimental design skills in solving chemistry problems

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ABSTRACT
The main objective of this four-year empirical research project has been to develop the experimental design skills of 12-16 year-old Hungarian pupils in Grades 7–10 of junior high school through guided inquiry, using six chemistry experiment worksheets each school year. Group 1 (control group) and Group 2 follow step-by-step instructions, but after the experiment, Group 2 also answers a series of questions about the design of the experiment. Group 3 is required to design the experiments, guided by the series of questions. The impact of the intervention on 603 pupils' experimental design skills and disciplinary content knowledge were measured by structured tests at the beginning of the project and at the end of three school years. By the end of the third year the intervention only had a small positive effect on the development of experimental design skills in Group 3 (Cohen's d: 0.16), while the development of disciplinary content knowledge was slightly negatively affected for both experimental groups (Cohen's d for group 2: -0.07; Cohen's d for group 3: -0.19).

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Introduction

Models in Inquiry-based Science Education

Inquiry-based teaching strategies are generally considered to be inductive in nature. They are characterised by being question- and learner-centred and use practical activities to provide data from which to develop concepts, while in the more traditional deductive instructional laboratories the role of these is to verify a concept previously presented (Bunce & Cole, 2007, p. 59). Piaget's functioning model has been used as a rationale for inquiry-based instructional strategies (Lawson et al., 1989). According to this model, if there is an incompatibility between the assimilated information and the learner's existing mental structure, either the mental structure or the perception of the information must change (Piaget, 1963). One model of inquiry education influenced by Piaget's

functioning model is the learning cycle approach (Karplus & Thier, 1967), when the learner is exposed to the information, followed by activities that help to accommodate and then organise the information. Another model of inquiry that is consistent with the learning cycle approach is the Process Oriented Guided Inquiry learning (POGIL) that uses key scientific processes to develop scientific concepts (Farell et al., 1999), while pupils solve scientific problems in cooperative learning groups. Science Writing Heuristic (Burke et al., 2006) and the Argument Driven Inquiry (Walker et al., 2013) are other examples of models that emphasise asking scientific questions, designing appropriate procedures to test those questions, supporting conclusions with experimental evidence, and communicating ideas clearly (Reynders et al., 2019).

As early as 1989, there was considerable evidence that inquiry-based laboratory activities had real educational advantages over more traditional approaches (Lawson et al., 1989). However, according to a 1997 survey in the United States, fewer than 10% of college chemistry laboratories used this approach (Abraham et al., 1997). Following the recommendations of the Rocard Report (Rocard et al., 2007), the European Commission's 6th and 7th Framework Programmes supported several international projects on inquiry-based methods to stimulate interest in science taught in schools. As a result of that, and the work of many other educational researchers and school science teachers around the world, resources for inquiry-based teaching and learning are freely available online (e.g. McLoughlin et al., 2015). Training programmes for science teachers in inquiry-based education have also been developed (e.g. Bolte et al., 2012). Successful implementation of teaching/learning materials developed by science teachers and piloted in classrooms with positive feedback from pupils have been reported (e.g. Dumitrescu et al., 2014), resulting in improved achievement, even for Grade 8 pupils (Savec & Devetak, 2013).

There have been many other studies on the benefits of using inquiry-based learning. For example, the review of research on POGIL by Rodriguez et al. (2020) claimed that it is more effective in supporting learning than lecture-based approaches. More recently a successful adaptation of a guided inquiry laboratory experiment for undergraduate food chemistry students was reported by Rodríguez-Berrios and Rodríguez-Vargas (2025). Yet, according to Restucia et al. (2018) many science, technology, engineering, and mathematics (STEM) undergraduate students finish their studies with inadequate experimental design skills (EDS). This is despite the fact that curriculum based solely on recipe-like experiments does not provide learners with the opportunity to evaluate experimental techniques, design and plan experimental protocols (Domin, 1999; Fay et al., 2007).

Matthews (2018) points out that learners can gain meaningful insights into the construction of scientific knowledge through processes of inquiry, reasoning and planning only if they are properly organised and reflected upon. Given the limited prior knowledge of pupils, the gradual development of EDS at school level is even more challenging than in university courses. Negative beliefs about science and practical work, difficulties in planning such activities, persuading pupils to reflect on their experiences and outcomes, and concerns about evaluating practical inquiry also hinder the use of these pedagogical strategies (Akuma & Callaghan, 2019). In addition, during practical work, cognitive overload of the pupil's working memory can easily occur (Johnstone & Wham, 1982). Therefore, it is worth focusing on identifying independent variables, measuring dependent variables, controlling for confounding variables and recognising the relationship between them, which is the essence of experimental design (Arnold et al., 2018; Arnold et al., 2021; Cannady et al., 2019; Pedaste et al., 2015). Lazonder and Harmsen's (2016) meta-analysis of studies on guided inquiry instructions concluded that more specific instruction promotes better quality learning outcomes.

Therefore, pupils coming from a traditional learning style should be provided with adequate and appropriate scaffolding to successfully solve an inquiry-based task (Seery et al., 2019) to reduce cognitive load and student resistance, and increase their chances of successfully answering the question asked at the beginning of the guided inquiry task. One such tool is the Experimental Design Diagram developed by Julia Cothron and colleagues (2000), based on the ‘fair testing’ method (i.e. 'how to vary one thing at a time' or 'holding other things/variables constant'). This consists of a series of questions to help students identify and control variables, formulate a hypothesis and design the

experiment. A prompt should also be chosen to arouse the learners' interest and curiosity (Cothron et al., 2000). The systematic use of this worksheet structure to do experiments is expected not only to help the learners carry out a specific experiment, but also to provide them with an opportunity to understand and generalise the process of designing experiments. In this way, puplis can acquire epistemic knowledge about scientific experimentation, which refers to how it generates knowledge and why this knowledge is justified (Lee et al., 2024).

Objectives and Research Questions (RQ) of the Present Study

The main objective of the present four-year empirical research project has been to develop the experimental design skills (EDS) of pupils in Grades 7-10 through guided inquiry. Experimental design activities are recommended in the National Curriculum of Hungary (2020) for the development of scientific literacy. However, the number of tried and tested teaching materials for the development of EDS is limited. Some of those had been prepared and used by the research team in previous studies (Szalay & Tóth, 2016; Szalay et al., 2020; Szalay et al., 2021). As with a previous longitudinal project, in the current longitudinal study, the researchers want to influence how a large sample of pupils perform experiments in schools during all four years of compulsory chemistry lessons. However, in contrast to that previous project, in the present project pupils in the experimental groups are given help in learning how to design experiments in the form of a series of questions similar to the Experimental Design Diagram developed by Julia Cothron and colleagues (2000). These questions focus on identifying independent variables, measuring dependent variables, identifying the relationship between them and controlling for confounding variables. Also of interest is whether the intervention has any impact on learners' disciplinary content knowledge (DCK). This type of instruction used had a significant positive effect on the EDS of the Grade 7 experimental group who were asked to answer these series of questions before they designed the steps of their experiments (Szalay et al., 2023), but not for the other experimental group, who performed the experiments in the same way as the control group, step-by-step following a recipe and then answered the series of questions. Although the trend changed in the second year, the intervention still resulted in a positive change in EDS for the experimental group that designed their own experiments according to the series of questions (Szalay et al., 2024). Therefore, in the third school year of the present project, the following research questions were posed in order to find answers to the long-term effects of the methods used.

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

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 pupils in the control group by the end of the third year of the present project?

RQ3: Was there a difference in the development of the EDS between pupils in the two experimental groups by the end of the third year of the present project?

