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The Effectiveness of a blog resilience programme for first-year basic organic chemistry students

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ABSTRACT
Teaching resilience to students is essential so that they can thrive in the face of adversity and develop into effective problem solvers. In this study, we developed a resilience intervention programme by using a blog platform and examined its effectiveness among first-year university students enrolled in a basic organic chemistry course. Based on the pre- and post-survey using the Resilience Scale-10 questionnaire, participants in the experimental group reported increased self-determination and adaptability to their new environment following their transition from high school to university life. Moreover, the paired *t*-test showed a statistically significant difference in participants' resilience levels after participating in the resilience activities (p<.001). Lastly, based on the reflective essays submitted, participants indicated increased motivation and enthusiasm for learning about organic chemistry in the future.

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Introduction

Incorporating resilience building into students is important in a future-ready educational system. This approach aims to improve the individual's resiliency to address the sudden transition, adversity, loss and risk situations that are plaguing us in today's world (Duchek, 2020). Furthermore, an educational system that promotes resiliency among students will enable them to experience the sense of competence, belongingness, motivation, self-determination, adaptation, usefulness and optimism in all their undertakings when they transit into employment later on (Schonert-Reichl & Lawlor, 2010). Over the years, many resilience programmes have been designed and implemented to strengthen resiliency among children and adolescents, particularly targeting those with some vulnerability, such as with disease or disability (García-Parra et al., 2021).

Resilience programmes are also gaining importance in today's conventional educational system. In Massachusetts (US), college students referred for counselling often present with depression, anxiety or other psychiatric problems (Kirsch et al., 2015). A recent survey carried out in India revealed that 50% of their participants, which consisted of university students, have experienced anxiety, depression and stress due to various issues and psychological disturbance (Herbert & Manjula, 2022). 25 % of higher education students in Germany have had symptoms of burnout, and the rates of anxiety and depression among them were recorded as 17.4 % and 15.4 %, respectively (Lohner & Aprea, 2021). The COVID-19 surge worldwide has also exacerbated the mental health crises among children and adolescence (Meherali et al., 2021). A report showed that higher education students experience psychological disturbances including depression, anxiety and other affective disorders at a higher rate compared to general population (Pedrelli et al., 2015). Educators should consider higher education students as a vulnerable population and ensure their well-being as one of the important organisational goals for institutions of higher learning. This does not imply compromising academic quality but rather managing potential impact on the students' well-being.

Several resilience-related activities or programmes have been administered to the undergraduates of higher education institutions. For example, the use of resilience journals (Lohner & Aprea, 2021), fostering students resilience via development of supportive staff attitude and evidence-based practices (Brewer et al., 2022), outdoor adventure activity (Kelly, 2019), college dance training (Bohn & Hogue, 2019), yoga and mindfulness practice (Bartos et al., 2021), capacity building and prosocial programme led by youth (McCarty et al., 2022), implementation of community service-learning programme (Song et al., 2017). However, most of these resilience activities were conducted through face-to-face resilience training. The current trend of training students on resilience is shifted towards using the digital platforms. Reports have emerged on resilience programmes conducted online, such as the CORE programme (Herrero et al., 2019), Space for Resilience (Roig et al., 2020), the Online Positive Psychology Intervention (Yurayat & Seechaliao, 2021), internet-based multi-approach intervention (De Fabritiis et al., 2022). But the number of interventions available today are still insufficient for those who need them (Palma-Gómez et al., 2020). Online interventions offer potential solutions by providing global accessibility while promoting resilience and well-being through a medium that is accessible to everyone. Online interventions can play an important role in delivering content at little or no cost to individuals without requiring extensive assistance from psychologists or mental health therapists (Kazdin & Rabbitt, 2013).

Regarding the promotion of resilience intervention programmes among university science students. Limited studies were recorded in literature about their effectiveness (Robinson et al., 2021). An exception is Stoliker et al. (2022) who brought about positive change for nursing students exhibiting burnout and psychological disturbance. Organic chemistry is considered one of the toughest subjects at university level (Kan et al., 2015), yet no resilience programme has been implemented along with the teaching of this subject. Overall, resilience programs are important as they enhance students' self-determination and adaptability, particularly in challenging academic environments

Digital Platform as Medium of Course Content Delivery

The "e-learning" theory is grounded based on the use of technology to create new learning opportunity and promote effective learning among users (El-Sabagh, 2021). Over the decades, the web page or internet has become an essential medium in disseminating learning materials, as they can carry multiple multimedia elements such as the videos, interactive activities and reading materials (Manon, 2020). Apart from disseminating information, internet-based instructional learning encourages users to make connection to the course content and to share their thoughts through guided instruction (Buelow et al., 2018). Reformers grasp the opportunity to utilise the digital platform to introduce quality literacy to users (Demirezer and İlkörücü, 2023; Ikhsan et al., 2024; Nicholaidou et al., 2021; Ristanto 2022; Rusdiyana et al., 2024). This is evidenced by a previous study, in which a well-designed online course was shown to be able to motivate users learning in a particular subject. Study also revealed that an online course can promote effective study among learners just as much as conventional teaching (Biel & Brame, 2016).

The use of e-learning such as the social-media platform for delivery of learning content has been found to be effective, inexpensive, ease in use and accessible, making it a powerful tool that aids course instructors in overcoming limitations in presenting course materials, relating new knowledge to existing knowledge more effectively and promoting creativity in teaching (Kidd, 2012). The use of social media in teaching enables collaborative learning among students, by allowing students to retrieve and share information online in the social media, such as through their mobile phones. According to one study, the use of social media proved to be very useful especially for students who feel uncomfortable to express themselves in front of their peers. This in turn opens another platform for collaborative learning and teaching which is also beneficial for students who are physically challenged. The outcome of above research shows that the use of social media has revolutionised the teaching and learning process, through enabling students to work collaboratively (Ansari & Khan, 2020).

Padlet

The bulletin board Padlet was co-founded by Nitesh Goel and Pranav Piyush, in San Francisco, California. It is an online and collaborative sharing platform that invites users to share and organize the information over the digital bulletin board or blog. Participants in Padlet can share their views, text, images, videos and reading materials in real time. Since the invention of Padlet, it has been used widely as a collaborative learning tool in higher education institutions (Ali, 2021; Ramachandiran & Mahmud, 2019). The Padlet was chosen in this study as it is aligned to the purpose of this study, which enable the experimental group participants from organic chemistry and course lecturer collaboratively work on a project, post reading materials and comment to achieve the interactive learning and resilience building. Furthermore, users can register Padlet basic feature for free.

While educators have begun to embrace social media as a teaching and learning tool, research addressing how blogs can facilitate resilience literacy among users remains scarce. Since blogging enables users to share comments, exchange ideas and reflect on learning experiences, blogs can be a potential platform for social constructivist learning (Liu & Chen, 2010). Literature suggests that blogging allows students to develop analytical thinking and enhance their learning to a higher level. This is because students need to understand, analyse and clarify their thoughts before starting to write in the blog about their feelings on a certain subject (Yang, 2009). Organic chemistry is widely perceived as one of the most challenging courses that a chemistry or science student must learn, which requires students to be able to reason, perform critical thinking, make judgements and solve the problems. Resilience learning can enhance motivation and confidence of students to learn difficult subjects, such as organic chemistry and other general courses.

Although many well-established approaches to teach resilience literacy have been described in the literature, there is still a scarcity of research that examines how blogging can facilitate resilience literacy among students. To address this research gap, this study aims to analyse the importance and effectiveness of existing "*We Lead You to Success*" resilience intervention from the perspective of undergraduate students undertaking the basic organic chemistry course. As such, the purpose of this research was set off such as listed below:

(1) How engaged are participants with the "We Lead You to Success" programme?
(2) What changes in resilience occur in participants before and after the implementation of the "We Lead You to Success" programme?
(3) What are the experiences of participants in the experimental group as reflected in their reflective writing?

Methods

Research Design

This study used the quasi-experimental method with the non-equivalent control group design conducted at Universiti Malaysia Terengganu, located in Kuala Nerus district in the Terengganu state of Malaysia at 2022/23 academic year. This method was preferred due to the easiness of implementation and flexibility to compare the effectiveness of "*We Lead You to Success*" resilience intervention pre- and post-implementation strategy. The lesson plan of this course was included in the appendix section of this manuscript.

Participants

Prior to the commencement of academic year 2022, 36 participants (30 females and 6 males) from the control group and 36 participants (28 females and 8 males) from the experimental group who were studying basic organic chemistry at the Universiti Malaysia Terengganu (UMT), Malaysia, participated voluntarily in the current research. Prior to the commencement of this research, participants of the basic organic chemistry course were briefed on the purpose of this study and seek their consent that the data will be analysed for educational research purpose and the possibility of translating the obtained data into publication. Participants were subjected to Resilience Scale-10 (RS-10) questionnaire and required to submit a short reflective essay at the beginning, mid-term and after the end of the course. In addition, participants were asked to post a comment on Padlet after watching or reading resilience videos or materials given by the course lecturer. The use of Padlet in this study serves two functions. Firstly, all lecture notes and tutorial handouts regarding the basic organic chemistry course were uploaded on this webpage. Secondly, the course lecturer also uploaded the resilience videos and resilience study material on the same Padlet page. This ensures the participants not to miss out on the opportunity to be exposed to the resilience activity, and at the same time, access lecture notes and tutorial handouts for this course. Similarly, the same platform was used to post comments and reflections after watching the videos and resilience materials in the designated column. Their feelings and comments would be a source of motivation to others in the intervention group. To sum up, all the lecture notes, tutorial handouts, resilience videos, resilience materials and participants' feeling after watching the resilience videos were all posted on the Padlet wall, collectively known as the "We Lead you to Success: A Resilience Programme". This research has sought the consent of the ethics board of the University Malaysia Terengganu (UMT/JKEPM/2021/8).

"We Lead you to Success" Programme

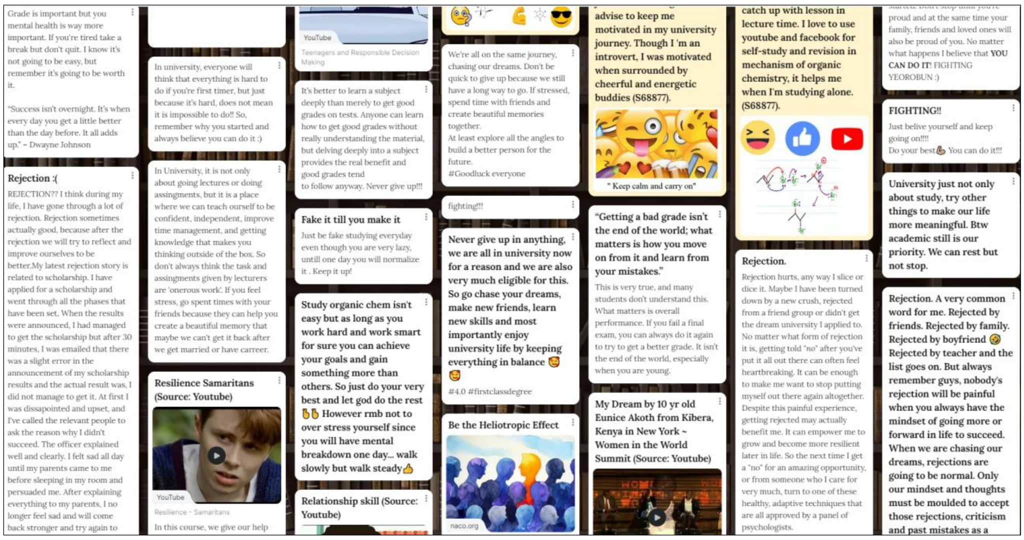
At the beginning, the controlled class was designed so that the participants received only face-to-face teaching, while a Padlet wall together with the face-to-face teaching instructional method was implemented in the experimental group setting (Figure 1). The delivery of the resilience learning content in the experimental group was conducted using videos and resilience reading material adapted from Youtube and internet sources (Table 1). Starting from week 3, participants received a video or reading material regarding to the resilience learning. Students were asked to post their comment to the Padlet after watching the resilience videos or materials. In principle, the use of Padlet in this setting is to enable the administer of resilience learning to participants in the out of class setting to the experimental group. Yet, we found this method useful as previous study suggested the appropriate use of blog can enhance students' engagement in learning activities, both on- and off-campus (Ivala & Gachago, 2012). In this way, experimental group participants did not study in a passive way by merely discussing course content or tutorial, they were able to engage in the resilience programme designed by current course lecturer

Procedure

Control Group: The basic organic chemistry course comprised of two one-hour lessons per week, for 14 weeks. The control class was designed to provide participants with face-to-face instruction and lessons from the beginning of the academic semester. An RS-10 questionnaire was administered on week one and again at the end of the course on week 14. group. The pre- and post- RS-10 survey forms were administered to both control and experimental groups to examine students' self-determination and adaptability throughout the course of their basic organic chemistry learning. Figure shows the Padlet wall created for this study. In this course, the control group participants received similar course content as experimental group participants. In terms of assessment, two formative tests, each consists of (20 %), assignment (20 %) and final examination were subjected to control group participants. The similar assessment was applied to experimental group participants.

Figure 1

Padlet wall created for the resilience learning in basic organic chemistry course



Experimental Group with "We Lead You to Success: A Resilience Program": After obtaining consent from the participants, the corresponding author implemented the "We Lead You to Success" resilience enhancement programme to the experimental group, which consisted of 8 males and 28 females, alongside with face-to-face instructional learning. On week two, they were briefed on the concept of resilience via PowerPoint presentation, introduction to reflective essay, programme activity, and the use of Padlet containing study materials and videos in the resilience enhancement programme.

Starting from week three to week 13, this resilience enhancement programme utilised socio-emotional learning materials (Table 1) that are vital in promoting life skills, including healthy identity development, emotion management, interpersonal skills and responsible relationship. Through socio-emotional learning, students learnt to become more resilient by learning to cope and overcoming adversity and do not give up easily. There are many useful socio-emotional learning materials available for teaching and learning from online resources such as YouTube, which is available free of charge and educators can utilize these tools with their students or children on resiliency. The purpose of integrating Padlet into this setting was to ease the administration of resilience learning to participants beyond the classroom environment. The method employed proved useful, as previous research has shown that making appropriate use of a blog can increase student engagement in both on- and off-campus learning activities. By using this approach, participants in the intervention group were able to engage with the resilience program designed by the current course lecturer, rather than studying passively through discussions of course content and tutorials.

Table 1

List of resilience video and web study material

Week	Title of Resilience Video and Web Study Material
3	"*Resilience Samaritans*" - video
4	"*Eunice Akoth performs her poem "My Dream"*""- video
5	"*Be the heliotropic effect*"- web study material
6	"*Exam stress relief and techniques*"- video
7	"*Learning to succeed by learning to fail*"- video
8	"*The science of gratitude*"- video
9	"*How socio-emotion learning benefits everyone*"- video
10	"*Self-awareness*"- video
11	"*Self-control*"- video
12	"*Relationship skill*"- video
13	"*Responsible decision making*"- video

From week 3 till week 14, students read up on the resilience materials and watched the videos adapted from YouTube to gain knowledge on resilience via the Padlet platform. Students' comments after reading and watching the resilience material or videos were monitored by the class lecturer. At week 2, 7 and 14, participants uploaded their reflective essays through the Google Forms to understand participants' own life experience, especially in the intervention group. To evaluate changes in participants' resilience before and after the programme, the Resilience Scale-10 (RS-10) [32] was administered to the participants on week 1 and 14. Participants' engagement on resilience activity posted over the Padlet was monitored by using questionnaire after week 14. Table 2 shows the implementation process for the resilience programme.

Table 2

Implementation process of the resilience program in the administered basic organic chemistry course

Week	Activity
Week 1	· Seek participants' consent on the current study.
Week 2	· Presentation on the concept of resilience. · Briefing on the resilience programme activity · Reflective essay submission by students (beginning stage)
Week 3-6	· Posting the video on Padlet and monitoring participants' comment
Week 7	· Mid-semester break
Week 8-13	· Posting the video on Padlet and monitoring participants' comments
Week 14	· Administering the Resilience Scale-10 (RS-10) to participants (post-survey) · Administering the questionnaire on the engagement of resilience programme · Reflective essay submission by students (end course stage)

Questionnaires

In this study, participants completed the Resilience Scale-10 (RS-10) (Jardim et al., 2021) and the questionnaire on the engagement of participants over Padlet. The former was directed to participants as questionnaire for the pre- and post-surveys to investigate participants' resilience change in the intervention and control groups during their first year at UMT. The second objective of this study was to measure changes in participant resilience before and after implementation of the "We Lead You to

Success" programme using the RS-10 questionnaire. The RS-10 questionnaire containing 10 questions with five-point Likert type items were used to elicit participant responses. The 10 questions or items were thoroughly reviewed by a panel consisted of 7 researchers from different areas, including psychology, education and management. These 10 questions were yielded as they were more likely to link to daily life of participants and without triggering memories of previous traumatic events. For the reliability of the measurement of RS-10, previous literature confirmed the robustness of this instrument, with Cronbach's alpha values between 0.81-0.84 (Jardim et al., 2021). In this research, a paired *t*-test was employed to analyse changes in participants' resilience between pre- and post-surveys. To measure participants' engagement on the activities posted on Padlet, frequency of visit to the Padlet was determined as wells as the answer-option type of feedback to the administered activities.