Methods

Research Design and Participants

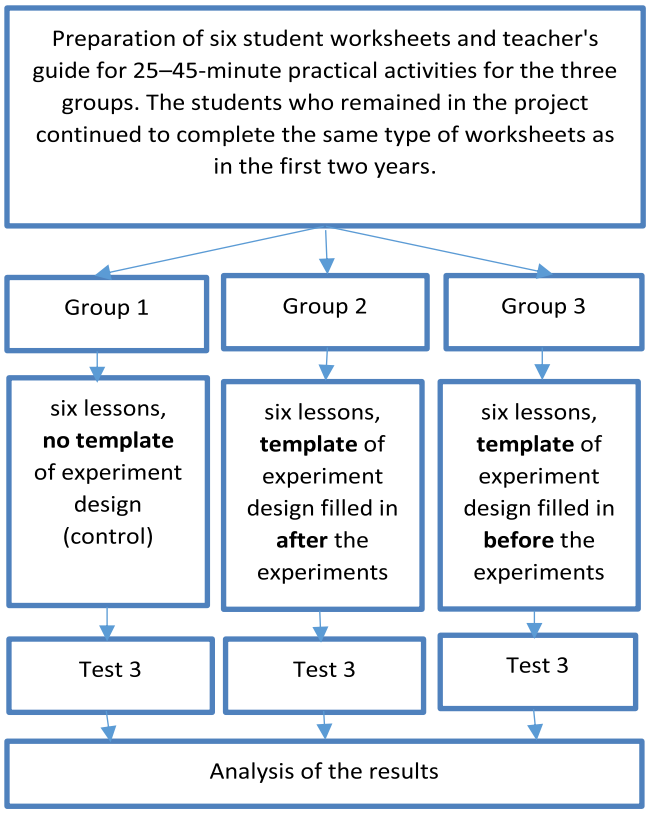
The research model has a quasi-experimental design with a non-equivalent control group. Nine hundred thirty-one seventh-grade pupils completed a test (called Test 0, T0) in September 2021. They were enrolled in 38 classes in 25 Hungarian schools. After evaluating the results of Test 0, the classes were divided into Groups 1, 2 and 3, with no significant difference between the groups in terms of either the mean initial performance of the pupils on DCK and EDS tasks or the hypothesised parameters (school ranking, mothers' education, gender). The

pupils remain in the same group they were in at the start of the project for four years. Therefore, only pupils who stay in the same school from Grade 7 to Grade 10 (from age 12–13 to age 16–17), were selected to participate in this project. Thus, the full four years of their compulsory chemistry studies can be influenced by the worksheets provided by the research group and their progress could be followed by the tests completed each year [Test 1 (T1), Test 2 (T2) and Test 3 (T3) at the end of the first, second and third school year, respectively)]. If a pupil has missed a test for any reason, their results are no longer taken into account. Therefore, 603 tests were evaluated at the end of the third school year.

Group 1 is the control group, which follows step-by-step instructions to carry out the experiments, what Banchi and Bell (2008) called a 'structured inquiry'. Groups 2 and 3 are the experimental groups. Group 2 follows the same step-by-step instructions as Group 1, but after completing the experiment they also answer a series of questions about the identification of the independent variable, the dependent variable and the constants on their worksheet. Their answers are discussed with their teachers. This teaching method can be seen as a simplified version of the approach used by Reynders et al. (2019), who assigned the relevant questions to the laboratory report during the discussion of the experimental procedure. The treatment of Group 3 can be called guided inquiry (Schoffstall & Gaddis, 2007), as the question to be investigated is given on their worksheet and learners have to design an experiment to find the answer. The set of questions (a 'template') on their worksheets can be considered as a shortened and simplified version of the Experiment Design Diagram based on the 'fair testing' method developed by Julia Cothron and colleagues (2000). Answering the series of questions concerning the identification of the independent variable, the dependent variable and the constants before the experiment helps these pupils to control variables, discuss the hypotheses and then define the steps of the experiment. The answers are discussed with Group 3 by their teachers before the experiments are carried out. The two experimental groups (Group 2 and Group 3) were treated differently to see if this set of questions really helps to develop learners' experiment design skills, which would be more effective: to use it after the step-by-step experiment (for Group 2) or to use it to plan the steps of the experiment before pupils carry out the experiment (for Group 3)? The research group prepared six worksheets for each school year, in three versions for Groups 1, 2 and 3. Teachers chose the lessons in which they used the worksheets and tests provided by the research team. The research model of the quasi-experimental design with a non-equivalent control group used in the third year of this project is summarised in Figure 1. (The set of questions to help develop experimental design skills is referred to as a 'template' for simplicity.)

Figure 1

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



Thirty-four in-service chemistry teachers and five university chemistry lecturers were involved in the four-year project in September 2021. The participation of teachers was voluntary. Unfortunately, by the end of the third year, five of the teachers who worked with the participating pupils in the first year had stopped teaching or simply did not have enough time to participate in the research group anymore, so their pupils are no longer included in the sample. Three of the teachers who originally taught the participating pupils were replaced by other teachers for reasons beyond the control of the research team.

The teachers were in direct contact with the research team leader by e-mail. They asked for advice when needed, despite the very detailed instructions given in the worksheets and teacher's guides. Teachers emailed feedback to the research team leader on the piloting of the worksheets and photos of their pupils doing the experiments. The photos are available on the research team's website (MTA-ELTE Research Group, n.d.). Each school year, teachers were also asked to complete a questionnaire on the testing of the six worksheets from the previous school year (Vélemények az MTA-ELTE, n.d.). They were asked about their experiences with the piloting. Analysis of the questionnaire results showed that pupils in the experimental groups were typically able to answer the series of questions on experimental design with little or no help from their teachers.

Ethical Considerations

The research team had to develop its own ethical protocol to ensure informed consent and to protect the privacy and confidentiality of individuals (Lawrie et al., 2021), as no local procedure was available. The process was described in a paper on the results of the first year of this four-year project (Szalay et al., 2023).

Data Collection Tools

Worksheets

Each worksheet and accompanying teacher's guide describes chemistry experiments that take about 25-45 minutes. The topics of the worksheets were linked to the National Core Curriculum of Hungary (2020) and agreed with the participating teachers. Tables containing the topics and the corresponding experimental design tasks of the first two years' worksheets have already been published (Szalay et al., 2023; Szalay et al., 2024) and see Table A1.a – b in Appendix for those used in the third year. Three versions of the first 18 worksheets (for Groups 1, 2 and 3) prepared for the first three year of the project are available in English on the project website (MTA-ELTE Research Group, n.d.). The worksheets were used with pupils working in small teams.

From the second year onwards, the teacher's guides for the Group 1 worksheets include a request for the teacher to draw pupils' attention to the importance of experiments in science. In the experimental groups worksheets it is emphasised that evidence in science is collected through well-designed experiments and that understanding how to design an experiment can be useful in debunking pseudoscientific fraud.

All worksheets include a context-based task with elements of systems thinking under the heading “Let's think!”, with the primary goal of maintaining interest (e.g., Chen & Xiao, 2021; del Mar López-Fernández et al., 2022; Klemeš, et al., 2021; MacDonald et al., 2022). These are identical across all three groups' worksheets. Although systems thinking and contextual pedagogy share common features, they also have important differences (York & Orgill, 2020). Systems thinking allows learners to see the system as more than the sum of its parts (Reid & Amanat Ali, 2020). Incorporating more aspects of systems thinking into chemistry education can have other clear benefits for pupil learning by developing more higher order thinking skills (Szozda et al, 2022).

The first versions of each worksheet were prepared by the participating teachers and the leader of the research group and then read by the five university lecturer members of the research group, who are experts in the development of chemistry teaching materials for school pupils. The authors then improved the worksheets based on the experts' suggestions. This second version was proof-read by one of the experts and the leader of the research group and the final changes were agreed. The worksheets used in the third school year of this project can be downloaded from the research team’s website (MTA-ELTE Research Group, n.d.).

Tests

According to Vorholzer et al (2020), measuring pupils' ability to design experiments is critical in science teaching. Assessment of laboratory work should focus on developing higher-order competencies such as experimental design and understanding of epistemic practice. Since there is concern that the amount of DCK acquired during the learning process may be reduced by the time spent with the EDS tasks, the development of DCK should also be followed by tests. Therefore, both EDS, as part of the inquiry skills, and DCK had to be assessed (e.g. Cooper, 2013; Reed & Holme, 2014; Rodriguez & Towns, 2018; Underwood et al., 2018). In order to monitor the progress of the pupils' performance, each test in this project consisted of different test questions based on knowledge and skills that the learners had previously acquired by completing the worksheets provided by the reseach group. However, the questions of all four tests (Test 0, Test 1, Test 2 and Test 3) were structured in the same way and categorised according to the levels of the dimensions of cognitive processes according to the revised Bloom's taxonomy (Bloom et al., 1956; Krathwohl, 2002). Each test contained eighteen compulsory items, each worth 1 point. Nine items were used to assess EDS and the other nine for the DCK (three for recall, three for understanding and three for application).

When designing the EDS tasks, different evaluation criteria (Sirum & Humburg, 2011), evaluation tools (Chen et al., 2019; Tseng et al., 2022) and the Science Olympiad (2020) experimental

design checklist were consulted for guidance. This led to the conclusion that experimental design tasks should require the identification of independent, dependent and controlled variables and the use of fair testing (Csíkos et al., 2016). The experimental design tasks should include the content knowledge needed to solve the tasks (Cannady et al., 2019). The tasks were placed in the context of everyday life, to capture the pupils' interest. The following experimental design task was used in Test 3 to compare the development of pupils' EDS in the three groups.

The 'bath bomb' is a ball made of citric acid, baking soda, starch and cocoa butter with a few drops of essential oil and colouring. It's fun to use, because it bubbles up fragrantly when added to the bath water. In water, the reaction of baking soda and citric acid produces carbon dioxide gas. Let's say you want to make lots of these bath bombs as gifts for your friends. According to a source on the Internet, 50 g of citric acid requires 100 g of baking soda. However, based on the reaction equation and the molar masses, 192 g of citric acid reacts with 252 g of baking soda. You don't want to waste the materials (which cost money), so you decide ***to experiment by reacting small amounts of citric acid and baking soda to see which mass ratio*** *produces more gas. (This can be compared, for example, to reacting the materials in bottles, with a balloon placed over the mouth of the bottle after adding water to the substances.)*

a) What would you change during the experiments?

b) Which of the products of the chemical reaction that is important for bubbling depends on the change you cause?

c) How could you test the amount of the reaction product named in (b)?

d) How would you decide which mass ratio to use?

e) Why is it always important to shake the contents of the bottles thoroughly?

f) Put a ***+*** *sign* ***in front of the statement in the list below if you think it is true****, and a* ***-*** *sign* ***in front of the statement if you think it is not true****. (You can write another sign after a clear cross-out if you change your mind.)*

- ☐ *The same mass of citric acid should be used in each experiment.*
- ☐ *The same mass of baking soda should be used in each experiment.*
- ☐ *The same volume of bottle should be used in each experiment.*
- ☐ *The bottles used for each experiment should be made of the same material.*

Note: pupils may choose either baking soda or citric acid as the independent variable in their answer to question (a), but their answers in part (f) of the task must be consistent with their choice.

Tests 0, 1, 2 and 3 were 40-minute paper-based tests each. The completed tests were coded by the teachers so that they knew the names and genders of the pupils, but the researchers only received anonymous data for statistical analysis. The pupil codes will remain the same throughout the four years of the project. Each pupil's code is entered in a row in an Excel spreadsheet, and the same row is used to show the scores they received for specific items in each test. The participating teachers corrected the tests and recorded the marks in the Excel spreadsheet as instructed, see individual instructions for Tests 0, 1, 2 and 3 on the research team's website (MTA-ELTE Research Group, n.d.).

Validity

The five university lecturers (as members of the research team) and the experienced chemistry teacher, who reviewed all the teachers' corrections and made changes where necessary, formed a panel of experts. They provided the evidence of content validity, as they were able to judge whether the items adequately sampled the domain of interest (Crocker & Algina, 2006). This measure worked against construct underrepresentation, which is a major threat to construct validity (Wren & Barbera, 2013). In order to avoid construct-irrelevant

variance, the tasks in each test could be solved after the pupils had completed the tasks on the previously provided worksheets. Table 1 shows how each task in Test 3 can be matched to the corresponding content of each worksheet.

The tasks in each test should differ from previous tests for two reasons. Firstly, the measurement of transferable EDS, especially far transfer, which is needed when learners have to use these skills in a completely different context. The other reason is to avoid repetitive testing effects (Cannady et al, 2019; Schafer et al, 2023). The chances of successfully solving a task would have been higher if it had been applied a second time, because it could have caused construct-irrelevant easiness.

Table 1

Matching the content of the tasks of test 3 and the topic(s) of the worksheets for the third year

No. of task in Test 3	No. and title of worksheet and topic
1. a	Worksheet 17: Sour as vinegar (acid base reactions)
1. b	Worksheet 15: The superglue and others (rates of chemical reactions)
2. a-f	Worksheet 17: Sour as vinegar (acid base reactions)
3.	Worksheet 16: Geyser in a bottle – the Mentos-Cola story (chemical equilibrium)
4.a-b	Worksheet 18: Hydrogen peroxide as a 'miracle cure'? (redox reactions)
5.	Worksheet 14: Can you walk on water? (intermolecular forces)
6.	Worksheet 18: Hydrogen peroxide as a 'miracle cure'? (redox reactions)
7.	Worksheet 13: Exploding colours (excitation energy and flame tests)

The following item evaluation and review process was carried out for all the tasks in each test. The first version of the test and its marking instructions were prepared by the research team leader. Then, the same university lecturers of the research team who had checked the content of the worksheets checked the test tasks and the marking instructions. Modifications were made on the basis of their suggestions. 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 (Wren & Barbera, 2013).

Each of the tests was piloted with two different groups of pupils who were of a similar age to the sample but who did not participate in the research. Test 3 was piloted in two classes (total N=60) with pupils aged 14-15. The chemistry teachers who organised the pilot test and corrected each pilot test suggested improvements to the wording of the tasks and the correction instructions based on their experience. The tests and their marking instructions were further improved based on the results of the pilot before they were completed by the pupils in the sample. Participating teachers had not seen any of the tests to be taken at the end of the school year before trying out all six of the worksheets. This was to ensure that the test items did not even subconsciously influence teachers' teaching behaviour, as this 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 exclude the risk of maturation (Shadish et al., 2002)

Similarly to the procedure used by Goodey and Talgar (2016), the research team tried to standardise the marking in order to ensure that the marking key is applied in the same way for all the same types of corrected test. An experienced chemistry teacher reviewed all the teachers' corrections and suggested changes to the marking instructions. After discussions within the research group, changes were made. On the basis of these, some scores given by the teachers were modified to apply a uniform evaluation process, free from individual teacher's decisions. The scoring process is consistent with the recommendation that full consensus should be reached through negotiated agreement (Watts & Finkenstaedt-Quinn, 2021).

Data Analysis

Data Collection

The number of pupils (*N*) completing all four tests (Test 0, Test 1, Test 2 and Test 3) in each group is as follows: Group 1: 163; Group 2: 224; Group 3: 216, altogether 603 (298 boys and 305 girls).

The following data were collected and analysed:

- Total scores for Test 0, Test 1, Test 2 and Test 3.
- Scores for EDS tasks for Test 0, Test 1, Test 2 and Test 3.
- Scores for DCK tasks for Test 0, Test 1, Test 2 and Test 3.
- Gender.
- School ranking. The pupil's school ranking amongst Hungarian secondary schools, according to the website (Legjobbiskola, n.d.) The ranking is based on the results of the school-leaving examinations and competency tests published by the national Education Office. The participating schools were grouped into high, medium and low-ranking categories and a categorical variable was used according to these three levels.
- Mother's education. Two categories were created according to whether or not the pupil's mother (or guardian) had a degree in higher education. This categorical variable was intended to characterise the socio-economic status of the pupil. (The mother's education was chosen because most children spend much more time with their mother than their father in the first few years of their lives. Furthermore, in the event of a divorce, children tend to live with their mother in this country.)