Prior to the statistical analysis using SPSS 20.0, the scores for items 1, 2, 3, 4 and 5 were recorded in the way that represented the self-determination factor and items 6, 7, 8, 9 and 10 recorded the adaptability factor of both control and experimental groups (Table 3). The gain scores (post-pre) for the self-determination and adaptability were calculated in the statistical analysis as dependent variables. Moreover, the authors also investigated whether the pre-scores could give an effect to the gain scores. In the descriptive data, no statistical difference was observed between self-determination pre-scores ($F = 3.242$, $p = .08$) and adaptability pre-scores ($F = 1.931$, $p = .170$) for both courses. To test for the internal reliability of factor 1 and factor 2 of the RS-10, Cronbach's Alpha values were calculated (Table 3). All the values were above the acceptable 0.7 value and are all in agreement with the previous literature (Jardim et al., 2021).

Table 3

The Cronbach's Alpha results for resilience program administered-basic organic chemistry course, Pre and Post tests

Cronbach's Alpha	Pre-survey	Post-survey
Self-determination	0.723	0.823
Adaptability	0.749	0.789

Reflective Essay

In this reflective essay, participants were asked to describe how they felt about their experience in learning of basic organic chemistry at the beginning, mid-term and at the end of the course. Over the years, a reflective essay was employed as an instructional tool for participants to express and reflect their perception on their learning activities (Cha *et al*., 2016). Participants' reflective essays were systematically analysed and reviewed by two of the authors who examined qualitatively on their writings to categorize the elements provided by the participants on their perception before and after the resilience program, as well as their comments on Padlet and also the current activity. After obtaining consent and categorisation from all authors, the current manuscript was prepared. The inter-rater reliability was 92 %.

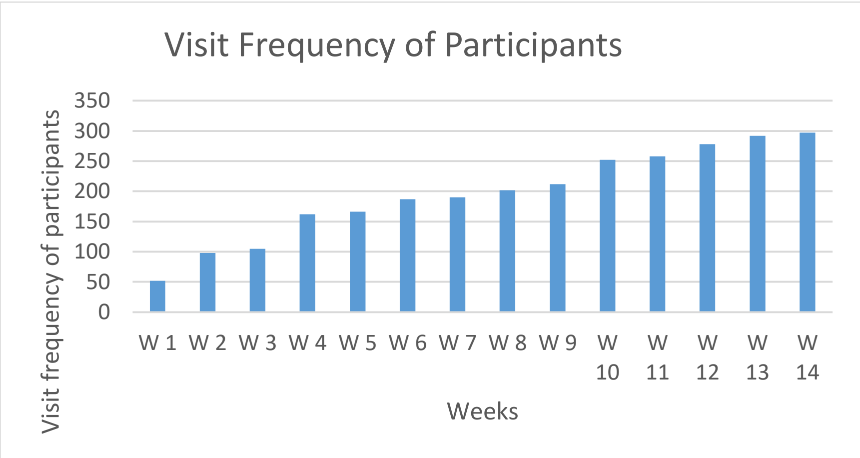
Findings

Participants' Engagement of The Resilience Programme Administered via the Padlet

For participants' engagement in the Padlet, based on the survey result, none of the participants encounter any issues during sign up and blog access as the account for Padlet is available for free on the internet. Participants needed to access the Padlet starting from week 3 to view the posted video and post their comments online. A quick survey on participants' engagement on Padlet was carried out using Microsoft form administered to each student on weekly basis. The frequency of participant visits to Padlet was tabulated at the end of course as shown Figure 2. The result shows that the number of participant visits to Padlet increased steadily from week 1 to week 14. According to the survey results, each participant visited Padlet at least once a week (Total visits=52; M=1.4). Moreover, the number of visits from the participants increased from week 1 to week 14. During the final week, week 14, participants reported visiting Padlet more than 8 times a week (Total visits=297; M=8.25).

Figure 2

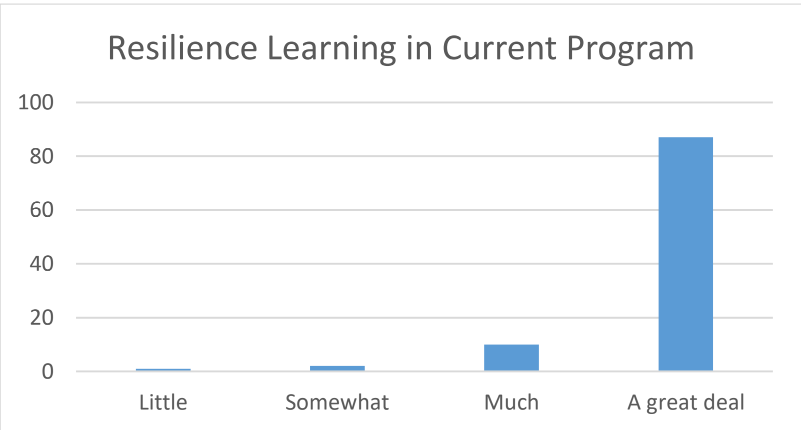
Frequency of participants visit on Padlet wall based on survey result



Participants in the resilience programme-administered basic organic chemistry group were asked to rate how their participation in the Padlet has enriched their learning in the resilience learning. Figure 3 shows that at the end of the course, about 87 % students suggested that the participation in the Padlet has enriched their resilience learning. 10 % of the participants found that the Padlet is much helpful in the learning of resilience. In the survey, only a small percentage of the participants suggested that the Padlet has somewhat (2 %) or little (1 %) effect helping them to study about resilience. We also found that participants who consistently visit and getting most out of the Padlet had consistently attended the physical class.

Figure 3

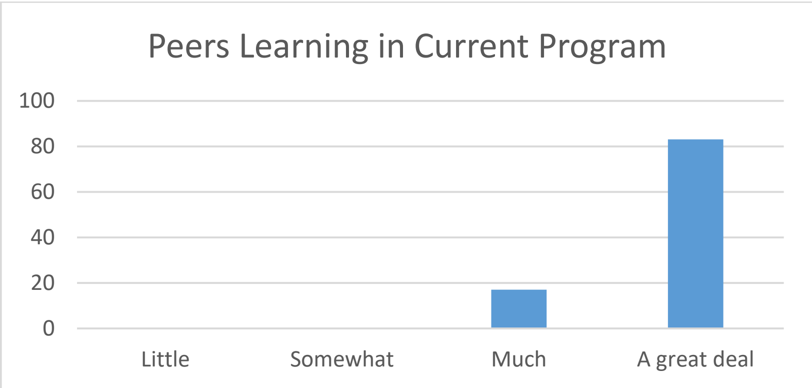
Participants feedback to question "How much did Padlet participation enrich your resilience learning



Participants were also asked whether the current activity posted on Padlet provided them with an opportunity to learn from their fellow classmates and hear their perspective. Approximately 83% of respondents affirmed that they significantly gained from their peers' comments on Padlet (Figure 4). Conversely, only 17% of participants claimed noteworthy acquisition from their classmates' comments on Padlet. Overall, 97% of participants provided feedback indicating they could apply the positive experiences they learned from their peers to overcome present and future obstacles.

Figure 4

Participants feedback to question "How much did this activity hosted in Padlet provide you an opportunity to learn from peers



Participants' Resilience Changes Before and After the Program

The results of one-way ANOVA test indicated that there was a significant difference between the experimental and the control groups, with gains in self-determination (F = 14.038, p<.001) and adaptability (F = 20.183, p<.001) in the experimental group (Figure 5). The effect size (eta-squared) was also examined within this study. Based on the result obtained, there was a small effect size existed for self-determination (eta-squared = 0.17) to medium (eta-squared = 0.23). Consequently, we can conclude that participants in the resilience programme-administered basic organic chemistry course experienced more self-determination and adaptability during their first year of study compared to the conventional course. Table 1 summarises the means and standard deviations for the items of Resilience Scale-10 for pre- and post-results in the controlled (n = 36) and experimental group (n = 36).

Figure 5

The mean sum scores for participants administered with resilience program in the basic organic chemistry course

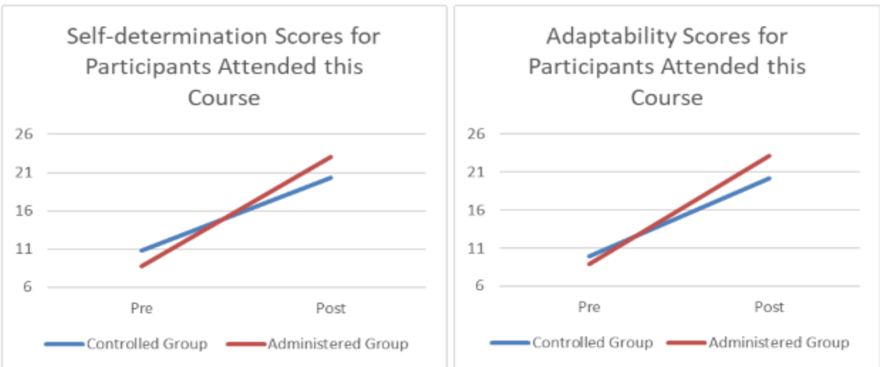


Table 2

Means and standard deviations for the items of Resilience Scale-10 for pre- and post-results in the control group (n = 36) and experimental group (n = 36)

Items	Control Group				Experimental Group			
	Pre		Post		Pre		Post	
	M	SD	M	SD	M	SD	M	SD
Factor 1: Self-Determination	10.83	4.103	20.334	4.338	8.778	3.599	23.056	3.074
1. I feel I know myself well.	1.750	0.770	3.834	0.910	1.694	0.668	4.361	0.762
2. I like myself just as I am.	1.722	0.779	4.056	0.791	1.583	0.649	4.778	0.485
3. I think I have the necessary skills to be successful in life.	2.056	0.826	4.194	0.856	1.8334	0.737	4.722	0.513
4. I feel comfortable with my body.	1.972	0.845	4.194	0.889	1.778	0.761	4.917	0.500
5. I feel I have good self-esteem.	2.000	0.793	4.056	0.893	1.889	0.785	4.278	0.815
Factor 2: Adaptability	9.861	4.142	20.139	4.318	8.889	3.756	23.139	3.193
6. I have total confidence in my skills to solve my problems.	1.917	0.692	3.861	0.931	1.801	0.668	4.722	0.513
7. I have been successful in overcoming difficulties in life.	1.944	0.860	4.000	0.756	1.722	0.815	4.528	0.609
8. I manage to minimize the negative effects of difficulties.	2.056	0.860	4.111	0.855	1.861	0.762	4.694	0.577
9. I take on my problems, giving them the importance they have, without undervaluing or overvaluing them.	1.834	0.910	4.139	0.867	1.611	0.803	4.611	0.688
10. When a situation cannot be changed, I accept the fact with serenity	2.111	0.820	4.028	0.910	1.889	0.708	4.584	0.806

Discussion

The discussion first reviews on the use of Padlet as a tool for resilience learning which was implemented online after the class each week. Based on participants' rich responses, one participant in the experimental group commented that the activities would be great if it could be carried out in the physical classroom. The result of this finding is consistent with a previous study (Ladyshewsky et al., 2012) where participants prefer to do learning activities in physical classroom. However, when online learning activities were introduced after the classroom setting, the learning process was found to be as efficient due to time limitation to cover the entire course content (Ivala & Gachago, 2012; Tagoe 2012). Undoubtedly, the advancement of technology has made learning easier and more flexible and has given lecturers more options to design content delivery such as recorded videos, YouTube videos and podcasts so that they are accessible to everyone at any time.

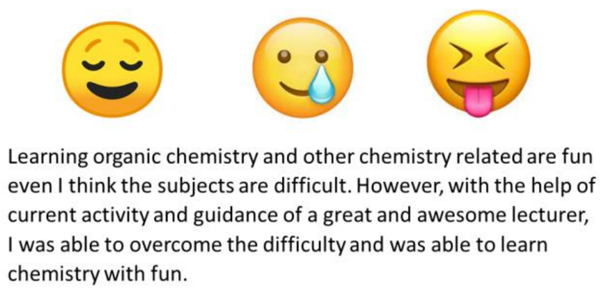
Participants also reflected on their feelings after being exposed to the videos and study materials related to resilience learning. Overall, 72 % of participants posted their comments at the end of course. The selected excerpts were also included in this manuscript. One of the predominant comments made by learners was encouragement to others not to give up so easily. The idea of the importance of mental health was also presented in one of the comments posted by participants via Padlet. Additionally, one of the participants indicated that the current programme promoted empathy among their peers as shown in one of the students' reflective essays. No doubt, a resilience programme that focuses on peer mental health support is important to promote self-recovery and efficacy of participants as proven in this study and previous research (Cooper et al., 2024). Resilience programmes promote pro-social behaviours and empathy among participants (Schonert-Reichl et al., 2012). Both collaborative learning and positive social learning were achieved by the participants administered with the current programme. Moreover, this programme helped participants to explore, share, learn and practice the virtues gained. A similar effect was observed in previous studies where resilience programs for youth have resulted in positive outcomes, including social support among peers (Stokar et al., 2014).

In the current research, overall resilience scores for the experimental group were significantly improved, as well as scores on subscales of self-determination and adaptability among participants were significantly enhanced. The current study showed that participants in the experimental group were more self-determined and adaptable compared to the control group based on the RS-10 survey. In addition, the number of participants who experienced happy learning was found to be higher in the experimental group compared to control group.

As shown in one of the reflective essays after the course (Figure 6), students noted that they needed the intervention of the resilience programme to learn better and overcome difficulties in the course. Other comments included that they felt much better and experienced the process of happy learning when undertaking the resilience-related videos and materials on Padlet. It is noteworthy that the resilience activities will be efficient, if positive emotion was taught with the aid of the instructor that show positive affect to the younger generation (Bai et al., 2014). Overall, “We Lead you to Success: A Resilience Programme” has shown positive outcomes on students' learning that may be beneficial to future participants based on the reflective essay submitted by current participants.

Figure 6

One of the participants administered with resilience program in the basic organic chemistry course commented on the current activity



Finally, we have examined participants’ final exam performance, and the average scores were summarised as shown in Table 5. The average final exam score made by the experimental group was 67.4 %, higher than that recorded by the control group (61.2 %). Statistically, there was no significant difference between the final exam scores ($F = 15.412$, $p = 0.890$) for both groups. The result of this finding was in agreement with previous studies, which revealed higher motivation of learning was promoted among students though no immediate improvement in academic achievement observed (Liu et al., 2022; Macnamara & Burgoyne, 2023). As indicated by the above result, the resilience program administered participants felt more self-determined and adaptable in the new environment, emotionally happier and motivated to learn. The positive emotion and resilience promoted in this out-of-class program has impacted on participants emotionally and motivation to learn in the subject taught and thus led to a better final exam score as compared to the controlled group. In a previous study reported by Mäkinen (2021), blogging promotes a certain kind of intimacy and enable the sharing of details of an individual’s life. Though bloggers might not want to share their whole stories of life or may be fragmented or curated part of life, what interest us was the blogs allows audience of getting a glimpse of someone’s personal life and feelings. Sometimes, having a sense of knowing the bloggers as if like reading a blog of a friend. This presumed intimacy which can be considered as an affective ‘glue’ that capable to build the virtual networks and enable blogging to become a meaningful way of connecting to the world of others, which can potentially lead to peers motivating in the time of adversity.

Table 5

Comparison of students' final exam marks for both intervention and control groups

	Control group (*n* = 36)		Experimental group (*n* = 36)	
	M	SD	M	SD
Average score	61.2	10.1	67.4	7.9

Limitations and Future Research

The population of participants in sample group was relatively small and the consequence of the resilience activities might not be felt by a larger group of participants. Moreover, the benefit showcased in this research to enhance on participants resilience was implemented awareness during their first-year undergraduate study. It does not guarantee participants will maintain the positive emotion throughout their duration of study in university or future lives. This research could be further expanded by involving participants from other courses to examine the effectiveness and explore its potential as a supplementary tool for enhancing resilience while tackling challenging concepts.

Conclusion and Implications

The purpose of the current research was to evaluate the effectiveness of a digital resilience program which employed Padlet, an online educational tool, in the after-class basic organic chemistry course session to build resilience among first-year undergraduate students. Previous studies have shown that the use of social media to instil learning activities after class session can benefit students and found to be much effective. As such, this study took advantage of Padlet and implemented the resilience activities as part of the instructional tool for participants in the learning of basic organic chemistry, as well as to promote collaborative and social learning skills. Based on the results obtained, the one-way ANOVA test indicated that there was a significant difference between the experimental and the control groups, with gains in self-determination (F = 14.038, p<.001) and adaptability (F = 20.183, p<.001) in the experimental group. Moreover, participants in the experimental group felt more self-determined and adaptable in their first year. In addition, the participants in the experimental group experienced happy learning when undergoing the resilience program compared to those in the control group. Moreover, participants indicated that they felt more motivated and energetic after completing with the resilience activities based on their submitted reflective essay. In education, resilience equips students with high achievement motivation and performance in learning, though with the presence of stressful events that might make students at risk of dropping out of university or school. In future, the current program can be used as a potential instructional tool to promote resilience learning among university students, especially after class session as an intervention programme for first year university students to foster resilience at university level.

Conflicts of Interest

The authors declare no conflict of interest.