Statistical Methods

Chi-square tests were used to check that there were no statistically significant differences between the three groups in terms of either prior knowledge measured by Test 0 or hypothesized parameters (school ranking, mother's education, gender). Cronbach's alpha values for the four tests were acceptable: 0.740 for Test 0, 0.678 for Test 1, 0.689 for Test 2 and 0.743 for Test 3.

Statistical analysis of the data was performed using SPSS Statistics software. ANOVA and ANCOVA were performed, as ANCOVA can be used to adjust for the initial difference and reflect the effect on the dependent variable (Howell, 2012). The raw mean scores (before ANCOVA analysis) and their standard deviation (SD) of the three groups were calculated for all four tests (Test 0, Test 1, Test 2 and Test 3) in the whole test ('TOTAL'), the DCK tasks and the EDS tasks.

The effect of the intervention on the development of the experimental groups (Groups 2 and 3) was measured by the Cohen's d effect size (Cohen, 1988). These values were calculated by taking the means and standard deviations of the four differences between the four test scores (T1 - T0, T2 - T1, T3 - T2 and T3 - T0). It was assumed that, in addition to the three types of instruction methods used in the intervention for the three groups, other parameters (school ranking, mother's education, gender) and a covariate (prior knowledge, i.e., scores on the Test 0) also influenced the results. In the ANCOVA analysis, the effect sizes of these parameters and the covariate were characterized by the calculated Partial Eta Squared (PES) values. The significance value of $p<0.05$ was used to test for differences between groups. For multiple comparisons, a Bonferroni correction was applied and a significance value of $p<0.013$ was used when comparing the results of four tests.

Results

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 = 603) = 2.234, p = 0.327)] and gender [X^2 (2, N = 603) = 1.216, p = 0.545)]. However, there is a significant difference in the composition of the groups with respect to school ranking [X^2 (4, N = 603) =39.74, p = 0.000)], since the difference is significant between Group 1 and Group 2 [X^2 (2, N = 387) =17.45, p = 0.000)], Group 1 and Group 3 [X^2 (2, N = 466) =25.41, p = 0.000)] and Group 2 and Group 3 [X^2 (2, N = 445) =9.11, p = 0.011)]. The number of pupils in low, medium and high-ranking schools in each group is shown in Table A2. ANCOVA analysis was used to address this problem.

Answers to the Research Questions

Tables A3–A6 show the raw mean scores, prior to ANCOVA analysis, and their standard deviations (SD) for the three groups for the T0 – T3 tests for the whole test ('TOTAL'), the DCK tasks, the EDS tasks and the results of the ANOVA analysis. It revealed no significant difference between groups in the performance of either $T0_{TOTAL}$ or $T0_{DCK}$ or $T0_{EDS}$. Group 3's performance at the end of the first year of the project (Grade 7) exceeded that of the other two groups on the $T1_{TOTAL}$ and $T1_{EDS}$ tasks, while Group 2 performed significantly worse in $T1_{DCK}$ than the control group (Group 1) and the other experimental group (Group 3). No significant difference was found between the three groups in the sample between the T2 test ($T2_{TOTAL}$) and its subtests ($T2_{DCK}$ and $T2_{EDS}$). Group 3 again outperformed the other two groups at the end of the third year of the project (Grade 9) in the EDS tasks ($T3_{EDS}$). There was no significant difference found in $T3_{TOTAL}$ and $T3_{DCK}$ among the three groups in the end of the third school year.

For further analysis, the dependent variables were the differences between test scores. Based on the means and standard deviations of the differences between the four test scores (T1 – T0; T2 – T1, T3 – T2 and T3 – T0), Cohen's d effect size values were calculated that are presented in Figure 2 for the whole test ('TOTAL'), in Figure 3 for the DCK tasks and in Figure 4 for the EDS tasks.

These results also show that Group 3 made better progress in the EDS tasks than the control group in the first and third years of the project, while Group 2 made less progress in the EDS tasks than the control group during these years. The second year shows a reverse trend in this respect. However, taking the full three-year period into account, Group 3's Cohen's d effect size in the EDS is positive, while that of Group 2's is negative. In the DCK tasks, Group 2 performed worse than the control group in the first year and better in the second year. Group 3 made less progress in the DCK tasks than Group 1 in the third year. Over the entire three-year period, both experimental groups had a negative Cohen's d effect size in DCK compared to the control group.

Figure 2

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, T3 – T2 and T3 – T0) for the whole test (N=603)

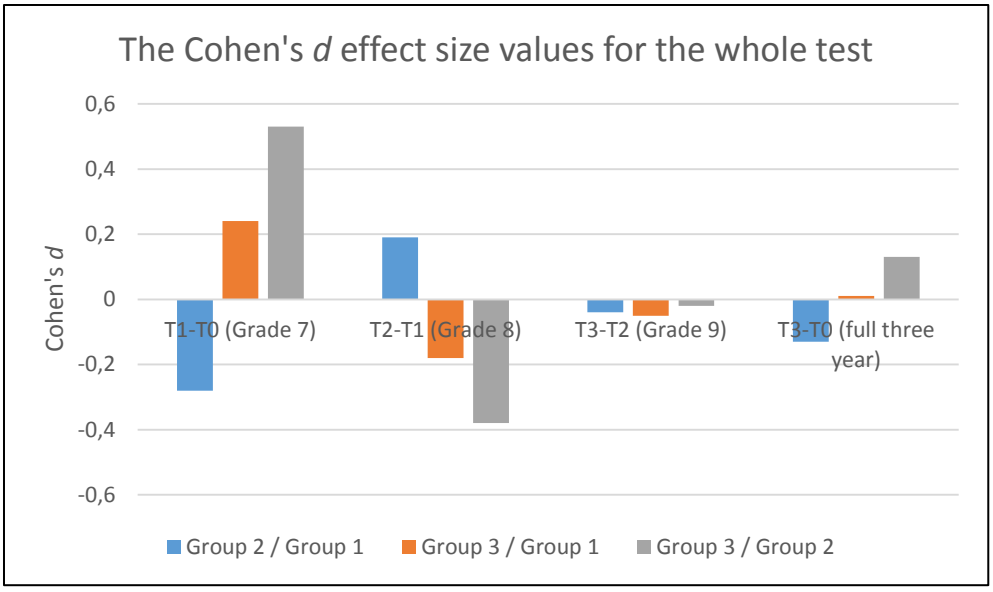
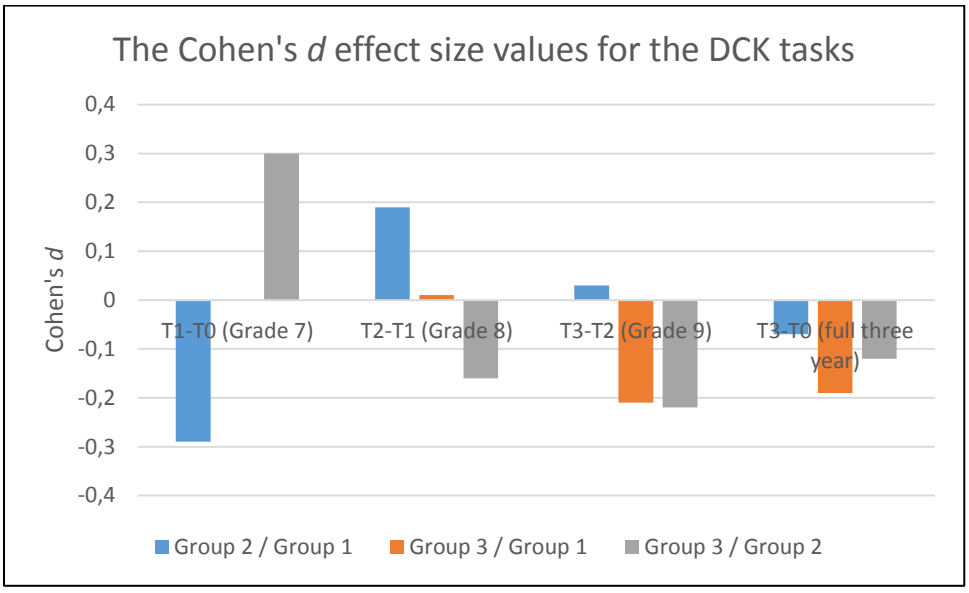


Figure 3

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, T3 – T2 and T3 – T0) for the DCK tasks (N=603)



Since it was assumed that pupils' test scores were influenced by parameters other than the intervention, 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, once the sample was reduced by the number of pupils who missed any of

the tests, the composition of the groups showed a significant difference in terms of school ranking. The Partial Eta Squared (PES) values for each parameter and the covariate effect sizes are shown in Table 2–4.