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Journal of Turkish Science Education, 2025, 22(2), 198-219.
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Appendix

LESSON PLAN
FACULTY OF SCIENCE & MARINE ENVIRONMENT (FSSM)

NAMA PENSYARAH : Assoc. Prof. Dr. Chia Poh Wai
PROGRAM :
NAMA/ KOD KURSUS: CHM3702
SEMESTER : I 2022/2023
KREDIT : 2 (2+0)
HARI/ MASA : Monday (4-6 pm), lecture room 4-07, level 4, central lecture complex

MINGGU (M) Week (M)	**TOPIK PENGAJARAN** Teaching topics	**CLO**	**AKTIVITI PENGAJARAN** Teaching activity	**AKTIVITI PENILAIAN** Assessment activity	**AFTER CLASS ACTIVITIES (*We Lead you to success program*)**
M1 (16 - 22 OCT 2022)	**CHEMICAL BONDING AND MOLECULAR STRUCTURE** • Chemical bonds – ionic bonds, covalent bonds • Lewis structure – drawing method, charge formalism • Resonance Structure - resonance theory, hybrid resonance, resonance structure sketch. • Determination of molecular shape (covalent bond) – length, bond strength, bond angle, molecular geometry • Sketching organic structure – solid structure, skeletal structure	At the end of the lecture students can: ♣ know the concept of chemical bonds ♣ Explain the basic concepts of chemical bonding, hybridization, resonance, stereochemistry, acid-base theory	Activities -Introduction and description of the course and its content. -review understanding with Kahoot quizzes. -gives watching videos to understand more clearly and interestingly	Mini project/assignment announcement (poster & mind map): - Make a mind map of the latest notes and info for each chapter for each group - students are divided into groups and given assignments (posters) related to PLO1 & PLO7.	

	• Hybridization- sp3, sp2, sp hybrid orbitals			-students are also required to upload the mid map and poster in the padlet	
M2 (23 - 29 OCT 2022)	**Deepawali holiday**				
M3 (30 OCT - 5 NOV 2022)	**ACID AND BASE THEORY** • Bronsted-Lowry definitions of acids and bases • Examples of Bronsted-Lowry reactions of acids and bases • Acid strength relationship with pKa value • Definition of Lewis acid-base • Examples of reactions Lewis acid-base-conjugate acid, conjugate base	At the end of the lecture students can: • Understand the definition of acid-base • Understand the types of acid-base reactions • Relate acid strength to pKa value	Activities- Introduction and explanation of the topic and its content -review understanding with Kahoot quizzes. -watch the video to understand more deeply about acid bases	Make a mind map of the latest notes and info for each chapter for each group	*"Resilience Samaritans"* - video
M4 (6 - 12 NOV 2022)	**INTRODUCTION TO FUNCTIONAL GROUPS** • Know the functional groups of organic compounds and classification based on functional groups (hydrocarbon compounds, alcohols, alkyl halides, ethers, epoxides, amines, carbonyl compounds) • Rules for Naming Organic compounds according to IUPAC	understand the types of functional groups of compounds	Activities- - description of the course and its content - review understanding with a kahoot quiz -Animated youtube videos about related	Make a mind map of the latest notes and info for each chapter for each group	*"Eunice Akoth performs her poem "My Dream""*- video

M5 (13 - 19 NOV 2022)	**ALKANE COMPOUNDS** • Classification of alkane compounds - aliphatic, cyclic (cycloalkane) • Naming according to IUPAC- aliphatic alkanes, cycloalkanes • Relationship of molecular shape with physical properties (boiling point, melting point and solubility) • Chemical properties of alkanes- o Fossil fuel alkane preparation reaction o Combustion reaction – results in CO_2 and H_2O o Radical reaction - Halogenation mechanism (chlorine and bromine)	At the end of the lecture students can: • Classify compounds • Apply the correct IUPAC naming system and stereochemistry to name an organic compound • Distinguish chemical properties	Activities- - description of the topic and its content -review understanding with a crossword quiz.		*"Be the heliotropic effect"*- web study material
M6 (20 NOV - 26 NOV 2022)	**ALKANE COMPOUNDS** • Conformation of aliphatic alkanes o eclipsed conformation o staggered conformation o anti conformation o gauche conformation o Newman projection o Conformational stability • Conformation of cyclic alkanes **STEREOCHEMISTRY** • Isomers- structural isomers, stereoisomers • Chiral or non-chiral molecules – related by exact overlap, plane of symmetry		Activities- - description of the topic and its content - instructional videos related to structures found in stereochemistry	**Test 1 (W6)** **TB** **(15%)**	*"Exam stress relief and techniques"*- video

M7 (27 NOV - 3 DIS 2022)	**STEREOCHEMISTRY …** • Stereogenic center (chiral carbon) – aliphatic alkanes, cyclic alkanes • Determination of R and S configuration:- Cahn–Ingold–Prelog rules • Diastereomers & meso compounds	At the end of the lecture students can: • Distinguish the structure of isomers	Activities- - description of the topic and its content - instructional videos related to structures found in stereochemistry		*"Learning to succeed by learning to fail"*- video
4 - 10 DEC 2022	**MID-SEMESTER BREAK**				
M8 (11 - 17 DEC 2022)	**ALKENE COMPOUNDS** • Classification of alkene compounds - terminal and internal alkene, cycloalkene. • Alkene naming according to IUPAC • Naming stereoisomers - cis, trans, E and Z • Relationship between molecular shape and physical properties (melting point, boiling point and solubility) • Chemical properties of alkenes -	At the end of the lecture students can: • Distinguish the structure of isomers	Activities- - description of the topic and its content - instructional videos related to structures found in stereochemistry		*"The science of gratitude"*- video
M9 (18 - 24 DEC 2022)	**ALKENE COMPOUNDS …** o Alkene preparation reaction – alkyl halide dehydrohalogenation, alcohol hydration o Hydrohalogenation reaction (electrophilic addition of HX (hydrogen halide) - mechanism, Markovnikov rule, stereochemistry of electrophilic addition reaction.	At the end of the lecture students can: • Distinguish the type of alkene reactions	Activities- - description of the topic and its content		*"How socio-emotion learning benefits everyone"*- video

	o Hydration reaction-reaction mechanism o Halogenation reaction- mechanism, stereochemistry of halogenation. o Halohydrin formation reaction - melanism, stereochemistry and regioselectivity. o Hydroboration-oxidation reaction – mechanism.				
M10 (25 - 31 DEC 2022)	**ALKYNE COMPOUNDS** • Alkyne classification - terminal and internal alkyne, cycloalkyne • Naming of alkyne compounds according to IUPAC • Relationship between structure and physical properties (melting point, boiling point, solubility) • Chemical properties of alkynes -	At the end of the lecture students can: • Apply the correct IUPAC naming system and stereochemistry to name an organic compound • Distinguish chemical properties	Activities- - description of the topic and its content - related instructional videos		*"Self-awareness"*-video
M11 (1 - 7 JAN 2023)	o Alkyne preparation reaction – example: HX elimination reaction (from geminal and vicinal dichloride) o Addition reaction of alkyne compounds - addition mechanism of HX, X2, H2O, hydroboration-oxidation) o Acetylide- anion formation reaction from terminal alkyne (because sp hybridized C-H more acidic than sp2 and sp3), reaction with HX.	At the end of the lecture students can: • Distinguish the type of alkyne reactions	Activities- - description of the topic and its content - related instructional videos -review understanding with Kahoot quizzes		*"Self-control"*-video

M12 (8 - 14 JAN 2023)	**AROMATIC COMPOUNDS** • Naming compounds derived from benzene- mono substituted, disubstituted, poly substituted. • Aromatic Criteria- Huckel's Rule • Spectroscopic analysis of benzene compounds	At the end of the lecture students can: • Familiarize yourself with the naming of compounds derived from benzene	Activities- - description of the topic and its content - related instructional videos -review understanding with Kahoot quizzes		*"Relationship skill"*- video
M13 (15 - 21 JAN 2023)	**AROMATIC COMPOUNDS …** Electrophilic substitution reactions of benzene o Halogenation reaction o Penetration reaction o Sulfonation reaction o Friedel-Crafts alkylation reaction o Friedel-Crafts reaction	At the end of the lecture students can: • Understand substitution reactions	Activities- - description of the topic and its content - related instructional videos -review understanding with Kahoot quizzes		*"Responsible decision making"- video*
M14 (22 - 28 JAN 2023)	**Chinese New Year Holiday**				
M15 (29 JAN -4 FEB 2023)	**Study Week**				
M16 (5 – 11 FEB 2023)	**Final Examination**				

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Health issues within the socioscientific context: Systematic literature review

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ABSTRACT
Health issues present significant and complex challenges to society. This study aimed to investigate research trends related to health issues as socioscientific issues (SSI). The SSI articles analysed were from three prominent data sources: Scopus, Google Scholar, and Pubmed. Articles were retrieved via Harzing's Publish or Perish application based on published between 2018 to 2023 and the keyword "Socioscientific Issue". There were 415 articles obtained and screened using the Prisma technique, leaving 81 eligible articles. The articles underwent qualitative content analysis and quantitative bibliometric analysis using the VOSviewer software to determine research topics, research objectives, and the learning model implemented. According to the research findings, qualitative analysis showed the dominant topics were genetic modification (28.3%), COVID-19 (17.2%), and food additives (6.7%). The primary objectives were to develop argumentation skills (16.2%), conceptual understanding (13.7%), and decision-making (11.1%). The frequently implemented learning models were problem-based (28.4%), case-based (24.7%), and inquiry-based learning (16.0%). The quantitative bibliometric analysis revealed the most SSI topics were COVID-19, antibiotic resistance, and obesity. The main objectives were to develop argumentation skills, regulate emotions, and decision-making. The frequently implemented learning models were problem-based, case-based and practice-based learning. Furthermore, exploratory studies on SSI learning within the health context for improving willingness to act, communication and motivation.

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Introduction

Health issues present significant and complex challenges to society. The emergence of various diseases poses potential threats to quality of life, despite rapid advancements in knowledge and treatment technologies, coupled with improvements in healthcare services. Health matters stand as a quintessential contemporary challenge of the 21st century, demanding health literacy for individuals to respond intelligently and responsibly (Subiantoro et al., 2021). Therefore, exploring a range of issues relevant to health and their broader societal impacts can hold great learning value (Lund et al., 2019).

Learning in the primary classroom should engage pupils in science through meaningful and relevant experiences. Pupils will be interested in science by equipping them with skills applicable both in their academic journey and real-world scenarios (Mildenhall et al., 2019). To accomplish this, it is essential to bridge the gap between scientific concepts and their practical application in society (Quigley et al., 2020). One valuable approach to achieve this integration is through socioscientific issues instruction (Ewing & Sadler, 2020) in several topics, including health topics.

Socioscientific Issues (SSI) form the basis of an interdisciplinary learning approach which can increase the relevance of knowledge mastery and its societal utility, aligning with the contemporary objectives of science education (Chen & Xiao, 2021; Ewing & Sadler, 2020). The term "SSI" encompasses a range of social issues characterised by their intricate connections to scientific concepts, procedures and technologies (Zeidler et al., 2002). SSI issues are contemporary and typically encompass a scientific element while also drawing from various scientific disciplines. Moreover, they often entail moral and ethical assessments, further enhancing their multifaceted nature (Sadler & Zeidler, 2005; Zeidler et al., 2002). The SSI topic in learning is a special phenomenon attached to social issues that can liven up the learning atmosphere. This particular phenomenon that has been selected will be followed by interdisciplinary specific ideas (Ewing & Sadler, 2020).

The SSI approach has proven effective in accomplishing multiple learning objectives. It enhances students' informal reasoning by fostering skills in argumentation, connecting these arguments to natural scientific concepts, deciphering data patterns, and evaluating information to devise complex problem-solving solutions (Sadler & Zeidler, 2005). Moreover, SSI cultivates the capacity to engage in discussions, interpret events, and draw conclusions (Dawson & Venville, 2010), thereby playing a pivotal role in elevating students' scientific literacy (Sadler & Zeidler, 2005). Beyond this, SSI learning nurtures a sense of social responsibility (Driver et al., 2000) as students grapple with real-world issues in their surroundings, encouraging them to develop a critical perspective on how to navigate and thrive in society (Yun et al., 2020).

Utilising the appropriate learning model can improve learning outcomes. Socioscientific issues provide a meaningful context for students' real-life experiences. The integration between learning models and SSI holds the potential for mutually reinforcing science education goals (Ke et al., 2021), equipping students with competencies to navigate their future effectively (Zeidler & Nichols, 2009) and make informed decisions based on scientific principles and technology (Bossér & Lindahl, 2019). However, systematic research on the SSI learning models remains relatively limited (Zangori & Forbes, 2014).

A literature review of SSI is useful as a practical reference source for SSI learning trends. Numerous literature reviews have been conducted and published on various research trends within SSI learning. These encompass areas such as addressing sustainable development goals (Hernández-Ramos et al., 2021), mastering pedagogical knowledge (Chen & Xiao, 2021), exploring the potential of SSI learning to boost scientific literacy and science communication (Li & Guo, 2021), developing the SSI approach in physics education (Deta et al., 2021), and preparing students for the 21st century in biology education (Nurtamara et al., 2020). However, there is a noticeable scarcity of studies reviewing SSI learning research within the health context. Hence, this research was undertaken to address the following inquiries:

a) What are the trends in SSI learning research within the health context from 2018 to 2023 based on qualitative content analysis?

b) What are the trends in SSI learning research within the health context from 2018 to 2023 based on quantitative bibliometric analysis?

Methods

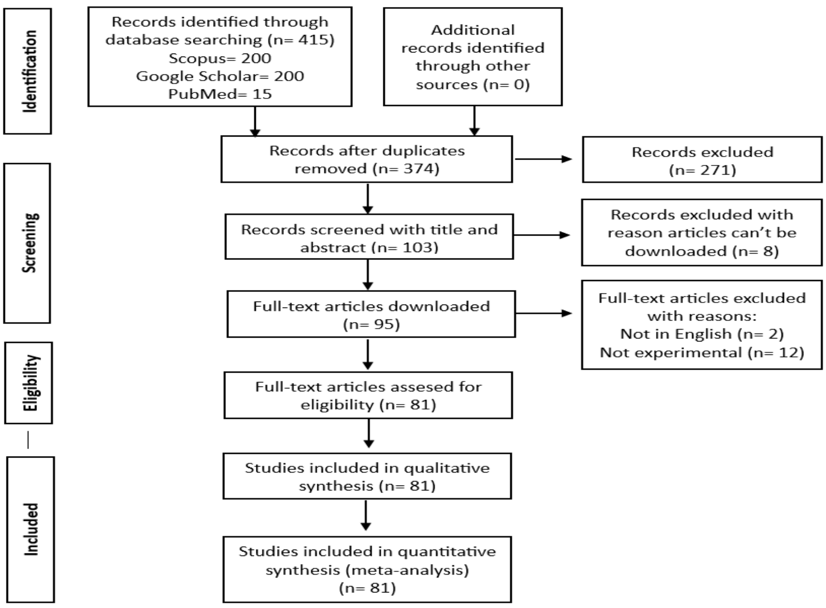
Article Selection

The methodology employed in this literature review follows a series of well-defined steps, drawing inspiration from previous similar studies. The initial step involved the collection of primary data, specifically a selection of articles, through the utilisation of Harzing's Publish or Perish (PoP) publication rating application on August 23, 2024. The chosen keyword for this search was "Socioscientific Issue," and the articles were restricted to those published within the last five years, spanning from 2018 to 2023. This time frame was chosen to ensure the inclusion of the most recent publications, thereby ensuring the relevance of the Socioscientific Issue topics discussed. Three data sources were selected for this search: Scopus, Google Scholar, and PubMed. These choices were made based on accessibility. The fact that Google Scholar offers free access, and Scopus and PubMed only require an API (Application Programming Interface) key. Additionally, the selection of PubMed was aligned with the specific focus of this literature review, which centres on human health.

The obtained articles were then subjected to a filtration process using the prism technique, allowing for the identification of articles eligible for further analysis. Data collection via Harzing's Publish or Perish resulted in a total of 415 articles, distributed as 200 from Scopus, 200 from Google Scholar, and 15 from PubMed. Scopus and Google Scholar were constrained to a maximum of 200 articles each based on the highest citation criteria. These articles were stored in Research Information System files and combined using the Mendeley reference manager (Jumini et al., 2022). The reference manager automatically eliminated duplicate articles. A secondary filtration process involved analyzing titles and abstracts for qualitative content, focusing on human health-related articles. These selected articles were downloaded, and subjected to inclusion criteria such as being in English and of experimental research. The article selection process is depicted in Figure 1.

Figure 1

Flow chart of the article selection using the prisma technique



Dual analysis strategy was employed to ensure a comprehensive understanding of SSI topics, learning objectives and learning models. It is recognising that a holistic approach combining both qualitative and quantitative methodologies yields more insightful results compared to either approach in isolation (Creswell, 2012).

Qualitative Analysis

Qualitative content analysis was conducted to determine research trends encompassing the examination of SSI topics employed, research objectives pursued, and learning models applied to the research in each article. The data was tabulated in the form of percentages and described descriptively. The list of reviewed articles sorted by year of publication can be seen in Appendix 1. It pays particular attention to the topics, research objectives, and SSI learning models implemented.

Quantitative Analysis

The quantitative analysis was conducted with the assistance of VOSviewer version 1.6.20 software to discern research trends in SSI learning within the context of health. Analysis was conducted to determine research trends on the contribution of the author and co-author, SSI topics employed, research objectives pursued, and learning models applied to the research. The bibliometric metadata analysis findings were visualised in a map format using the VOSviewer application (van Eck & Waltman, 2009).