Figure 4

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, T3 – T2 and T3 – T0) for the EDS tasks (N=603)

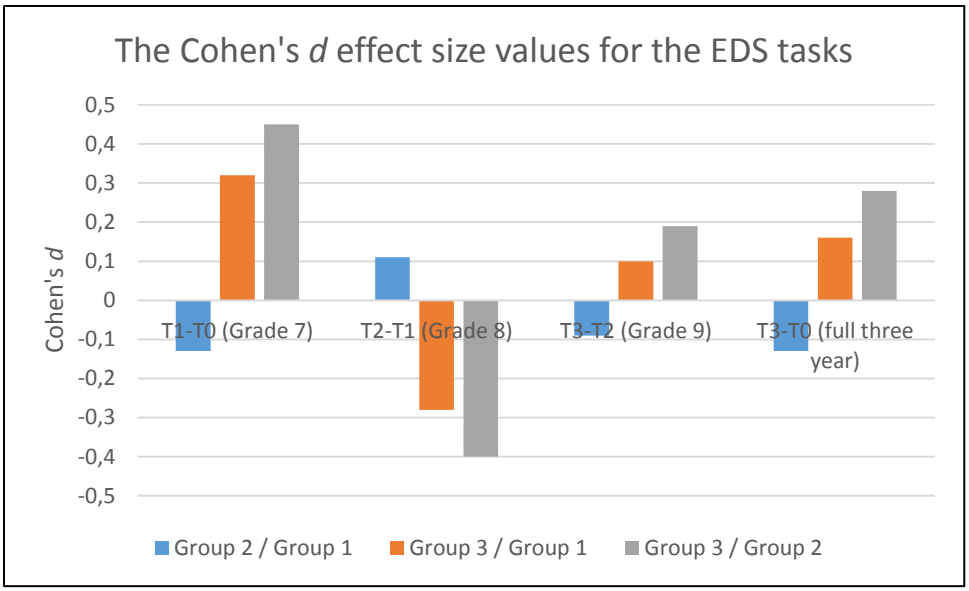


Table 2

The effects of the assumed parameters and the covariate (Prior knowledge, T0TOTAL) on the changes for the whole test ('TOTAL') in the beginning of the project (T0) and in the end of Grade 7 (T1), Grade 8 (T2), Grade 9 (T3) (N=603)

Parameter	PES (Partial Eta Squared)			
(Source)	T0TOTAL	T1TOTAL	T2TOTAL	T3TOTAL
Group	0.002	0.059*	0.004	0.002
School ranking	0.083*	0.052*	0.012	0.022*
Mother's education	0.008	0.002	0.000	0.000
Gender	0.003	0.004	0.000	0.001
Prior knowledge (T0TOTAL)	-	0.132*	0.123*	0.089*

Note: * Significant at $p < 0.013$ level (Bonferroni correction)

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. In the first year (in the Test 1), significant effect sizes (PES) were found for three parameters after the intervention for changes in the whole test and DCK tasks: type of intervention ('Group'), school ranking and prior knowledge. Of these, prior knowledge had the largest effect size in the whole test and school ranking in the DCK tasks. In the first year, only the type of intervention and prior knowledge seemed to have a significant effect on performance in the EDS tasks. Based on the results of the present analyses, it appears that at the end of the second school year (in the Test 2), only prior knowledge had a significant effect

on changes in the whole test and both subtests, but school ranking also had a significant effect size in the EDS tasks. School ranking and prior knowledge influenced pupils' performance in the whole test and in both subtests in the third year of the study. However, the intervention also had a (barely) significant effect size in the EDS tasks.

Table 3

The effects of the assumed parameters and the covariate (Prior knowledge, $T0_{DCK}$) on the changes for the DCK tasks in the beginning of the project (T0) and in the end of Grade 7 (T1), Grade 8 (T2), Grade 9 (T3) (N=603)

Parameter	PES (Partial Eta Squared)			
(Source)	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T3_{DCK}$
Group	0.000	0.035*	0.002	0.012
School ranking	0.022*	0.109*	0.002	0.034*
Mother's education	0.019*	0.000	0.002	0.000
Gender	0.007	0.002	0.001	0.002
Prior knowledge ($T0_{DCK}$)	-	0.044*	0.050*	0.016*

Note: * Significant at $p < 0.013$ level (Bonferroni correction)

Table 4

The effects of the assumed parameters and the covariate (Prior knowledge, $T0_{EDS}$) on the changes for the EDS tasks in the beginning of the project (T0) and in the end of Grade 7 (T1), Grade 8 (T2), Grade 9 (T3) (N=603)

Parameter	PES (Partial Eta Squared)			
(Source)	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$	$T3_{EDS}$
Group	0.003	0.050*	0.003	0.014(*)
School ranking	0.090*	0.012	0.056*	0.014(*)
Mother's education	0.000	0.005	0.007	0.001
Gender	0.000	0.004	0.000	0.004
Prior knowledge ($T0_{EDS}$)	-	0.076*	0.064*	0.066*

Note: * Significant at $p < 0.013$ level (Bonferroni correction)

The effect of the assumed parameters on the scores (absolute mean scores) estimated by the ANCOVA analysis model for the four tests for the whole test, the DCK tasks and the EDS tasks, as well as the significance of the differences, are presented in Tables A7–A9 in the Appendix. These data show that Group 3 performed better in the EDS task than the other two groups at the end of each school year, although the difference was not significant in the second year (Test 2). Among the other parameters, only in terms of the pupil's school ranking (low, medium, high) were there significant differences in EDS scores at the end of each year. In the DCK tasks, Group 2 in the first year and Group 3 in the third year scored significantly lower than the other two groups. The school ranking also caused significant differences in DCK scores, except at the end of the second year. Gender does not appear to have had much of an influence on EDS scores. The difference caused by the higher education degree of the pupil's mother was significant for EDS scores only in the second year.

Tables 5–7 show the relative estimated mean scores (the ratio of the estimated mean scores of the experimental groups compared to the control group) for the whole test and the subtests at the beginning of the project (Grade 7, T0) and at the end of each school year (Grade 7, T1; Grade 8, T2; Grade 9, T3).

The ratios in Table 5 suggest that the intervention did not have much impact. However, subtest data in Tables 6 and 7 show that this is due to the combined effects in the DCK and EDS tasks. Table 6 shows that in the DCK tasks, Group 2 scored lower than the control group

at the end of the first year and Group 3 at the end of the third year. According to these data, the performance of Group 3 in the EDS tasks was higher than that of the control group at the end of each year, but the effect of the intervention appears to have been strongest in the first year and weakest in the second year.