Findings and Discussion

A focused subset of 81 SSI learning articles within the health context was obtained through the prism technique from 415 articles on Socioscientific Issues (SSI) learning. To elucidate research trends within this subset, a combined approach encompassing both qualitative and quantitative analyses was employed.

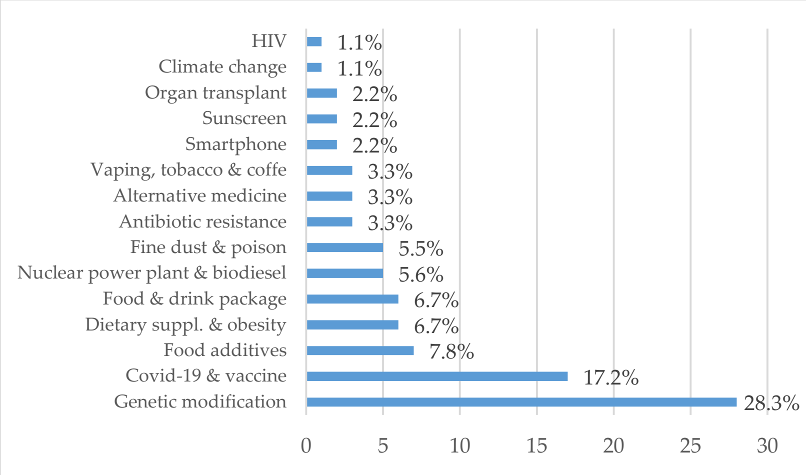
Trends in Research Based on Qualitative Content Analysis

Topics of Socioscientific Issues Learning in the Health Context

The distribution of topics used in SSI learning is shown in Figure 2. The SSI topics most frequently occur are genetic modification, COVID-19 and vaccines. Genetically modified organisms (GMOs) can be applied to plants, animals, and humans (Cebesoy & Rundgren, 2023, Christenson & Walan, 2023).

Figure 2

Topics of socioscientific issues learning in the health context



Genetically Modified Foods (GMF) are produced from GMO. In the last decade, the GMF has often caused controversy because plants are genetically engineered to possess enhanced traits and resistance to pests. The production of GMF involves the use of transgenic drugs and vaccines, which can lead to high costs and ongoing debates regarding the health safety of consuming GMF products (Ceyhan et al., 2021). GMF has been successfully used in SSI learning (Genc & Acar, 2021; Herman et al., 2021; Leung & Cheng, 2020; Muis et al., 2021; Özturk et al., 2021; Wen & Wei, 2018).

COVID-19 and vaccines emerged and started spreading in early 2020 as a global health crisis. The third most frequently explored Socioscientific Issues (SSI) topic is food additives (Capkinoglu et al., 2022; Choi & Lee, 2021; Friedrichsen et al., 2021; Martini et al., 2021; Wiyarsi et al., 2021). Although the utilisation of food additives as an SSI learning topic remains relatively limited, there is a growing recognition of its potential benefits. Many educators traditionally prioritize content delivery as the primary educational objective, but SSI learning has proven to be a valuable approach for enhancing students' broader skill set. By incorporating SSI topics such as food additives, educators can effectively cultivate students' communication abilities, problem-solving skills, critical thinking, scientific inquiry aptitude, social and environmental awareness, literacy, higher-order thinking capabilities, creativity, and collaborative competencies (Nida et al., 2021).

The least frequently addressed topics are climate change, biodiesel, and HIV. Climate change and biodiesel are subjects extensively studied due to their significant environmental implications. Climate change is one of the most pressing problem for today’s global community (Prasad, 2022). Meanwhile, HIV, while a complex and vital topic with far-reaching consequences for both health and a nation's resilience if not properly managed, remains relatively underrepresented in the literature. It appears that discussions surrounding HIV are predominantly confined to medical advancements and health ethics within the context of SSI learning. It is warranting further exploration (Fan et al., 2020).

The Objectives of Socioscientific Issues Learning in the Health Context

Various objectives of SSI learning are presented in Table 1. The primary objective is to enhance argumentation skills (Atabey, 2021; Bächtold et al., 2023; Baytelman et al., 2020; Capkinoglu et al., 2022; Fan et al., 2020; Georgiou et al., 2020; Johnson et al., 2020; Lee & Tran, 2023; Rietz et al., 2021; Torres & Cristancho, 2018). This result is the same as that found by Falah et al. (2024). Argumentation is a central tenet of critical thinking (Ennis 1985). Concerning SSI, students need argumentation to justify their decisions and evaluate the decisions. An argument should be supported by scientific evidence (Kacar & Balim, 2021).

Table 1

The objectives of socioscientific issues learning in the health context

Objectives of Socioscientific Issues Learning	n	%
Argumentation	19	16.2
Conceptual understanding	16	13.7
Decision making	13	11.1
Critical thinking	10	8.5
Reasoning	8	6.8
Perception	8	6.8
Epistemological cognition and HoM	8	6.8
Moral, emotions, empathy, and ethical	8	6.8
Attitude and disposition	7	6.0
Literacy	6	5.1
Responsibility, awareness, and willingness to act	6	5.1
Creativity and communication	3	2.6
Engagement and motivation	3	2.6

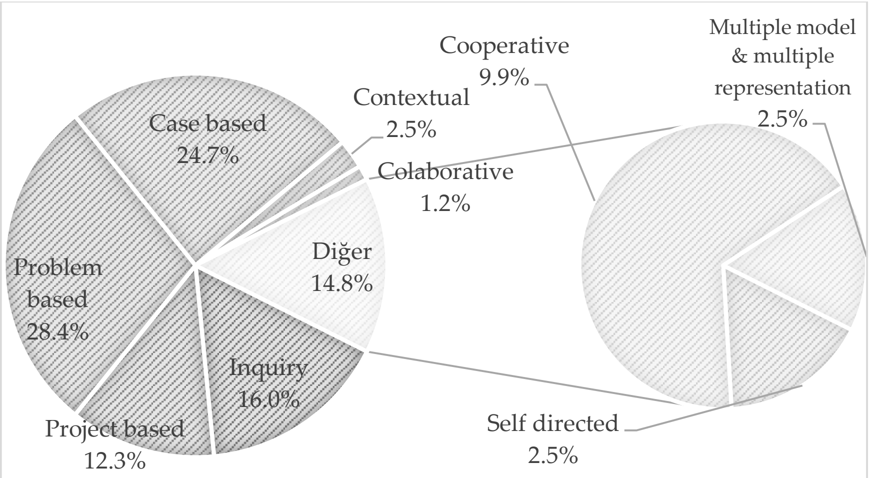
The second most prevalent objective in Socio-scientific Issues (SSI) learning is enhancing student conceptual understanding. Providing adequate and clear knowledge will help students understand concepts (Golestaneh & Mousavi, 2024). Several studies have succeeded in improving conceptual understanding using SSI learning (Altan et al., 2018; Annisa & Subiantoro, 2022; Christodoulou et al., 2021; Karakaya & İrez, 2022; Kärkkäinen et al., 2019; Ke et al., 2021; Lin et al., 2020; Lund et al., 2019; Subiantoro et al., 2021). Research objectives to improve literacy are few, this is also the same as the results of a study on scientific literacy assessment (Istyadji & Sauqina, 2023). However, an aspect of SSI learning that remains relatively underexplored is the cultivation of student creativity. There has been limited research in this area, with only one study dedicated to fostering students' public awareness of air pollution (Kim, et al., 2020).

The Models of Socioscientific Issues Learning in the Health Context

The learning model implemented into SSI learning is shown in Figure 3. The most commonly utilized SSI learning model is Problem-Based Learning (PBL). PBL provides opportunities for teachers facilitating students to solve a problem through group work (Muhfahroyin et al., 2023). Several researchers have successfully implemented PBL using health issues (Cian et al, 2020; Genc & Acar, 2021; Gul & Akcay, 2020; Leung, 2020; Martini et al., 2021; Minken et al., 2021; Özturk et al., 2021; Purwati et al., 2019; Seiter & Fuselier, 2021; Sibic & Topcu, 2020; Subiantoro et al., 2021; Sparks et al., 2022; Tyrrell & Calinger, 2020; Wiyarsi et al., 2021). This finding aligns with the conclusions drawn from a literature review study by Hernández-Ramos et al. (2021).

Figure 3

The learning models of socioscientific issues in the health context



Case-based learning (CBL) is the second most frequently implemented SSI learning model within the health context. CBL in science education has developed rapidly (Dewi & Rahayu, 2023). PBL and CBL learning models in the health context cannot be compared to which is better. PBL uses open inquiry, while CBL uses guided inquiry. Both have strengths and weaknesses, although CBL allows for a wider range of problem-solving skills (Srinivasan et al., 2007). Several researchers have successfully implemented CBL using health issues (Adal et al., 2022; Aydin et al., 2019; Baytelman et al., 2020; Büssing et al., 2020; Dalaila et al., 2022; de Freitas et al., 2023; Herman et al., 2022; Kammerer et al., 2021; Lee et al., 2020; Namdar et al., 2020; Nida et al., 2021; Yerdelen et al., 2018).

Trends in Research Based on Bibliometric Quantitative Analysis

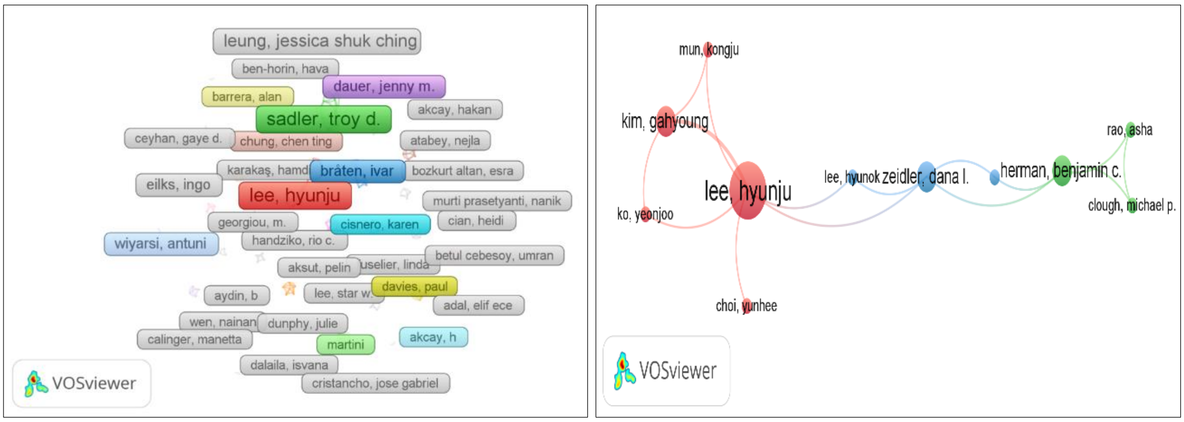
The analysis of research trends encompasses the examination of the contribution of authors, SSI topics employed, learning objectives pursued, and learning models implemented. Notably, a total of 213 authors have contributed to this endeavour, collectively producing 81 published articles.

Contribution of Author and Co-Author

It is essential to assess the contributions made by authors and co-authors because they have been meritorious in the advancement of SSI research and learning, especially within the realm of human health. The contribution of the authors is presented in Figure 4. The author with the highest number of publication documents can be identified by the size of the label, and this confirmed by analyzing metadata. Based on Figure 4, the top three authors with the highest number of published documents, in descending order, are Troy D. Sadler, Lee Hyunju, and Jessica Shuk Ching Leung.

Figure 4

Authors and co-authors of research on socioscientific issues learning in the health context



Metadata in Vosviewer showed the number of documents from the authors is Troy D. Sadler (5), Patricia Friedrichsen (5), Lee Hyunju (4), Laura Zangori (4), Leung (3), and Li Ke (3 articles). It is worth noting that in Figure 4, both Laura Zangori and Li Ke are not visible because their labels are obscured by the Troy D. Sadler label, which is part of the same green cluster. The shared label colour indicates that these authors are connected because they have contributed to articles in the same journal (van Eck & Waltman, 2009).

Several authors have conducted collaborative research, as can be seen in Figure 4. Lee Hyunju is the author with the highest level of collaboration, working alongside six other authors. Dana L. Zeidler and Benjamin C. Herman have collaborated with four other authors each. Notably, the collaboration between Lee Hyunju, Dana L. Zeidler, and Lee Hyunok has focused on researching the various challenges faced by students and educators during the transition from traditional learning to SSI learning. They employed case-based learning (Lee et al., 2020).

Topics of Socioscientific Issues Learning in the Health Context

The variety of SSI topics used in learning are shown in Figure 5. All of the topics meet the requirements of the SSI used in learning. SSI is a special phenomenon attached to social issues that can liven up the learning atmosphere. This particular phenomenon that has been selected will be followed by interdisciplinary specific ideas (Ewing & Sadler, 2020). SSI topics were characterized by their intricate connections to scientific concepts, procedures, and technologies (Zeidler et al., 2002), contemporary, often entail moral and ethical assessments (Sadler & Zeidler, 2004), open-ended, complex, controversial (Atabey, 2021), and allowed from multiple viewpoints (Sadler & Zeidler, 2005).

Figure 5

The topics of socioscientific issues learning in the health context

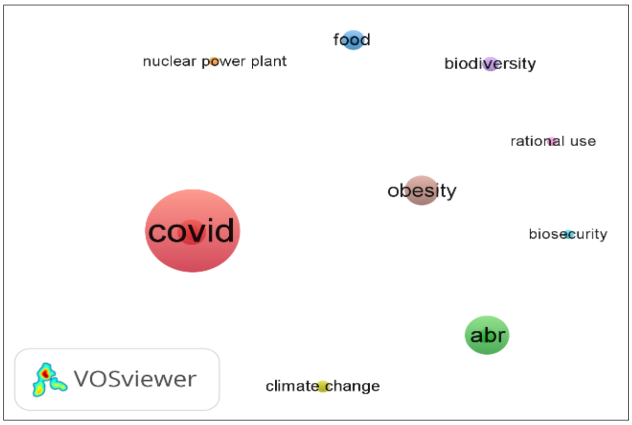


Figure 5 shows the most frequent SSI topic is COVID-19. Based on metadata, the topic of covid appeared as many as 36 occurrences. Several studies have successfully used topics on COVID and vaccination to develop a variety of student skills (Atabey, 2021; Estigarribia et al., 2022; Ha et al., 2022; Han-Tosunoglu & Ozer, 2022; Herman et al., 2022; Karakaş, 2022; Ke et al., 2021; Lee & Tran, 2023; Salman & Yilmaz, 2021; Sulistiani et al., 2022; Subiantoro et al., 2021). COVID-19 represents a contemporary pandemic disease that swiftly evolved into a global health crisis. Within a short timeframe, it had far-reaching impacts on various sectors, including education, the economy, and social life (Atabey, 2021). Many learning models were developed during the COVID pandemic (Karaarslan-Semiz et al., 2023; Putri et al., 2022; Sasmito & Sekarsari, 2022). The COVID-19 pandemic stands out as one of the most formidable and challenging topics of our era, given its multifaceted nature, encompassing scientific, social, and ethical dimensions (Han-Tosunoglu & Ozer, 2022).

Health-related topics such as antibiotic resistance (Owens et al., 2019; Peel et al., 2019; Sagmeister et al., 2021) are still relatively underutilised in the context of Socioscientific Issues (SSI) learning. However, the issue of antibiotic resistance, characterised by the emergence and proliferation of antibiotic-resistant pathogenic microorganisms, presents a multifaceted challenge to public health. This complex problem spans various fields of science, ranging from medicine to politics and economics, making it a suitable candidate for interdisciplinary exploration within SSI learning. Integrating antibiotic resistance topics into SSI learning holds particular relevancy for students' future development, as it can foster a sense of responsibility towards addressing critical health issues (Sagmeister et al., 2021). This emphasis on responsibility aligns with one of the key objectives of the "Global Action Plan on Antibiotic Resistance" strategy, which seeks to enhance awareness and understanding to promote the responsible use of antibiotics (World Health Organization, 2015).

The results of this bibliometric analysis diverge from the findings of qualitative content analysis, highlighting the significance of both approaches. In the qualitative content analysis, the primary topic is genetic modification, with a total of 31 studies identified. This discrepancy arises because authors may not consistently include "genetic modification" as a keyword in their articles, rendering it undetectable by the VOSviewer system, which relies on keyword terms for analysis. Therefore, to ensure a more comprehensive understanding, it is essential to combine both software-assisted quantitative analysis and qualitative content analysis in research endeavours.

The Objectives of Socioscientific Issues Learning in the Health Context

The various objectives of SSI learning are presented in Figure 6 which shows the primary objective of SSI learning is the enhancement of argumentation skills. Argumentation is a fundamental practice in science to support or justify the claims. Learning argumentation skills is a critical part of science education. The quality of an argument or justifications used in an argument is also associated with content knowledge and rationalistic informal reasoning, characterized by the use of logic and reason. Argumentation skills align with the ability to apply the process of science (Lee & Tran, 2023).

Figure 6

The objectives of socioscientific issues learning in the health context

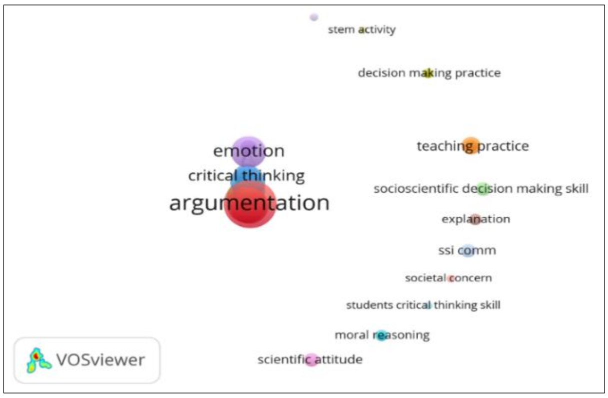


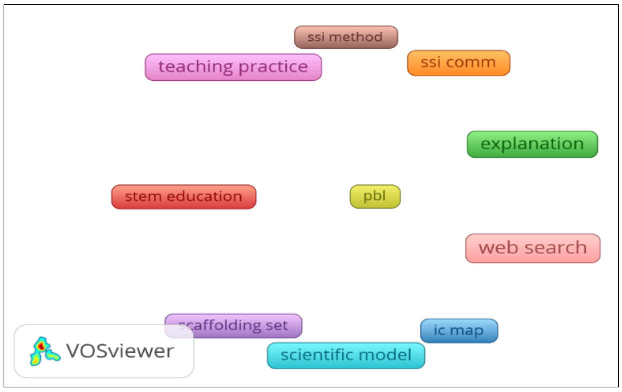
Figure 6 also shows the second major objective of SSI learning research is regulating emotion. The important role emotions play in engaging students with socio-scientific issues cannot be disregarded. Students are emotionally connected with health issues (Lombard et al., 2020), including biosecurity (Ram et al. 2020). The third learning objective that appears on the visual map is critical thinking. However, confirmation of the metadata in Vosviewer shows that the third most common occurrence is decision making which is divided into 2 keywords.

The Learning Models of Socioscientific Issues in the Health Context

The learning model implemented into SSI is shown in Figure 7. The most commonly utilized in a sequence, include problem-based learning (PBL), case-based (CBL) and practice-based learning.

Figure 7

The models of socioscientific issues learning in the health context



The majority of labels visible on the map depict learning models and learning methods. This occurs because bibliometric analysis relies on keywords from article titles and abstracts during the full counting process, even though many articles do not explicitly mention the names of the learning methods employed within these sections. Therefore, to provide a more comprehensive overview, this map analysis was complemented by metadata item analysis which reveal the primary SSI learning models used. CBL and PBL are two approaches that can introduce real-world complexity into the classroom to reduce the gap between academic training and professional practice. PBL is more complex than CBL because it requires students to create a solution without direct help from the educator (Pinto, 2023).

The Relationship Between Topics, Objectives, and Learning Models of Socioscientific Issues in the Health Context

The main goal of interdisciplinary education is sustainable education to face the world's challenges and fight for human rights. Education is expected to be able to increase global awareness and foster cognitive, social and behavioural competencies that support goals (UNESCO, 2023). Therefore, the relationship between SSI topics, objectives, and learning models is focused on the major SSI learning objectives obtained in this study which include developing argumentation, regulating emotional objects and decision making, as presented in Figure 8.

Figure 8

The relationship between topics, objectives, and learning models of socioscientific issues learning

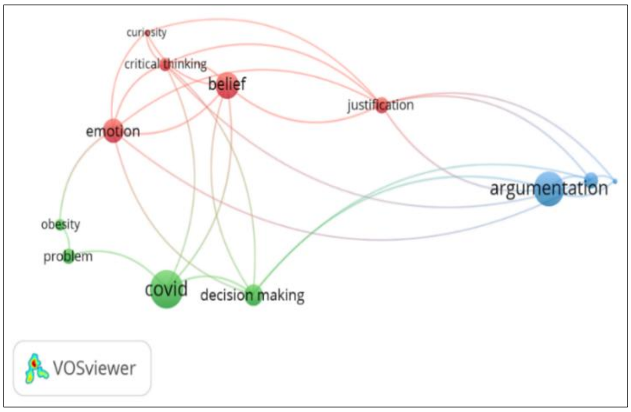


Figure 8 shows that argumentation is connected to justification and decision-making. This indicates that argumentation skills have been successfully developed along with justification and decision making skills. In Figure 8, it also appears that decision-making is connected with argumentation, belief, and critical thinking. This indicates that decision-making skills play an important role in these connected skills. The decision-making is also connected to COVID, this indicates that the COVID-19 topic can be used to develop decision-making (Sadler et al., 2021). Emotions play a role in critical thinking, belief justification, decision-making, and curiosity. In addition, the topic of obesity was successfully used to improve emotion objects (Leung & Cheng, 2023). In Figure 8, there is also a problem label representing problem-based learning (PBL) connected to obesity and emotion, this indicates that SSI learning within the topic of obesity using PBL has been successfully implemented for regulating emotions.

Conclusion and Implications

The qualitative content analysis and quantitative bibliometric analysis of 81 articles from Scopus, PubMed, and Google Scholar in Socioscientific Issues (SSI) reveals trends in SSI learning within the health context research. Qualitative content analysis reveals the dominant topics were genetic modification (28.3%), COVID-19 (17.2%), and food additives (6.7%). The primary objectives were to develop argumentation skills (16.2%), conceptual understanding (13.7%), and decision-making (11.1%). The frequently implemented learning models were problem-based (28.4%), case-based (24.7%), and inquiry-based learning (16.0%). The quantitative bibliometric analysis reveals the most SSI topics were COVID-19, antibiotic resistance, and obesity. The main objectives were to develop argumentation skills, emotions, and decision-making. The frequently implemented learning models were problem-based, case-based and practice-based learning. Both results of qualitative analysis and quantitative analysis reinforce each other. A major implication is these findings can be used as a practical source of information for researchers and educators in determining learning objectives, models, and SSI topics within the health context. The following are two points of recommendations for researchers regarding SSI studies. There is potential to conduct SSI to develop argumentation, regulate emotion, and decision-making for students, especially in health education. The scope of this research is still too broad, further exploration is needed to improve willingness to act, communication and motivation which still receives limited attention.

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Appendix 1

List of articles reviewed

No.	Publication	Topics of SSI	Research Objectives	Learning Models
1	Wen, N., & Wei, R. (2018). Examining effects of informational use of social media platforms and social capital on civic engagement regarding genetically modified foods in China. *International Journal of Communication.*	Genetically modified foods	Examine the willingness to speak as a predictor of civic engagement	Project-based learning
2	Torres, N., & Cristancho, J. G. (2018). Analysis of the forms of argumentation of teachers in training in the context of a socio-scientific issue. *Journal of Turkish Science Education.*	Consumption of coffee	Analyze the forms of argumentation	Case-based learning
3	Altan, E. B., Ozturk, N., & Turkoglu, A. Y. (2018). Socio-scientific issues as a context for STEM education: a case study research with pre-service science teachers. *European Journal of Educational.*	GMO	Determine students' evaluations of the use of SSI in STEM education	STEM Problem-based learning
4	Yerdelen, S., Cansiz, M., Cansiz, N., & Akcay, H. (2018). Promoting preservice teachers' attitudes toward socioscientific issues. *Journal of Education in Science.*	GMF, alternative medicine, organ transplant	Promote students' attitudes toward SSI	Case-based learning
5	Yapicioglu, A. E., & Aycan, S. (2018). Pre-service science teachers' Decisions and types of informal reasoning about the socioscientific issue of nuclear power plants. *Educational Policy Analysis and Strategic Research*.	Nuclear power plants	Effect on decisions, positions, and level of informal reasoning	Case-based instructional activities
6	Aydin, F., Aksut, P., & Demir S. N. (2019). The usability of infographics within the framework of learning outcomes containing socioscientific issues. *Cumhuriyet International Journal of Education.*	Packaged food	Examine the views usability of infographics in order to raise awareness of issue	Case study learning
7	Kärkkäinen, S., Hartikainen-Ahia, A., … (2019). Adolescents' learning and experiences of solving the need for dietary supplementation through socioscientific issue (SSI) method. *Health Education.*	Dietary supplementa-tion	Develop information seeking and critical thinking skills for solving problem	Three stage models learning

8	Kim, G. Ko, Y., & Lee, H. (2019). The effects of community-based socioscientific issues program (SSI-COMM) on promoting students' sense of place and character as citizens. *International Journal of Science and Mathematics Education.*	Fine dust	Promote students' sense of place and character of citizen	Community-based SSI (SSI-COMM) Program
9	Öztürk, A., & Doğanay, A. (2019). Development of argumentation skills through socioscientific issues in science course: A collaborative action research. *Turkish Online Journal of Qualitative Inquiry*.	Genetic tests in health insurance dan GMO products	Develop argumentation skills	Problem based learning
10	Purwati, R., Suranto, … (2019). Problem-based learning modules with socio-scientific issues topics to closing the gap in argumentation skills. *TOJET: The Turkish Online Journal of Educational Technology*	GMO	Improve argumentation skills	Problem based learning
11	Lund, E. S., Bråten, I., ... (2019). Direct and indirect effects of textual and individual factors on source-content integration when reading about a socio-scientific issue. *Reading and Writing.*	Sun exposure	Determine direct and indirect effects on readers' ability to integrate information	Case based learning
12	Wiyarsi, A., & Çalik, M. (2019). Revisiting the scientific habits of mind scale for socio-scientific issues in the Indonesian context. *International Journal of Science Education*.	Alternative medical treatment	Develop scale measuring the Indonesians' scientific habits of mind levels	Problem based learning
13	Peel, A., Zangori, ... (2019). Students' model-based explanations about natural selection and antibiotic resistance through socio-scientific issues-based learning. *International Journal of Science Education.*	Antibiotic resistance and natural selection	Explore students' explanation ability	Model-based explanations (MBEs)
14	Çalik, M., & Karatas, F. O. (2019). Does a "science, technology and social change" course improve scientific habits of mind and attitudes towards socioscientific issues? *Australian Journal of Teacher Education.*	Vaccination, health risk of modern technologies, and herbal medicines,	Improve students' habits of mind and attitudes towards SSI	Inquiry based STSC learning
15	Sagmeister, K. J., Schinagl, ... (2021). Students' experiences of working with a socio-scientific issues-based curriculum unit using role-playing to negotiate antibiotic resistance. *Frontiers in Microbiology.*	Antibiotic resistance	Develop multiple perspectives and responsibility	Collaborative based learning included a mini congress

16	Büssing, A. G., Dupont, J., & Menzel, S. (2020). Topic specificity and antecedents for preservice biology teachers' anticipated enjoyment for teaching about socioscientific issues: investigating universal values and psychological distance. *Frontiers in Psychology.*	Preimplantation genetic diagnosis	Develop universal value of benevolence	Case based learning
17	Tyrrell, D. C., & Calinger, M. (2020). Breaking the COVID-19 ice: integrating socioscientific issues into problem-based learning lessons in middle school. *Edmedia.*	Covid-19 (vaccine and ventilators)	Engage a motivational and scientific literacy	Problem based learning
18	Fan, Y. C., Wang, T. H., & Wang, K. H. (2020). Studying the effectiveness of an online argumentation model for improving undergraduate students' argumentation ability. *Journal of Computer Assisted Learning.*	HIV/ AIDS	Enhancing rrgumentation ability	IpadE Training embeds with a web-based model
19	Lombard, F., Schneider, D. K., … (2020). Balancing emotion and reason to develop critical thinking about popularized neurosciences. *Science & Education.*	Stem cells as potential cures for diseases	Developing critical thinking, emotional empathy and cognitive empathy	Project based learning
20	Kim, G., Mun, K., & Lee, H (2020). Exploration of Middle School Students' Ideas of Fine Dust Issues Using Issue Concept Maps. *Asia-Pacific Science Education.*	Fine dust	Exploring students' ideas and enhancing awareness	SSI Program using issue concept map (ic map)
21	Lin, J. W., Cheng, T. S., … (2020). The effects of socioscientific issues web searches on grade 6 students' scientific epistemological beliefs: the role of information positions. *International Journal of Science Education.*	Smartphone usage and nuclear power plant	Enhancing scientific epistemological belief (SEB)	Discovery-based web searches Program
22	Ke, L., Sadler, … (2020). Students' perceptions of socio-scientific issue-based learning and their appropriation of epistemic tools for systems thinking. *International Journal of Science Education.*	Vaping unit (electronic cigarettes)	Enhancing students' positive perceptions and epistemic thinking	Inquiry learning
23	Gul, M. D., & Akcay, H. (2020). Structuring a new socioscientific issues (SSI) based instruction model: Impacts on pre-service science teachers' (PSTs) critical thinking skills and dispositions. *International Journal of Research in Education and Science.*	Climate change	Fostering critical thinking and dispositions	Problem based learning

24	Namdar, B., Aydin, B., & Raven, S. (2020). Preservice science teachers' informal reasoning about hydroelectric power issue: the effect of attitudes towards socio-scientific issues and media literacy. *(IJRES)*.	Hydroelectric power plant	Examine the role of media literacy as major predictors of informal reasoning	Case based learning
25	Lee, H., Lee, H., & Zeidler, D. L. (2020). Examining tensions in the socioscientific issues classroom: students' border crossings into a new culture of science. *Journal of Research in Science Teaching.*	Genetic modification technology	Explore the tensions to navigate students across the subcultures of science and science education	Case study
26	Ram, R. (2020). Engaging young people in science education through socioscientific issues of biosecurity. *Kotuitui.*	Biosecurity of exporting product	Investigate the emotionally connected engagement	Interpretative inquiry Program
27	Nurtamara, L., & Prasetyanti, N. M. (2020). The Effect of Biotechology Module with Problem Based Learning in the Socioscientific Context to Enhance Students' Socioscientific Decision Making Skills. *International Education Studies.*	Farm and food biotechnology	Enhance decision making skills	Problem based learning
28	Georgiou, M., Mavrikaki, … (2020). Investigating the impact of the duration of engagement in socioscientific issues in developing Greek students' argumentation and informal reasoning skills. *American Journal of Educational Research.*	Genetically modified foods	Develop argumentation and informal reasoning skills	Research project (RP) Group Program
29	Johnson, J., Macalalag, A. Z., & Dunphy, J. (2020). Incorporating socioscientific issues into a STEM education course: exploring teacher use of argumentation in SSI and plans for classroom implementation. *Disciplinary and Interdisciplinary Science Education Research.*	Collony collapse disorder (CCD)	Explore scientific argumentation skills and plan implementation ability	Project based program
30	Leung, J. S. C. & Cheng, M. M. W. (2020). Conceptual change in socioscientific issues: learning about obesity. *International Journal of Science Education*	GMF	Enhance the number of multiple dimensions	SSI teaching and learning
31	Cian, H. (2020). The influence of context: comparing high school students' socioscientific reasoning by socioscientific topic. *International Journal of Science Education*.	GMO	Comparing students' reasoning sophistication levels	Online problem-based survey Program

32	Leung, J. S. C. (2020). A practice-based approach to learning nature of science through socioscientific issues. *Research in Science Education.*	Obesity	Improve students' use of NOS understanding for actively applying.	Practice based learning
33	Nida, S., Rahayu, S., & Eilks, I. (2020). A survey of Indonesian science teachers' experience and perceptions toward socio-scientific issues-based science education. *Education Sciences*.	Food biotechnology and food ingredients	Explore Indonesian science teachers' experience and perceptions toward SSI	Science pedagogies-based SSI Program
34	Baytelman, A., Iordanou, K., & Constantinou, C. P. (2020). Epistemic beliefs and prior knowledge as predictors of the construction of different types of arguments on socioscientific issues. *Journal of Research in Science Teaching.*	vaccines, consumption of bottled vs tap water, and high-voltage lines	Investigate students' epistemic beliefs and prior knowledge as predictors of argument	Cased based learning
35	Sibic, O., & Topcu, M. S. (2020). Pre-service Science Teachers' Views towards Socio-scientific Issues and Socio-scientific Issue-based Instruction. *Journal of Education in Science Environment and Health.*	Biotechnology (GMO, cloning, organ donation, and stem cells)	Explore students' views towards SSI and SSI based instruction	SSI based instruction
36	Minken, Z., Macalalag, Jr., A., ... (2021). Development of teachers' pedagogical content knowledge during lesson planning of socioscientific issues. *International Journal of Technology in Education.*	GMO	Develop teachers' pedagogical content knowledge	Professional development workshop series
37	Salman, M., & Yilmaz, A. (2021). The relationship between the attitude towards socioscientific issues and views on COVID-19 and vaccine. *International Journal of Psychology and Educational Studies.*	Covid-19 and vaccine	Examine the relationship between attitude towards SSI and health literacy	Case based Program
38	Muis, K. R., Chevrier, M., Denton, C. A., & Losenno, K. M. (2021). Epistemic emotions and epistemic cognition predict critical thinking about socio-scientific issues. *Frontiers in Education*.	Genetically modified foods	Examine the role of epistemic emotion and epistemic cognition as predictor of critical thinking	Project based learning
39	Subiantoro, A. W., Handziko, R. C., & Wibowo, Y. (2021). A narrative inquiry of socio-scientific issues-based e-learning development in biology to promote student health literacy. *Biosfer: Jurnal Pendidikan Biologi.*	Covid-19	Promote students' health literacy	Inquiry based e-learning
40	Dauer, J. M. (2021). Students' Civic Engagement Self-Efficacy Varies Across Socioscientific Issues Contexts. *Frontiers in Education.*	Food insecurity	Investigate students' feelings of self-efficacy for civic engagement	STEM-cased-based learning