Table 5

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 four tests (N=603)

Ratio	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T3_{TOTAL}$
Group 2 / Group 1	1.02	0.90	0.99	0.96
Group 3 / Group 1	0.99	1.09	1.04	1.00

Table 6

The estimated mean scores of the experimental groups divided by the estimated mean scores of the control group for the DCK tasks in the four tests (N=603)

Ratio	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T3_{DCK}$
Group 2 / Group 1	1.01	0.85	0.96	0.95
Group 3 / Group 1	1.01	0.99	1.02	0.86

Table 7

The estimated mean scores of the experimental groups divided by the estimated mean scores of the control group for the EDS tasks in the four tests (N=603)

Ratio	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$	$T3_{EDS}$
Group 2 / Group 1	1.03	0.97	1.02	0.97
Group 3 / Group 1	0.97	1.19	1.04	1.10

Discussion

Based on the data presented, at the end of the third year of the project, it appears that of the two methods used to treat the experimental groups, the one applied to Group 3 has a small positive effect on the development of experimental design skills. Group 3 seems to have benefited from answering the series of questions before carrying out the experiments, which helped them to learn to design the experiments when they were 12–13-year-old. This may be the reason why this method had a significant positive impact on the development of EDS in the first year. However, the effect size of the changes in the EDS has decreased by the end of the three-year period. Group 2, on the other hand, only answer the questions on designing experiments after they have carried out the experiments step-by-step, following the recipe in their worksheet. This method does not seem to have produced any positive long-term results in terms of changes in EDS. The reasons are not known, but those pupils might have found this activity less interesting and important after the experiments than Group 3 did before the experiments. The treatment of Group 3 is similar to the 'critical thinking' pre-laboratory group, while the treatment of Group 2 resembles the 'paved road' pre-laboratory group described by van Brederode et al. (2020). The current results show that the intervention applied to Group 3 produced the slightly better results, similarly to the 'critical thinking' group in the above-mentioned study. These results are also in line with a study by Tseng et al. (2022), where evaluative reflection on

peers' experimental designs improved pupils' science inquiry performance in designing experimental procedures more than recognising variables in the design of experimental procedures.

The present findings for Group 3 also support the need to provide learners from traditional learning styles with appropriate and adequate scaffolds to successfully complete an inquiry-based learning task (Seery et al., 2019). Scaffolding refers to the steps taken to reduce the degree of freedom in performing a task so that the learner can concentrate on the difficult skill to be learned (Bruner, 1978). The series of questions for identifying and controlling variables and constructing hypotheses play this role in the present research. Learners begin to think logically about abstract concepts and test hypotheses systematically at the Piagetian formal operational stage, which is expected from the age of 12 (Piaget, 1963). It is therefore understandable that seventh grade pupils can benefit from this intervention. However, the success of open-ended problem solving depends, among other things, on specific knowledge and understanding stored in long-term memory, so this type of problem solving is context-dependent (Reid & Amanat Ali, 2020, p. 471). Since each test contains different EDS tasks in different contexts, these measure whether far transfer has been achieved. This may be the reason why the effect sizes were found to be very limited in long term and not even significant in the second year. Nor did Cacciatore and Sevian (2009) find significant differences between groups in their performance in tasks not directly related to the content of the experiment.

However, it is difficult to understand what happened in the second year, when Group 2 developed better than Group 3. One possible reason might be that seeing the results of Test 1, which showed that the other two groups performed better, some teachers in Group 2 may have encouraged their pupils to work harder in the second year and/or to put more effort into Test 2 at the end of the second year. The opposite effect may have affected the performance of Group 3 in Test 2, who performed well in Test 1. However, these possible explanations are not supported by any evidence.
The DCK tasks included in the tests were intended to measure whether answering a set of questions aimed at developing EDS influences pupils' disciplinary content knowledge. This was investigated to see if the concern that the time needed to develop the EDS would reduce the time spent on learning content, which could reduce DCK, is justified. The decrease in the achievement of DCK tasks in Group 2 in the first year and in Group 3 in the third year indicates that this could not be ruled out.

The ANCOVA analysis showed that, in addition to prior knowledge, school ranking was the parameter that most often influenced pupils' test scores. It is reasonable to assume that in higher ranking schools, pupils' abstract thinking may develop faster in more challenging environments. On the other hand, these pupils are also likely to be more strongly encouraged by their teachers and parents to achieve higher levels of performance. Snook et al. (2009), in their commentary on Hattie's (2008) book, argued that in addition to social variables, 'school effects' are also important, and that of these, the teacher is considered the most important variable. Teachers from different schools work in different contexts, following different local curricula, which comply with the National Core Curriculum, but also have their own characteristics according to the institutions' own pedagogical programme. Siegler and colleagues (2010) also argued that school is the microsystem that, alongside the family environment, has the strongest influence on youngsters' development.

The ANCOVA model calculations show that the mother's educational background had only rare and weak significant effects on the development of pupils' knowledge and skills in experimental design in this study. This seems to contradict the OECD report (2005), which finds that the most significant source of variation in pupils' learning is due to differences in the skills and attitudes pupils bring to school. The Education and Training Monitor (2020) report also shows that socio-economic background is a strong predictor of pupil achievement. However, the virtual contradiction with the results of the present study can be explained by the fact that the present sample is not representative of the cohort, as these pupils went through a very tough selection process when they took entrance exams to their current school.

Gender does not appear to have had much effect on test scores in the present research. This means that they are closer to the results published by authors who found no significant difference in pupils' acquisition of science process skills (SPS) with respect to gender (e.g. Walters & Soyibo, 2001)

and under the circumstances of the present study do not support the finding reported by Tosun (2019) that gender is one of the most important predictors of SPS levels.

Conclusion

Summary of the Results and Answers to the Research Questions

Statistical analysis of the results of the four tests completed by the current sample of pupils showed that, in addition to the intervention, the prior knowledge and the school ranking had the biggest influence on scores in tasks measuring EDS. The intervention appeared to have more effect on performance in the first year, school ranking in the second year, and both had some effect in the third year. Prior knowledge seemed to have a bigger effect than the intervention at the end of each year. Prior knowledge and school ranking also had a significant effect on the DCK measured by end-of-school-year tests, except for school ranking in the second year.

The answers to the research questions are as follows.

RQ1: By the end of the first three years of the present project, the intervention resulted only in a very small significant positive change in the experimental design skills (EDS) of Group 3 compared to the control group (Group 1), as measured by the tests (Cohen's d: 0.16). Taking the mean scores of the EDS tasks estimated by the ANCOVA model, Group 3 seemed to have improved more than the other two groups by the end of each year, but the difference was only significant at the end of the first and third years. It can be assumed that the small positive change is still due to the fact that Group 3's worksheets contained questions supporting the experimental design. The change in Group 2's performance in the EDS tasks by the end of the third year was negative compared to that of the control group (Cohen's d: -0.13), although they appear to have made more progress in this respect than the other two groups in the second year of the project.

RQ2: By the end of the third year of the present project, both experimental groups had a negative change in disciplinary content knowledge (DCK) compared to that of the control group (Cohen's d for Group 2: -0.07 and Group 3: -0.19, respectively). Group 2 had a negative effect size in the first year (Cohen's d: -0.29) and Group 3 in the third year (Cohen's d: -0.21). Group 3 improved more than Group 2 in this respect in the first year (Cohen's d: 0.30), but less so in the second (Cohen's d: -0.16) and third years (Cohen's d: -0.22). Taking into account the three years, Group 3's performance is less good than that of Group 2 (Cohen d: -0.12) in DCK tasks.

RQ3: In terms of changes in scores in the EDS tasks, of the two experimental groups, Group 3 improved more than Group 2 in the first year (Cohen's d: 0.45) and in the third year (Cohen's d: 0.19), but less than Group 2 in the second year (Cohen's d: -0.40). Over the three years, Group 3 has a positive effect size in this respect compared to Group 2 (Cohen d: 0.28).

The intervention does not seem to have a strong positive effect, even in terms of EDS and even for the better performing Group 3. However, these tasks are designed to measure far transfer, as pupils will need to use their EDS in different contexts in their everyday lives. These problem-solving skills are context-dependent (Reid & Amanat Ali, 2020, p. 471) and not easy to measure. Prior knowledge and 'school effects', which are considered in the literature (e.g. Snook et al., 2009) as variables that influence performance, also had a significant impact on the results. Furthermore, test scores are also influenced by pupils' motivation to succeed in the test and their test-taking skills (Cannady et al., 2019).

Statistical analysis of the test results showed that from the beginning of the project to the end of the third year, Group 3 showed significantly, but only slightly better performance in EDS than the control group. The positive impact was strongest in the first year. It can therefore be assumed that significantly more pupils in Group 3 understood how to correctly perform a

fair test than in Group 1 in the first year of the present project. No significant positive difference in the development of EDS was found between the experimental groups and control group in the first year of the previous longitudinal study, when no such scaffold was used, and at the end of its third year (Szalay et al., 2021). This difference was probably caused by the series of questions used in the present project, which helped pupils to develop their EDS. This is consistent with Baird's (1990) view that purposeful inquiry is not spontaneous, it must be learned. Reducing cognitive load can help in this process. Therefore, the use of a series of questions, a simplified version of the Experiment Design Diagram described by Cothron and colleagues (2000), still seems to positively influence the development of the EDS. A recently published meta-analysis by Arifin et al. (2025) also found that guided inquiry (N=24) had a statistically significant positive effect on critical thinking, and that the educational levels with the largest effects included lower secondary and upper secondary schools.

The decrease in DCK task performance in Group 2 in the first year and in Group 3 in the third year shows that the time spent developing the EDS might in some cases negatively affect the amount of disciplinary content learned. This may discourage some teachers from using the worksheets developed in this project. Especially in Hungary and in the present situation, where the National Core Curriculum requires the practice of experimental design, but EDS is not measured in the chemistry final exam, which serves as a written university entrance exam. Therefore, when training pre-service and in-service teacher students, the benefits of developing experiment design skills should be emphasised and different methods for doing so should be introduced.

Limitations

Pupils must remain in the same school for the four years of the project. Therefore, only schools that teach chemistry as a separate subject from Grade 7 to Grade 10 can participate in the research. Pupils of these schools must pass an entrance exam at the age of 12 and only the best pupils are admitted. This implies that the sample is not representative of this cohort, but highly selective. This is unfortunate, but there is no other way to conduct such a longitudinal study of chemistry teaching in this country.

The sample size for this research decreased each year, as the results of pupils whose class no longer participates in the project or who just miss any of the tests are not counted. Changes in the composition of the sample have caused significant differences in the composition of the groups in terms of school ranking. In theory, ANCOVA can handle this, but in statistical analyses there is always a chance that changes that appear significant are not in reality. The high attrition rate and non-representative sample (selective, exam-admitting schools) severely limit external validity.

Performance in tests is determined at least in part by pupils' motivation to succeed in the test and their test-taking skills (Cannady et al., 2019). Several studies have shown that for many school pupils, the motivation to learn chemistry is primarily to get good grades (Salta & Koulougliotis, 2015; Schumm & Bogner, 2016; Ardura & Pe´rez-Bitria´n, 2018; Komperda et al., 2020; de Souza et al., 2022; Zhang & Zhou, 2023). It is also known that pupils' motivation to learn science often declines as they are getting older (Schunk et al, 2014; Vedder-Weiss & Fortus, 2011; Vedder-Weiss & Fortus, 2013). Therefore, lack of motivation is a particular problem when it comes to measuring changes in pupil performance in such a longitudinal research study, and for methodological reasons it is not possible to reward pupil performance with marks. Although the context-based and systems thinking tasks on the worksheets (see Table 1), as well as the context of the EDS tasks, hopefully attracted the interest of many pupils, it is likely that not everyone was equally committed to performing to the best of their ability in the tests.

There is no research that can investigate all the variables and theoretical relationships that underpin an instructional model (Mack et al., 2019). In addition, 40-minute paper-based tests do not provide a

complete picture of the impact of the intervention on pupils' knowledge and skill development. Reading comprehension is also important for science achievement (Neri et al., 2021), but its influence was not investigated in the present study.

The findings may be also influenced by a number of random events. Although the relatively large sample size should compensate for these in a statistical sense, we can never be absolutely certain (Lawrie, 2021).

Recommendations

The use of Group 3 worksheets and similar experimental design exercises, which guide students through the experimental design process using a series of questions, can be recommended to practising teachers as one possible way to develop EDS. However, teachers need to be aware that the use of these worksheets might reduce the amount of disciplinary content knowledge acquired.

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Conflicts of Interest

There are no conflicts of interest to declare.

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Appendix

Table A1.a

Topics and context of the worksheets no. 13-15 and teacher guides used in the school year 2023/2024.

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 pupil worksheets of all the three groups.
13.	Excitation energy and flame tests	Pupils carry out flame tests. They are given a table showing the wavelength ranges of the colours. They are also explained that the energy of a photon is inversely proportional to its wavelength. Group 3 pupils have to design experiments to find out whether the excitation energy of the metal atoms of two unknown metal salts they find on their tray is lower or higher than the excitation energy of the sodium of the table salt (sodium chloride).	Although fireworks are an eye-catching sight, they have many side effects. When they explode, they emit air pollutants and a sudden burst of sound and light, which can scare animals, and they can cause injuries. Pupils have to group particles, labelled with their chemical symbols and formulae, according to their role in the use of fireworks (combustible substances, combustion promoters, substances responsible for the colour effect, air polluting combustion products).
14.	Inter-molecular forces	Pupils are explained that the stronger the interaction between the particles of a liquid, the harder it is to separate them, so the harder it is to increase the surface area, and so the larger are the droplets of the liquid. Surfactants (such as dishwashing detergents) reduce surface tension because they make it easier to increase the surface area of the liquid, e.g. because the polar part of their particles is in the water and the apolar part is in the air. Pupils should compare the surface tension of pure water and water containing detergent. To do this, Group 3 pupils need to work out how to measure the volume of a single drop of two liquids.	The pond skater ("Jesus bug") can walk on water because the interactions that hold water molecules together are strong enough to keep the pond skater on the surface. However, the pond skater cannot run on the surface of the surfactant-contaminated water. Pupils should identify sources of natural and artificial surfactants that can pollute water. They should also identify the different types of direct environmental damage caused by the presence of surfactants and the resulting foaming.
15.	Rates of chemical reactions	Pupils are explained that we should always control the rate of chemical reactions according to our particular needs. They are then given materials and equipment to measure the rate of reaction between sodium thiosulphate solution and hydrochloric acid of different concentrations at different temperatures. Group 3 pupils have to design experiments to slow down the reaction and then to accelerate it.	The pupils have to imagine that their friend fell while cycling and they used Betadine containing iodine to disinfect a nasty bruise on his skin. But some of the brown Betadine spilled onto their friend's favourite light-coloured shorts. Iodine is not soluble in water, but according to the internet, "*the Betadine solution ... can be removed with a solution of sodium thiosulphate*", which is available from the chemist's. The pupils have to decide whether the sodium thiosulphate solution should be dilute or concentrated and whether it should be cold or hot to get the fastest result.

Table A1.b

Topics and context of the worksheets no. 16-18 and teacher guides used in the school year 2023/2024.

16.	Chemical equilibrium	Using a model experiment, pupils have to decide if it is true that a combination of Diet Coke and Mentos candy caused the death of a boy. They are explained that carbon dioxide gas is added to the solution during the production of carbonated soft drinks. In a closed bottle, carbon dioxide is involved in the physical and chemical processes that lead to the equilibrium between gas and liquid. Group 3 pupils have to design the model experiment.	In beer and champagne, carbon dioxide is produced as a by-product of fermentation. Sometimes the beer behaves like a geyser, but in extreme bad cases the beer bottle can explode. The pupils have to explain by circling the appropriate arrows on a diagram how a change in temperature affects the solubility of carbon dioxide, i.e. the amount of gaseous carbon dioxide in the bottle and therefore the pressure in the bottle.
17.	Acid base reactions	Pupils have to measure which bottles contain 10% and 20% vinegar. They can use red cabbage juice as an acid-base indicator. They are also given a solution of drain cleaner with sodium hydroxide as the main ingredient. Group 3 pupils have to design an experiment to find out which glass contains the more dilute and which the more concentrated vinegar solution.	If a corrosive chemical (e.g. descaler, rust remover, drain cleaner) gets on the skin, it should be washed off immediately with plenty of water. In the case of acid burns, a weak and dilute base solution can be used to neutralise, but not concentrated and strong alkaline solutions, which would also be corrosive. In the case of an injury caused by an alkali, a weak and dilute acid solution should obviously be used. The pupils have to choose which neutralising solution to use for the different types of injuries.
18.	Redox reactions	Starting with the fake news about hydrogen peroxide, which claims that it can cure almost any disease, even cancer, pupils are told that hydrogen peroxide is only an external disinfectant and should not be ingested. It is then used as an oxidising or reducing agent in experiments (reacting with sodium hypochlorite and potassium iodide). Group 3 pupils are asked to design an experiment, using matches and a wooden splint, to find out whether the hydrogen peroxide solution acts as an oxidising or reducing agent in the experiments. (They should recognise a pattern that if hydrogen peroxide is a reducing agent, it is oxidised to elemental oxygen, which ignites the glowing splint.)	Like hydrogen peroxide, hypochlorite is used for disinfection and decolourisation. However, the use of hypochlorite has its own dangers, as toxic chlorine gas is formed when hypochlorite is used in combination with acidic cleaning agents like hydrochloric acid. Pupils are asked to write down the reaction equation for that chemical reaction. They then have to show on a diagram, by circling the appropriate arrows, how the addition of acid shifts the equilibrium towards an increase in the amount of chlorine gas released into the air.