41	Subiantoro, A. W., Treagust, D., & Tang, K. S. (2021). Indonesian Biology Teachers' Perceptions about Socio-Scientific Issue-Based Biology Instruction. *Asia-Pacific Science Education*.	Food preservatives	Promote the implementation of SSI-based instruction in class rooms	Professional development program on SSI-based teaching and learning
42	Atabey, N. (2021). Science teachers' argument types and supporting reasons on socioscientific issues: COVID-19 pandemic. *International Journal of Psychology and Educational Studies.*	Covid-19 vaccination	Improve students' argumentation qualifications	Case-based learning
43	Owens, D. C., Sadler, T. D., & Friedrichsen, P. (2019). Teaching practices for enactment of socio-scientific issues instruction: An instrumental case study of an experienced biology teacher. *Research in Science Education*.	Antibiotic resistance	Identify science teaching practices for enactment on SSI instruction	Instrumental context-case study
44	Tülin, G., & Acar, F. E. (2021). Perspectives related to socio-scientific issues according to the scientific attitude points of secondary school students. *Journal of Psychology and Educational Studies*.	GMO foods and organic products	Investigate the perspectives related to SSI according to scientific attitudes	Problem based learning
45	Christodoulou, A., Levinson, R.,… (2021). The use of cartography of controversy within socioscientific issues-based education: students' mapping of the badger-cattle controversy in England. *International Journal of Science Education.*	Bovine tuberculosis from badger-cattle	Examine the pedagogical potential to unravel the complexity and to communicate SSI	SSI-based education
46	Friedrichsen, P. J., Ke, L., … (2021). Enacting co-designed socio-scientific issues-based curriculum units: a case of secondary science teacher learning. *Journal of Science Teacher Education.*	Obesogenic junk food	Enacting co-designed SSI-based curriculum units	SSI professional development within multiple case studies
47	Wiyarsi, A., Prodjosantoso, A. K., & Nugraheni, A. R. E. (2021). Promoting students' scientific habits of mind and chemical literacy using the context of socio-scientific issues on the inquiry learning. *Frontiers in Education*.	Abused food additive	Promote students' scientific habits of mind and chemical literacy	Inquiry learning
48	Herman, B. C., Newton, M. H., & Zeidler, D. L. (2021). Impact of place-based socioscientific issues instruction on students' contextualization of socioscientific orientations. *Science Education*	Genetically modified foods	Investigate of ecological worldviews, social and moral compassion	Place-based SSI instruction

49	Ke, L., Sadler, T. D., … (2021). Developing and using multiple models to promote scientific literacy in the context of socio-scientific issues. *Science &Education*.	Covid-19 pandemic	Promote understanding, decision making, and scientific literacy	Multiple scientific learning models
50	Kammerer, Y., Gottschling, S., & Bråten, I. (2021). The role of internet-specific justification beliefs in source evaluation and corroboration during web search on an unsettled socio-scientific issue. *Journal of Educational Computing Research*	Sunscreen containing nanoparticles	Enhancing students' justification beliefs	Case-Web based learning
51	Nida, S. Marsuki, M. F., & Eilks, I. (2021). Palm-oil-based biodiesel in Indonesia: a case study on a socioscientific issue that engages students to learn chemistry and its impact on society. *Journal of Chemical Education.*	Palm oil based biodiesel	Developing scientific literacy and responsible citizens	Case based learning
52	Martini, Widodo, W., … (2021). Improving undergraduate science education students' argumentation skills through debates on socioscientific issues. *Jurnal Pendidikan IPA Indonesia.*	Nuclear powerplant, food preservation, and GMO	Improving argumentation skills	Problem based learning
53	Rietz, L., Jönsson, A., & Lundström, M. (2021). Students' use of justifications in socioscientific argumentation. *Nordina.*	Food package containing polyfluoro-alkyl subtances (PFAS)	Explore students' justification in argumentation	Socio-scientific argumentati-on (SSA) instruction learning
54	Ceyhan, G. D., Lombardi, D., & Saribas, D. (2021). Probing into pre-service science teachers' practices of scientific evaluation and decision-making on socio-scientific issues. *Journal of Science Teacher Education.*	Genetically modified foods	Investigate students'critical evaluation and decision-making practices	Evidence based learning
55	Choi, Y., & Lee, H. (2021). Exploring the effects of implementing a research-based ssi program on students' understanding of ssi and willingness to act. *Asia-Pacific Science Education.*	Artificial food additives	Fostering student's understanding and willingness to act	Socioscientific inquiry based learning (SSIBL)
56	Seiter, K. M., & Fuselier, L. (2021). Content knowledge and social factors influence student moral reasoning about CRISPR/Cas9 in humans. *Journal of Research in Science Teaching.*	CRISPR/Cas9 as genetic modified technology	Promotes the development of moral reasoning	Problem based learning

57	Özturk, N., Altan, B. E., & Turkoglu, A. Y. (2021). Discussing socio-scientific issues on twitter: the quality of pre-service science teachers' arguments. *Journal of Education in Science, Environment and Health.*	Influenza vaccines	Develop argumentation qualities	Case based learning
58	Estigarribia, L., Chalabe, J. K. T., … (2022). Co-design of a Teaching-Learning Sequence to Address COVID-19 as a Socio-scientific Issue in an Infodemic Context. *Science & education.*	Covid-19	Develop on critical thinking and awareness of the responsibilities	Didactic Teaching Learning Sequence (TLS)
59	Han-Tosunoglu, C., & Ozer, F. (2022). Exploring pre-service biology teachers' informal reasoning and decision-making about COVID-19. *Science and Education.*	Covid-19 and social isolation	Investigating informal reasoning and decision making mode	Problem based learning
60	Erman, E. (2022). Using scaffolding Set to help student addressing socio-scientific issues in biochemistry classes. *International Journal of Instruction.*	Impaired biochemical processes in cells	Explain ability	Cooperative learning
61	Sulistiani, Kartimi, & Sahrir, D. C. (2022). E-modules with android appy pie based on socio-scientific issues to improve students' critical thinking skills. *Journal of Education Technology*.	Virus	Develop critical thinking skills	Problem based learning
62	Ha, H., Park, W., & Song, J. (2022). Preservice elementary teachers' socioscientific reasoning during a decision-making activity in the context of COVID-19. *Science & Education.*	Covid-19	Examine students' decision making activity	Multiple perspectives group discussion
63	Dawson, V., & Venville, G. (2022). Testing a methodology for the development of socioscientific issues to enhance middle school students' argumentation and reasoning. *Research in Science and Technological Education.*	Dam water for drinking	Enhance students' argumentation, critical thinking, reasoning, and decision making	Problem based learning
64	Dalaila, I., Widiyaningrum, P., & Saptono, S. (2022). Developing e-module based on socio-scientific issues to improve students scientific literacy. *Journal of Innovative Science Education*.	Immune system	Develop E-modul to improve students' scientific literacy	Case based learning

65	Annisa, D. N., & Subiantoro, A. W. (2022). Mobile augmented reality in socioscientific issues-based learning: the effectives on students' conceptual knowledge and socioscientific reasoning. *Jurnal Pendidikan IPA Indonesia*.	Tobacco	Investigate students's conceptual knowledge and reasoning	Mobile augmented reality in SSI-based learning
66	Şasmazoren, F., Karapinar, … (2022). The Effect of Using Scientific Scenarios in Teaching Socioscientific Issues in Science Course on Students' Logical Thinking Skills. *Kuramsal Eğitimbilim.*	DNA and genetic code	Develop students' logical thinking skills	Inquiry based learning
67	Karakaya, E., & İrez, O. S. (2022). The relationship between understanding the nature of scientific knowledge and reasoning and decision making in socioscientific issues. *Hacettepe Egitim Dergisi*.	Cholesterol levels	Investigate the relationship between uderstanding, konwledge, reasoning, and decision making	Study group cooperative discussion
68	Capkinoglu, E., Leblebicioglu, G., ... (2022). The impact of peer review on pre-service science teachers' written arguments about socioscientific issues related to chemistry. *International Journal of Progressive Education*.	Chemical additives in food	Investigate the impact of peer review on developing students' arguments	Argument driven inquiry (ADI) model learning
69	Karakaş, H. (2022). The effect of socioscientific issues-based discussions on increase of attitudes of primary school teacher candidates towards the life science teaching. *Journal of Turkish Science Education.*	Biotechnological vaccination	Determine the effect of SSI-based activites on the attitudes	SSI-based discussion
70	Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific issues thinking and action in the midst of science-in-the-making. *Science & Education.*	Covid-19	Determine students' perception about Covid-19 science and sociocultural	Case based learning
71	Walker, J. T. (2022). Critical biomaking: socioscientific issues as contexts for life science maker education. In *Proceedings of International Conference of the Learning Sciences, ICLS*	GMO	Develop critical problem solving and the problematizations of practice	SSI-STEM framed biomaker workshop
72	Sparks, R. A., Jimenez, P. C., ... (2022). Using critical integrative argumentation to assess socioscientific argumentation across decision-making contexts. *Education Sciences.*	Food security	Examine students' socioscientific argumentation across decision making	Critical integrative argumentation (CIA) learning

73	Adal, E. E., & Cakiroglu, J. (2022). Investigation of preservice science teachers' nature of science understanding and decision making on socioscientific issue through the fractal model. *Science & Education.*	Healthy meat	Develop decision-making skill and NOS understanding	Case-based learning
74	Bächtold, M., Pallarès, G., … (2023). Combining debates and reflective activities to develop students' argumentation on socioscientific issues. *Journal of Research in Science Teaching*.	GMF	Develop argumentation skills	Collaborative learning
75	Ben-Horin, H., Kali, Y., & Tal, T. (2023). The fifth dimension in socio-scientific reasoning: promoting decision-making about socio-scientific issues in a community. *Sustainability*.	Asthma in community	Develop decision-making and reasoning	İnquiry learning
76	Cebesoy, U. B., & Rundgren, S. N. C. (2023). Embracing socioscientific issues-based teaching and decision-making in teacher professional development. *Educational Review*.	GMO	Develop decision-making	Case based learning
77	Christenson, N., & Walan, S. (2023). Developing pre-service teachers' competence in assessing socioscientific argumentation. J*ournal of Science Teacher Education.*	GMO	Enhance argumentation	Case based learning
78	de Freitas, A. C., do Nascimento, … (2023). Biodiversity and citizenship in an argumentative socioscientific process. *Sustainability.*	Honey bee nutrient	Develop argumentation	Problem based learning
79	Garthwaite, K., Birdsall, S., & France, B. (2023). Exploring risk perceptions: a new perspective on analysis. *Cultural Studies of Science Education.*	İodium fluoroacetate	Enhance awareness	İnqury learning
80	Lee, S. W., & Tran, S. (2023). Students Need More than Content Knowledge To Counter Vaccine Hesitancy. *Journal of Microbiology & Biology Education*.	COVID-19	Develop argumentation	Case based learning
81	Leung, J. S. C., & Cheng, M. M. W. (2023). Prioritizing emotion objects in making sense of student learning of socioscientific issues. *Journal of Research in Science Teaching.*	Obesity	Regulate emotions	Problem base learning

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21st century skills and science achievement among secondary school students: A systematic review

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ABSTRACT
This study systematically analysed, evaluated and synthesised published studies on 21st-century skills and science achievement among secondary school students. By scouring 17 well-known online journal databases, 684 related studies were found. After the three-stage screening process, only 17 research papers were included in the study, which were summarised with respect to research needs, aims/objectives, methods, research instruments, participants, results, and implications for teaching and learning. Majority of these studies investigated the development of 21st-century skills and employed a quasi-experimental method. They used questionnaires developed and validated in previous studies while some studies developed and validated their own instruments, data matrixes, observation tools, and concept assessments. Synthesis of findings revealed that constructivist and constructionist pedagogical approaches such as problem-based learning (PBL), project-oriented PBL, context-based, and inquiry-based learning improved student achievement and supported the development of 21st-century skills. Learning modules used under these approaches were designed to encourage active learning through collaborative problem-solving, where students researched for information, deliberated on issues, and proposed solutions to a real-world problem. Moreover, learning activities emphasised the connections of learning contents to real-life scenarios to understand science concepts and principles. Meanwhile, the impact of gender, school location, educated/non-educated parents' job, and teacher outcome expectancy and efficacy on student achievement and 21st-century skills varied depending on the prevailing conditions that directly influenced learning.

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Introduction

Great technological innovations, particularly in the digital economy, have influenced communications, data and information creation, processing and dissemination, thereby affecting consumer behaviour, knowledge transmission, and political practices. Thus, both government and non-government organisations have called for digital inclusions and to take advantage of such innovations by preparing the present and future workforce to cope with the demands of living in the 21st-century digital economy (Martins-Pacheco et al., 2020). The young generation should be prepared to face the challenges of the rapidly changing society by developing the necessary skills and competencies, commonly called Key Skills or 21st-century skills (Bray et al., 2020). The 21st-century skills and competencies refer to a set of abilities and knowledge that are essential for individuals to thrive in today's rapidly changing, technology-driven world (Finegold & Notabartolo, 2016). Skills and competencies are often used interchangeably, but they have distinct meanings, especially in the context of education and workforce development. Skills refer to the specific abilities or proficiencies that individuals possess to perform tasks or solve problems. They can be technical, such as coding or operating machinery, or soft, such as communications or teamwork, and are often seen as the practical application of knowledge and can be developed through practice and experience. On the other hand, competencies encompass a broader concept that includes skills, knowledge, attitudes, and behaviours necessary to perform effectively in a specific context. They involve the ability to meet complex demands by mobilising various resources, including cognitive skills, interpersonal skills, and ethical considerations (Ananiadou & Claro, 2009; Rychen & Tiana, 2004). For instance, effective communication is a competency that requires knowledge of language, practical skills in conveying messages and the right attitude toward the audience. In this view, while skills are specific abilities to perform tasks, competencies are a combination of skills, knowledge, and attitudes that enable individuals to navigate complex situations effectively. In the past decade, several studies have tried to identify and define the skills students require in the 21st century. These skills were assessed based on various characteristics and abilities (Zorlu & Zorlu, 2021). Even though different sets of skills have emerged, they can be categorised into common groups. In particular, the US National Research Council's Committee on Defining Deeper Learning and 21st-Century Skills reviewed frameworks related to 21st-century skills by analysing eight reports and documents that presented research-based arguments on the skills necessary for success in education, work, and other aspects of life (Pellegrino & Hilton, 2012). The committee clarified the concept of 21st-century skills by identifying them, examining their significance, and exploring ways to develop them among students. It found a variety of skills per report and categorised them into cognitive, interpersonal and intrapersonal competencies. Consequently, the skills considered to be 21st-century skills were classified into cognitive and non-cognitive competencies. The committee argued that the development of these competencies is linked to deeper learning processes that support the transfer of both content and procedural knowledge across different contexts. More importantly, the committee's systematic review of correlational studies revealed that these clusters of skills positively influenced educational, career, and health outcomes, as well as civic participation. Accordingly, the committee recommended conducting more research to understand further the relationships between 21st-century skills and successful adult outcomes and to determine effective methods for teaching and assessing these skills (Pellegrino & Hilton, 2012). Building on this notion, this study examined research published in 17 journal databases to provide information to educators, researchers, school administrators, policy-makers, and other education stakeholders on developing 21st-century skills among learners.

Meanwhile, the demand for the blend of cognitive, interpersonal, and intrapersonal skills has been on the rise as the labour market considers this crucial in the quality of job performance and in learning new skills for complex tasks. Specifically, the shift from lower-skilled, manual labour to knowledge-based occupations has created a demand for competencies that go beyond specific technical skills and are essential for success in modern workplaces (Finegold & Notabartolo, 2016). Nowadays, possessing generic or transversal competencies is an advantage to secure employment. For instance, healthcare professionals work in knowledge-intensive and service-oriented occupations wherein providing quality care necessitates them to demonstrate empathy, effective communication, and problem-solving skills. In order to help workers thrive in the evolving labour market, the mechanism by which these skills can be developed, whether through education, training programmes, or workplace practices, should be explored. As mentioned above, the National Research Council's committee viewed these competencies as malleable dimensions of human behaviour, suggesting that 21st-century skills can be developed and enhanced through experience, education and interventions (Pellegrino & Hilton, 2012). When integrated with curriculum content, 21st-century skills are the behaviours and the thinking processes the students should use to collaborate with others, learn, and improve their understanding of the subject area content (Beers, 2011). The challenge now for all science educators is to develop these skills among students through science content and learning activities. Assefa & Gershman (2012) argued that the nature of the relationship between science content knowledge and 21st-century skills is symbiotic or interdependent. The seamless integration of these two factors will provide students with capabilities in content knowledge and allow creative and innovative thinking. In fact, Partnership for 21st Century Skills (2002), one of the pioneering organisations that proposed the 21st-century skills framework, supports the notion of a thematic and interdisciplinary approach to developing these skills. In line with this, a synthesis of studies is needed to reveal the research trends and themes, and to highlight unexplored or less explored issues about 21st-century skills and science education, particularly student achievement in science. This systematic review outlined how the research needs, aims, and objectives were addressed by the selected studies through their methodologies.

21st Century Skills Frameworks

From the literature, 21st-century skills are a set of skills that students should be equipped with to help them succeed in learning and in navigating today's complex and rapidly changing society (Dede, 2010; Finegold & Notabartolo, 2016; Mishra & Kereluik, 2011; Voogt & Roblin, 2012). Given that students live in a knowledge-based economy amid continuous technological advancements, developing 21st-century skills is an essential curricular element from primary schools to advanced learning institutions to promote lifelong learning. In developing these skills, active learning methodologies that support self-regulated learning should be adopted (Pellegrino & Hilton, 2012) as they not only encourage engagement in learning tasks but also enable students to cope with new challenges and technological changes. Although there are challenges in identifying and defining these 21st-century skills due to differences in perspectives, educational organisations have developed and proposed blueprints to define, characterise, and categorise skills and competencies that comprise the frameworks for 21st-century skills. Specifically, the six relevant frameworks respectively developed by Partnership21 (P21), Assessment and Teaching for 21st Century Skills (ATC21S), North Central Regional Educational Laboratory & Metri Group (NCREL/EnGauge), Organisation for Economic Co-operation and Development (OECD), National Educational Technology Standards for Students (NETS.S/ISTE), and the United Nations Educational, Scientific and Cultural Organization (UNESCO) were the primarily bases of the early review on 21st-century skills done by Dede (2010), Finegold and Notabartolo (2016), Mishra and Kereluik (2011), and Voogt and Roblin (2012). Table 1 presents the common elements across these six frameworks.

Table 1

Comparison of the 21st-century skills frameworks

Skills Domain	ATC21S	P21	NCREL	NETS.S	OECD	UNESCO
1. Creativity & Innovation	✓	✓	✓	✓		
2. Critical Thinking & Problem Solving	✓	✓	✓	✓		
3. Communication & Collaboration	✓	✓	✓	✓	✓	✓
4. Information & Communication Technology	✓	✓	✓	✓	✓	✓
5. Social Responsibility	✓	✓	✓		✓	✓
6. Life & Career	✓	✓				

For descriptive comparison, document analysis was employed to identify the elements common across the six frameworks based primarily on the explicit articulation of the skills. By clustering the skills from each framework, six skills domains were derived and used as the basis of comparison. A framework was only considered to possess an element common with other frameworks if the term for a specific skill domain appeared in the framework document. As such, only ACT21CS and P21 frameworks appeared to be identical with respect to the six skills domains, while the NCREl framework only lacks the life and career domain. The NETS.S framework does not contain a direct term for both social responsibility and life and career domains, while both OECD and UNESCO frameworks have no explicit mention of creativity and innovation, and critical thinking and problem-solving skills. Nonetheless, the framework documents may implicitly include a skills domain by defining or classifying a skill set similar to that of another framework but using a different terminology. As noted by the National Research Council's committee mentioned above, the reports and documents concerning 21st-century skills used different languages to describe the same construct (Pellegrino & Hilton, 2012). Another reason would be defining a terminology encompassing two or more specific skills that directly appear in another framework or may have defined similar terms in different contexts. For example, the NETS.S framework has no direct terminology for social responsibility but highlights technology's legal and ethical use under its digital citizenship domain. Similarly, the OECD framework emphasises creative thinking for innovation that fosters social and economic progress, while the UNESCO framework stresses the role of critical thinking in enabling individuals through a reflective mindset to promote peace, justice, and inclusivity in society. The skills domains shown in Table 1 are not merely derived from the framework documents, but are also supported by the literature, particularly Dede (2010), Finegold and Notabartolo (2016), Mishra and Kereluik (2011), and Voogt and Roblin (2012). Even though this study did not intend for a detailed comparison of the frameworks, a brief discussion provides a foundation for the six skills domains, which served as one of the inclusion criteria for selecting published studies on 21st-century skills and science achievement among secondary school students.

Student Achievement in Science

The US-based National Board for Professional Teaching Standards (2011) defined student achievement as the status of a student's knowledge, understanding, and skills at a specific point in time that is often measured through standardised tests and assessments designed to evaluate curricular mastery in various subjects. Student achievement and student learning are fundamentally different concepts, with the former pertaining to knowledge and skills at a particular point in time, typically assessed through tests. At the same time, the latter encompasses the growth and development of knowledge, understanding, and skills over time. This distinction highlights the significance of the learning process as achievement can indicate what a student knows at a given moment while learning captures the ongoing journey of acquiring and applying knowledge, underscoring the importance of progress and development in education (National Board for Professional Teaching Standards, 2011). According to the OECD (2021), teacher effect, professional development, teaching strategies, school context, and equity and opportunity are the key factors that affect student achievement. The effectiveness of teachers significantly influences student outcomes, wherein skilled teachers can greatly improve students' foundational knowledge and skills, resulting in enhanced academic performance. Also, continuous professional development for teachers is essential as this helps teachers keep abreast with innovative teaching strategies, improving their ability to meet the diverse needs of their students. Teachers who strongly believe in their teaching abilities are more likely to implement engaging and effective teaching strategies, which in turn enhance teaching outcomes (Taştan et al., 2018).

Meanwhile, the school context, which includes school culture, available resources, and support systems, contributes to the overall learning experience by providing an enriching environment and supporting greater student engagement. The educational environment, including both home and school settings, plays a critical role in shaping students' motivation and achievement. Supportive environments that encourage goal setting, self-regulation, and positive reinforcement can foster higher levels of achievement motivation (OECD, 2017). Sibomana et al. (2021) reported that adequate laboratory facilities and instructional materials resources led to better achievement of secondary school students in chemistry. Furthermore, supportive interactions between teachers and students can enhance emotional and cognitive engagement, leading to better academic outcomes (Vilia et al., 2017). As noted by Sibomana et al. (2021), positive teaching strategies can enhance students' motivation and interest in the subject, resulting in improved performance. These suggest that teacher training and professional development should focus on building strong, supportive relationships with students. Conversely, environments that lack support or fail to promote these qualities can lead to declines in motivation, particularly during adolescence, as at this stage, students begin to question the relevance of school and may struggle with their identity and future aspirations, which can be exacerbated by a negative or unsupportive environment, resulting in disengagement from academic pursuits.

Fostering better student achievement requires an equitable educational landscape whereby all students have access to high-quality education and resources regardless of their socioeconomic background or personal circumstances (OECD, 2021). The 2015 Programme International for Student Assessment results revealed the crucial roles of motivation, socioeconomic status (SES), and gender differences in student achievement. Students motivated to achieve their goals tend to exhibit higher self-esteem, cognitive flexibility, and greater study effort, leading to better academic performance. A study by Taştan et al. (2018) found that motivated students were more likely to engage deeply with learning materials, leading to better academic achievement in science. Kumar (2021) found a positive correlation between attitudes toward science and achievement among secondary school students and that their science achievement notably differed across attitude levels. While Sharma and Brahman (2023) found no significant difference in the scientific attitudes between male and female secondary school students, females outperformed the males in science achievement. The study also revealed a significant positive correlation between scientific attitude and achievement in science. These results support the notion that attitudes can influence academic outcomes.

Regarding SES, students from families with higher parental education levels tend to perform better academically (Sibomana et al., 2021), and those from disadvantaged families often report lower levels of motivation compared to their more advantaged peers (OECD, 2017). This lower level of achievement motivation can stem from various challenges, such as limited access to resources, less parental support, and negative school environments, all of which can hinder academic success. Similarly, De Silva et al. (2018) examined the factors that influence students' performance in science within developing countries, drawing on sociological and psychological theories, as well as empirical research, and reported that students from higher SES backgrounds tend to perform better academically due to their access to resources, educational materials, and supportive learning environments. This also involves active parental involvement, whereby parenting styles can have varying impacts on student outcomes and the school environment, wherein teacher quality and the availability of school resources affect students' achievements in science. Individual-level factors, including students' motivation, self-efficacy, and engagement, are also crucial for academic success and can mediate the effects of the identified factors.

In another study, analysing the data from the High School Longitudinal Study of 2009 in the US, Alhadabi and Li (2020) reported that students from lower SES backgrounds and certain ethnic groups, such as Hispanic and African American students, tend to have lower initial grade point average across academic classes. In addition, gender differences in motivation can influence how students approach their studies. For example, girls are often more likely to desire top grades and show concern for future opportunities, while boys may describe themselves as more ambitious. For this reason, girls may focus more on achieving high grades and securing future opportunities, while boys may be driven by a desire to outperform their peers (OECD, 2017). Contrary to this, Taştan et al. (2018) found that gender has no significant impact on achievement, but nationality has, with Russian secondary students performing better than their Iranian counterparts. This signifies that socio-cultural factors affect educational outcomes and calls for inclusive learning environments that cater to the diverse needs of students. Recognising these differences is crucial for educators, as it can inform teaching strategies and support systems tailored to the unique motivations of each gender. Overall, academic achievement in science is influenced by multifaceted factors, including scientific attitudes, SES, teacher efficacy, school climate, and student engagement and attitude toward science. Understanding the interplay among these factors, in the light of developing 21st-century skills, is essential for developing effective strategies, practices, and policies to improve science education and cultivate scientifically literate individuals ready to face the issues and challenges at present and in the future.

Significance of the Study

Analysing published works about what has been done and implemented about integrating 21st-century skills in the classroom setting and developing these skills among students is important in understanding how the 21st-century skills frameworks would practically incorporate into the science curriculum to enhance student learning outcomes. This study hopes to contribute to aligning education standards with appropriate 21st-century skills framework, enhancing student learning engagement through 21st-century skills, improving assessment practices that promote 21st-century skills, and advocating for lifelong learning and equity in education. By aligning science education with the 21st-century skills frameworks, educators can ensure that students learn scientific concepts and develop the skills necessary to apply this knowledge in real-world contexts (Voogt & Roblin, 2012). For instance, the OECD framework emphasises the importance of communication and ethical considerations in science, which can motivate students to explore scientific issues that impact their communities and the world (Ananiadou & Claro, 2009). This can make science more relevant and engaging for students, positively affecting their interest and motivation. Likewise, by adopting assessment practices that go beyond traditional testing to evaluate students' 21st-century skills in science, educators can gain a more comprehensive understanding of student achievement, helping them identify areas where students excel or struggle, and allowing teachers to design targeted interventions that can enhance learning outcomes (Griffin et al., 2012).

The frameworks that encourage the development of metacognitive skills, global citizenship, and social responsibility would enable students to reflect on their learning processes and adapt to new scientific knowledge and technologies, and help address equity issues in science education. Gaining an understanding of diverse perspectives, and the ethical implications of scientific advancements, as guided by these frameworks, can prepare students to engage with global challenges, such as climate change and public health (UNESCO, 2020). Additionally, by developing a continuous learning mindset, educators can help students remain relevant and informed throughout their lives (Voogt & Roblin, 2012). Overall, examining the frameworks in relation to students' achievement in science is essential for enhancing educational practices and outcomes. By developing the capacity to align science education with these frameworks and integrate the skills in the teaching-learning process, educators can create a more engaging, relevant, and equitable learning environment that supports academic achievement, prepares students for the complexities of the modern world, and fosters the development of responsible, informed citizens capable of addressing global challenges.

Objectives

This study evaluated and synthesised research on 21st-century skills and student achievement to identify trends, themes, or ambiguities. Answers to the following questions were sought:

1. What are the research needs addressed by the studies?
2. What are the aims/objectives of the studies?
3. What methodologies are used by the studies to achieve their aims/objectives?
4. What are the instruments used by studies to collect data?
5. What does the analysis of data in the studies reveal?
6. What are the implications of the results of the studies on teaching and learning?

Methods

This study employed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) framework. Published studies were searched by scouring 17 online journal databases: ProQuest Dissertations & Theses A&I, ProQuest Central, Education Database, Scopus, Gale Academic OneFile, Academic Search Complete, APA PsycARTICLES, Social Science Database, Sociology Database, Wiley Online Library All Journals, Psychology Database, SAGE Complete A-Z List, Cambridge Journals 2020 Full Package, JSTOR Arts & Sciences, Arts & Humanities Database, Science Database, and Springer Online Journals Complete. A total of 684 articles were found using the keyword "21st-century skills" or "twenty-first century skills" published from 2012 to 2022. This range of years was purposively selected as official reports on 21st-century skills frameworks were published in 2009 onwards, and, more likely, studies relating to 21st-century skills were published several years after this period. To exclusively select studies prior to the onset of the COVID-19 pandemic, the cutoff year was set to 2022. Searching within the 684 articles using the keyword "science achievement" or "student achievement" with full-text copies yielded 331 results. These 331 articles were further subjected to the first-stage screening process in which selection and exclusion criteria were applied. Figure 1. shows the flowchart of the screening process.

Selection Criteria

To further narrow down the 331 search results, the full-text articles were reviewed for appropriate relevancy in alignment with the study topic. The following criteria were applied in selecting the final journal articles:

1. published in peer-reviewed journals from 2012 to 2022;
2. investigated the development of 21st-century skills or the relationship of these skills with student achievement or factors that affect learning;
3. respondents/participants were Secondary School students (Grades 7 to 12);
4. published in English language or have an official English translation;
5. 21st-century skills were clearly specified; and
6. with clear data presentation and analysis of studied variables.

Exclusion Criteria

On the other hand, the following articles were excluded:

1. published earlier than 2012;
2. published in non-refereed or fictitious journals;
3. no numerical data or ambiguous data analysis;
4. no specific 21st-century skills enumerated/studied;
5. respondents/participants were or mixed with Grades 6 and below;
6. published in non-English language or without official English translation; and
7. 21st-century skills were just mentioned as part of the literature review or discussion.

After the first-stage screening process, a total of 27 journal articles proceeded through the second stage of screening, through which abstracts were reread, and the results of data analysis were scanned. In the final stage of screening, the articles were read in their entirety, and ten studies were excluded due to the following:

1. only a single skill was investigated, although the key phrase 21st-century skills were considerably present in the article;
2. presented only the results of the survey conducted and no substantial discussion on theoretical or practical explanations; and

3. no results or discussion on the implication of the skills investigated to student learning or achievement in science.

After the three-stage screening of the 331 articles generated from the keyword search in the 17 journal databases, only 17 full-text articles were included in this study. These journal articles were summarised, focusing on research needs, aims/objectives, methods, research instruments, participants, results, and implications for teaching and learning. They were also analysed in terms of scope, general sense, similarities, differences, findings, and general notions to evaluate the trends and themes.

Figure 1

The flow chart in searching and screening of published studies

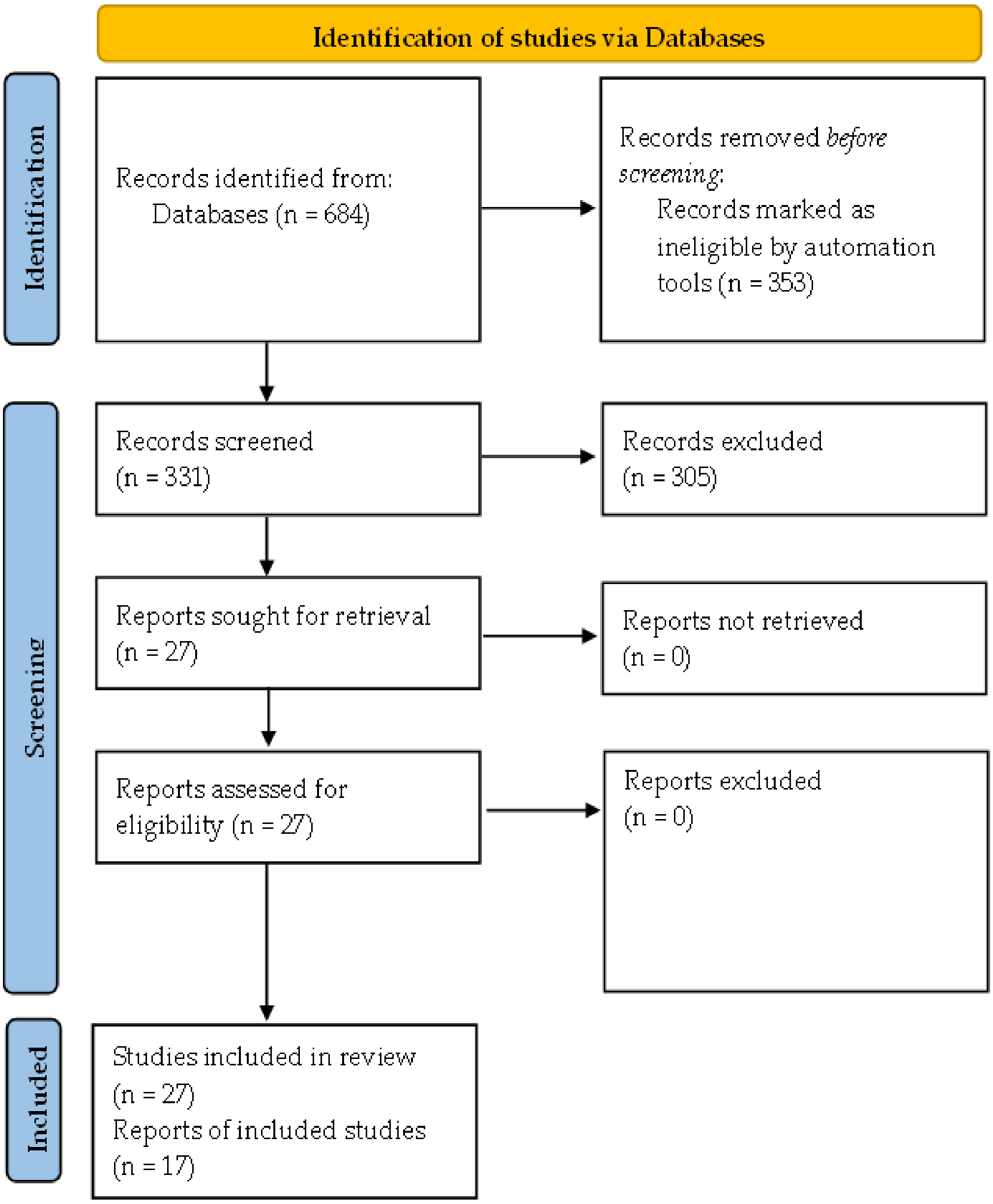

Table 2

The article selection results

Authors	Methods	Country	Grade Level
Arevalo & Ignacio (2018)	Exploratory-Comparative (single group; cumulative linear regression)	Philippines	Grade 10
Asrizal et al. (2022)	Quasi-experimental study (2 groups, post-test only)	Indonesia	Grade 8
Barquilla & Cabili (2021)	Quasi-experimental (2 groups; pre-/post-test)	Philippines	Grade 10
Benek & Akcay (2022)	Nested mixed design (pre/post-test, single group with permanence test and interview)	Turkey	Grade 7
Baran et al. (2021)	Quasi-experimental design (pre/post-test; single group)	Turkey	Grade 10
Diez-Ojeda et al. (2021)	Quasi-experimental (post-test only, single group)	Spain	Ages 15 to 16
Hadinugrahaningsih et al. (2020)	Qualitative (questionnaire, interview)	Indonesia	Grade 10
Han et al. (2021)	Quantitative (SEM – path analysis)	United States	Grades 8 to 12
Huang, et al. (2022)	Mixed-Method (pre-/post-test, interview)	Hong Kong	Junior high school
Kan'an (2018)	Quantitative (Linear regression, student t-test)	Turkey	Grade 8
Khoiri et al. (2021)	Quasi-experimental (2 groups)	Indonesia	Senior Secondary
Kinboon (2019)	Action Research (pre-/post-test)	Thailand	Grade 10
Lay & Osman (2018)	Quasi-experimental (2 groups, pre-/post-test)	Malaysia	Form 4 (Secondary)
Rasul et al. (2016)	Quasi-experimental (single group, pre/post-test)	Malaysia	Lower Secondary
Sekarini et al. (2020)	Mixed-Method (single group)	Indonesia	Grade 8
Semilarski, et al. (2021)	Quasi-experimental (2 groups, pre-/post-test)	Estonia	Grades 10 and 11
Tunkham et al. (2016)	Quasi-experimental (single group, pre-/post-tests)	Thailand	Grade 12