Table A2

The number of pupils in low, medium and high-ranking schools (N=603)

Group	Low ranking schools	Medium ranking schools	High ranking schools	Total
Group 1	49	78	31	158
Group 2	60	79	90	229
Group 3	72	47	97	216
Total	181	204	218	603

Table A3

The means of scores and their SD-s for the whole test ('TOTAL'), the DCK and EDS tasks of T0 and the results of the ANOVA analysis (N=603)

Group	$T0_{TOTAL}$ (SD)*	$T0_{DCK}$ (SD)**	$T0_{EDS}$ (SD)**
Group 1	10.87 (3.70)	5.37 (1.75)	5.49 (2.60)
Group 2	11.48 (3.28)	5.56 (1.79)	5.92 (2.41)
Group 3	11.18 (3.50)	5.56 (1.69)	5.63 (2.58)
$F(2, N = 603)$	1.477	0.667	1.508
p	0.229	0.514	0.222
Sign.	-	-	-

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

Table A4

The means of scores and their SD-s for the whole test ('TOTAL'), the DCK and EDS tasks of T1 and the results of the ANOVA Analysis (N=603)

Group	$T1_{TOTAL}$ (SD)*	$T1_{DCK}$ (SD)**	$T1_{EDS}$ (SD)**
Group 1	8.83 (3.53)	4.42 (2.08)	4.41 (2.09)
Group 2	8.45 (3.09)	3.98 (1.69)	4.47 (2.04)
Group 3	10.0 (3.36)	4.62 (1.97)	5.39 (2.10)
$F(2, N = 603)$	13.27	6.651	14.61
p	0.000	0.001	0.000
Sign.	1, 2 < 3	2 < 1,3	1, 2 < 3

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

Table A5

The means of scores and their SD-s for the whole test ('TOTAL'), the DCK and EDS tasks of T2 and the results of the ANOVA Analysis (N=603)

Group	$T2_{TOTAL}$ (SD)*	$T2_{DCK}$ (SD)**	$T2_{EDS}$ (SD)**
Group 1	9.33 (3.18)	3.52 (2.04)	5.81 (1.91)
Group 2	9.59 (3.07)	3.48 (1.94)	6.11 (1.81)
Group 3	9.90 (3.20)	3.74 (2.19)	6.16 (1.86)
$F(2, N = 603)$	1.526	0.961	1.853
p	0.218	0.383	0.158
Sign.	-	-	-

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

Table A6

The means of scores and their SD-s for the whole test ('TOTAL'), the DCK and EDS tasks of the T3 and the results of the ANOVA Analysis (N=603)

Group	$T3_{TOTAL}$ (SD)*	$T3_{DCK}$ (SD)**	$T3_{EDS}$ (SD)**
Group 1	7.99 (3.51)	3.41 (1.85)	4.58 (2.30)
Group 2	8.10 (3.73)	3.44 (2.10)	4.66 (2.47)
Group 3	8.34 (3.63)	3.15 (1.88)	5.19 (2.42)
$F(2, N = 603)$	0.458	1.443	3.858
p	0.633	0.237	0.022
Sign.	-	-	1,2 < 3

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

Table A7

The effects of the assumed parameters estimated by the model of the ANCOVA analysis (absolute mean scores) for the whole test ('TOTAL') and the significance of their differences for the four tests (N=603)

Group	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T3_{TOTAL}$
1. Group 1	10.83	8.98	9.47	8.21
2. Group 2	11.04	8.11	9.42	7.90
3. Group 3	10.74	9.78	9.84	8.18
Significant difference*	-	2 < 1 < 3	-	-
School ranking	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T3_{TOTAL}$
1. Low	9.79	8.14	9.15	7.74
2. Medium	10.53	8.79	9.56	7.69
3. High	12.29	9.95	10.02	8.86
Significant difference*	1 < 2 < 3	1 < 2 < 3	1 < 3	1, 2 < 3
Mother's education	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T3_{TOTAL}$
1. No degree in higher education	10.46	8.77	9.54	8.03
2. Degree in higher education	11.28	9.14	9.61	8.16
Significant difference*	1 < 2	-	-	-
Gender	$T0_{TOTAL}$	$T1_{TOTAL}$	$T2_{TOTAL}$	$T3_{TOTAL}$
1. Boy	11.06	9.13	9.60	8.02
2. Girl	10.68	8.79	9.55	8.18
Significant difference*	-	-	-	-

*Note. * $p<0.05$*

Table A8

The effects of the assumed parameters estimated by the model of the ANCOVA analysis (absolute mean scores) for the DCK tasks and the significance of their differences for the four tests (N=603)

Group	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T3_{DCK}$
1. Group 1	5.24	4.54	3.69	3.54
2. Group 2	5.30	3.84	3.56	3.38
3. Group 3	5.29	4.49	3.78	3.03
Significant difference*	-	2 < 1, 3	-	3 < 1, 2
School ranking	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T3_{DCK}$
1. Low	5.09	3.51	3.72	3.20
2. Medium	5.09	4.24	3.55	2.95
3. High	5.64	5.11	3.76	3.81
Significant difference*	1, 2 < 3	1 < 2 < 3	-	1, 2 < 3
Mother's education	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T3_{DCK}$
1. No degree in higher education	4.94	4.26	3.82	3.30
2. Degree in higher education	5.61	4.32	3.54	3.34
Significant difference*	1 < 2	-	-	-
Gender	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$	$T3_{DCK}$
1. Boy	5.42	4.37	3.73	3.40
2. Girl	5.13	4.21	3.63	3.23
Significant difference*	2 < 1	-	-	-

*Note. * p<0.05*

Table A9

The effects of the assumed parameters estimated by the model of the ANCOVA analysis (absolute mean scores) for the EDS tasks and the significance of their differences for the four tests (N=603)

Group	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$	$T3_{EDS}$
1. Group 1	5.60	4.40	5.76	4.61
2. Group 2	5.75	4.25	5.86	4.48
3. Group 3	5.44	5.24	6.00	5.09
Significant difference*	-	1, 2 < 3	-	1, 2 < 3
School ranking	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$	$T3_{EDS}$
1. Low	4.70	4.46	5.26	4.40
2. Medium	5.44	4.46	5.95	4.65
3. High	6.65	4.95	6.40	5.13
Significant difference*	1 < 2 < 3	1, 2 < 3	1 < 2 < 3	1, 2 < 3
Mother's education	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$	$T3_{EDS}$
No degree in higher education	5.52	4.42	5.67	4.62
Degree in higher education	5.67	4.83	6.08	4.84
Significant difference*	-	-	1 < 2	-
Gender	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$	$T3_{EDS}$
Boy	5.64	4.74	5.86	4.59
Girl	5.55	4.51	5.88	4.86
Significant difference*	-	-	-	-

*Note. * p<0.05*