Most of the selected studies (14) were conducted in Southeast and Western Asia, while the remaining three came from Europe and the USA. Eleven of these studies utilised pre-/post-test assessments, of which five only administered such assessments to a single group. The remaining studies used post-test assessment only. As shown in Table 2, the majority of the studies were conducted on specific grade levels, of which six studies were conducted on Grade 10 students, three studies on Grade 8 students, one each on Grade 7 and Grade 12 students, and one study recruited students of ages 15 and 16. The rest of the studies have a mixture of participants based either on age or grade level.

Results and Discussion

Research Needs

Table 3 shows the research needs addressed by the studies. The highest frequency is registered for the development of 21st-century skills, followed by the development of learning materials or the design of learning activities to enhance knowledge or conceptual learning.

Table 3

The research needs identified and addressed by the studies

Research Needs	Frequency
Develop 21st-century skills	13
Develop integrated learning materials (module/learning package)	5
Enhance knowledge acquisition/Conceptual Learning (achievement)	4
Integrate community service learning/socio-scientific issues	3
Assess 21st-century skills	2
Analyse multiple factors affecting learning	1

Research Aims/Objectives

Table 4 presents the aims/objectives specified by the studies. Aligned with the identified research needs, the studies primarily investigated the development of 21st-century skills followed by the development of learning material or design of learning activities and the enhancement of knowledge or conceptual learning.

Table 4

The aims/objectives specified by the studies

Aims/Objectives	Frequency
Develop 21st-century skills	13
Develop integrated learning material (module/learning package)	5
Enhance knowledge acquisition/conceptual learning (achievement)	4
Determine 21st-century skills and science achievement relationship	2
Determine the effect of community service learning/socio-scientific issues	3
Identify factors affecting learning	1
Increase/develop motivation	1

Research Methods

Table 2 and Figure 2 show that nine studies employed a quasi-experimental method, of which five employed a two-group (control and experimental) and four used a single-group design. A mixed-method design was found in two studies, and another three studies utilised modelling/regression analysis. One study employed a qualitative method, one used a nested mixed design, and another was classified as action research. The common skills investigated are critical thinking, problem-solving, collaboration, communication, and information and communication technology (ICT) skills. Three studies considered moral/spiritual values as 21st-century skills (Kan'an, 2018; Lay & Osman, 2018; Rasul et al, 2016), while six studies included creativity in 21st-century skills (Baran et al., 2021; Benek & Akcay, 2022; Hadinugrahaningsih et al., 2020; Kinboon, 2019; Khoiri et al., 2021; Tunkham et al., 2016).

Research Instruments

As presented in Table 5, most of the studies employed instruments adapted from previous studies that established the reliability and validity of the tools for data collection. Other studies included developing and validating instruments, rubrics, observation tools, and concept assessments. Interview forms, reflective journals, and field notes were also used.

Figure 2

Methods employed by the studies

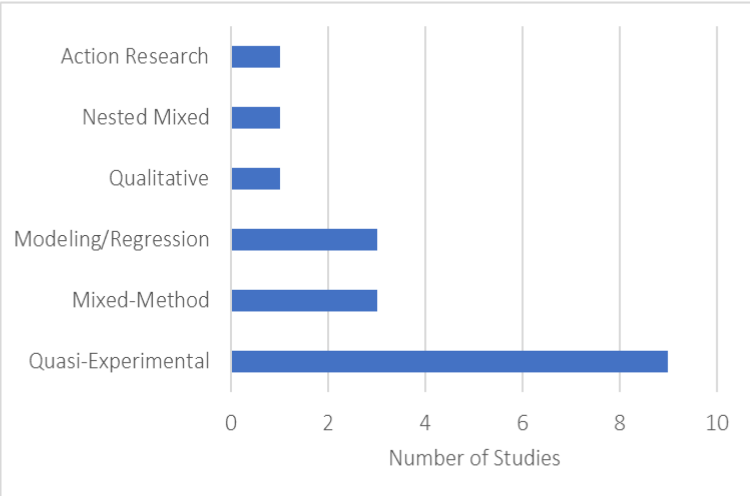

Table 5

Instruments used in the studies

Research Instruments	Frequency
21st CS questionnaire (adapted)	8
Achievement Test (developed/validated)	5
Interview form	6
Observation sheets (attitude, behaviour, collaboration)	5
21st CS questionnaire (developed/validated)	2
Performance sheets (3Cs)	2
Motivation Questionnaire (adapted)	1
Creativity Test (adapted)	1
Rubrics (IMT, Life and Career skills/validated)	1
Creativity Achievement (mind mapping score)	1
Self and Peer Assessment (collaboration)	1
STEM questionnaire- interest and 21st CS (adapted)	1
Achievement test (adapted)	1
Student STEM survey (adapted)	1
Teacher STEM survey (adapted)	1
STEM Knowledge Test (developed/validated)	1
21st Century Skills Rubrics (adapted)	1
Conceptual Learning (critical thinking, communication/developed & validated)	1
Creativity Questionnaire	1
Reflective journal	1
Field notes/informal interview notes	1

Themes and Findings

The 17 studies were analysed and evaluated in their entirety to determine any trends or themes. Based on the aims/objectives, findings, and implications, the studies were classified into Learning Modules, Pedagogical Approaches, and Learning-Related Factors.

Learning Modules

After implementing a learning module or learning activities package, the post-test scores of the group that received the treatment had significantly improved in 21st-century skills. In one study, only the high productivity domain (Lay & Osman, 2018) had improved, while in other studies, spiritual values (Rasul et al., 2016), responsible citizenship, and changeability of scientific knowledge skills (Semilarski et al., 2021), and cross-cultural skills, global awareness, and humanitarianism (Diez-Ojeda et al., 2021) did not have a significant improvement as these skills were less promoted during the intervention. Notably, in the study by Baran et al. (2021), the learning activities that were structured around project-based learning principles, emphasizing hands-on, collaborative, and real-world problem-solving experiences, failed to enhance students' cognitive and innovation skills significantly. This result can be attributed to factors such as the project focus, information access, project design, and time limitation. Since the projects were designed for practical applications and collaboration over fostering deep cognitive engagement and innovative thinking, the activities mainly revolved around executing predefined solutions or utilizing existing knowledge without promoting exploration or creativity, restricting the development of cognitive and innovation skills. In the same manner, students' dependence on the Internet for information can sometimes result in a passive learning experience as it favours searching for ready-made solutions instead of engaging in critical thinking or original problem-solving. Also, the timeframe allotted for project preparation may have been inadequate to compel the students to engage thoroughly with cognitive and innovative processes.

In the game design module MyKimDG by Lay & Osman (2018), students were given opportunities to represent macroscopic concepts and experiences at the sub-microscopic and symbolic level by designing and modifying a PowerPoint game about a Chemistry topic. This allowed students to share their ideas, which may induce cognitive conflict and lead to reconstructing an existing schema, resulting in an improved understanding of concepts and principles. The students also used the PowerPoint game to help their peers who experienced learning difficulties, increasing their self-efficacy as they experienced success. In the learning module developed by Tunkham et al. (2016), the significant difference in the achievement scores of Grade 12 students in favour of the post-test was primarily attributed to the integration of the subject matter (protein) into technology, engineering, and mathematics through the learning activities. Students' creativity and skills in information, media, technology, and life and career skills improved as they tried to solve problems, formulate solutions, and design, create, and improve products for use in the classroom and real-life situations. The students also used technology to search for information necessary for creating products and making product presentations.

In the ICT-based thematic teaching module implemented using the 5E model, Asrizal et al., (2022) reported a significant difference in Grade 8 students' attitudes toward learning in favour of the experimental group. Based on the observation and performance sheet data, this group obtained a higher attitude score than the control group. The same result was noted for communication, creative thinking, and critical thinking skills. Those in the experimental group scored higher in these skills and there was a significant difference between the achievement scores of the two groups in favour of the experimental group. This positive performance can be attributed to active learning by connecting content with real-world contexts (Asrizal et al., 2022). The module encouraged students and motivated them to construct knowledge and experience meaningful learning by conducting investigations, writing reports, and solving problems through critical and creative thinking. Meanwhile, Barquilla and Cabili (2021) implemented an enhanced learning module on gases among Grade 10 students and found that although both control and experimental groups had better scores during the post-test, students in the experimental group doubled their pre-test scores after the treatment. In addition, there was a significant difference in the 21st-century skills of students from both groups in favour of the experimental group (Barquilla & Cabili, 2021).

Pedagogical Approach

Inquiry-based, problem-based, problem-oriented, or context-based learning encouraged students' active learning that led to improved 21st-century skills (Asrizal et al., 2022; Baran et al., 2021; Barquilla & Cabili, 2021; Han et al., 2021; Lay & Osman, 2018; Tunkham et al., 2016; Rasul et al., 2016). Under such approaches, students involved themselves in role-play, argumentation, and other activities as they can relate to the interdisciplinary connections among the learning contents based on common life/real-world scenarios (Semilarski et al., 2021). They took responsibility for their learning, brainstormed to generate solutions, and collaborated and communicated with group members to finish their projects (Baran et al., 2021). While doing the learning activities, the students expressed and defended their ideas and opinions, which helped them adapt and formulate solutions in real-life situations (Tunkham et al., 2016). Furthermore, sharing ideas may induce cognitive conflict, leading to a reconstruction of an existing schema and improving understanding of concepts and principles (Lay & Osman, 2018). In particular, Sekarini et al. (2020) reported that problem-based learning (PBL) with mind mapping improved students' creative thinking and collaboration skills as they systematically expressed their ideas into images, colours, and symbols while working together during experiments and learning activities. Generally, the project-based learning approach allowed students to exchange ideas collaborate with peers, share tasks, and resolve disagreements. The students' active engagement also contributed to developing their autonomous skills, as they learned to work independently and make decisions. As the projects offered the students real-life challenges requiring them to think critically and develop solutions, this enhanced their problem-solving skills as they navigated obstacles, explored various sources of information, and sought practical solutions.

The inquiry-based activities on chemical products produced by the local chemical industry, implemented through the 5E teaching model, favoured the development of critical thinking, self-direction, disciplinary knowledge, self-confidence, interpersonal communication, and organisation management among 15 to 16 years old secondary students (Diez-Ojeda et al., 2021). However, cross-cultural skills, global awareness, and humanitarianism were less observed. Nonetheless, the results were positive, with no significant differences observed between male and female students, both even scoring high in contents. In the context-based learning approach by Semilarski et al. (2021), which was implemented for 1.5 years, the perceived self-efficacy of Grade 10 students toward their 21st-century skills was significantly higher in the experimental group than the control group, particularly in cognitive and problem-solving skills, critical thinking, and mindset for scientific research. On the other hand, there was no significant change in responsible citizenship and changeability of scientific knowledge as these skills were less promoted during the intervention. Huang et al. (2022) integrated community service learning with science, technology, engineering, and mathematics (STEM) so that junior secondary school students may apply human-centred design in proposing a solution to housing problems in Hong Kong. The results of a paired sample t-test indicated that the students significantly improved scores in creative thinking, collaboration, perseverance, and career interest, with career interest and creative thinking as the most improved dimensions (Huang et al., 2022).

After undergoing socio-critical and problem-oriented learning processes, the 21st-century skills expressed the most by Grade 10 students, as measured by an adapted questionnaire coupled with direct observation, were communication and collaboration, social and cultural interaction, and information and ICT literacy (Hadinugrahaningsih et al., 2020). Also significantly observed were creativity and innovation, leadership and responsibility, critical thinking and problem-solving, and flexibility and adaptability. Less significantly expressed skills were self-regulation, productivity and accountability, and media literacy (Hadinugrahaningsih et al., 2020). In the study on the use of project-based learning STEM applications involving waste materials, pre-and post-test scores showed a significant increase in the 21st-century skills of Grade 10 students, including autonomous skills, and cooperation and flexibility were observed, along with their environmental sensitivity levels (Baran et al., 2021). In addition, the analysis of data from structured and semi-structured questionnaires and focus group interviews revealed that the students also developed creativity and increased their levels of concretising science concepts as they brainstormed and planned for the design and carried out their STEM projects (Baran et al., 2021). However, as discussed earlier, there was no significant change in the student's cognitive and innovation skills.

Lower secondary students who underwent project-oriented PBL improved their 21st-century skills, as shown by their pre-test and post-test scores, with the exception of the spiritual values domain (Rasul et al., 2016). The highest increase was observed in high productivity, followed by digital age literacy and, respectively, effective communication and inventive thinking. The inventive thinking improved as the students collaborated in small groups to deliberate on possible solutions to a given problem. This collaboration resulted in an artifact design that supported high productivity skills. Further, technology was used to search for information related to students' tasks, particularly project creation (Rasul et al., 2016). In the same manner, PBL with mind mapping applied in motion and force topics improved the creative thinking and collaboration skills of Grade 8 students as they expressed their ideas in images, colours, and symbols in a systematic manner while working together during experiments and learning activities (Sekarini et al., 2020). Similarly, Grade 7 students' pre-and post-test scores, in favour of the latter, indicated that socio-scientific activities had improved the 21st-century skills of students (Benek & Akcay, 2022). There was no significant difference between the students' post-test and reassessment scores, signifying permanent gains in 21st-century skills. Moreover, there was no significant difference in students' pre-test and post-test scores among the cognitive, affective, and sociocultural sub-dimensions of the 21st-century skills scale (Benek & Akcay, 2022). The same findings were found between the post-test scores and the student's scores in reassessment four months after the intervention.

Learning activities developed using Web 2.0 tools like Pawtoon, Kahoot, and other ICT applications can enhance learning and improve students' achievement (Demirezer & İlkörücüi, 2023). As such, in the study by Kinboon (2019), by implementing information technology media in activity-based teaching, the Grade 10 students' post-test scores became significantly higher than the pre-test scores (Kinboon, 2019). That is, the student's academic achievement, technology skills, creativity and innovation skills, global awareness, and bilingual communication skills were found at high to the highest level. This signified that students' achievement and 21st-century skills improved through the ICT-interdisciplinary pedagogical approach based on STEM education. According to Kinboon (2019), to address real-life problems such as packaging a fermented fish, students used technology to search for accurate and relevant information, collaborated and shared ideas with their groups, and planned and created packaging designs. They also showcased their creativity and innovation in designing a webpage and their global awareness in presenting their outputs to a multi-religious and cultural community. This was also noted in the study by Baran et al., (2021), wherein Grade 10 students used the internet to get information about the process of conducting their STEM projects, and in the study by Rasul et al. (2016) and by Tunkham et al. (2016) in which students used technology to search for information relating to project creation, as well as in the study by Huang et al., (2022) where junior secondary school students learned the internet of things for community service-STEM integration.

Learning-Related Factors

Seven studies included socio-demographic factors in investigating either 21st-century skills or student achievement in science. These are gender, school location, and educated/non-educated parents' job (Arevalo & Ignacio, 2018; Benek & Akcay, 2022; Diez-Ojeda et al., 2021; Han et al., 2021; Huang et al., 2022; Kan'an, 2018; Khoiri et al., 2021). These studies concluded that, with the exception of school location and gender, the rest of the factors have no significant effect on 21st-century skills. In terms of career, Huang et al. (2022) reported that males tend to have a higher interest in STEM careers than females. Using a simple linear regression analysis, Kan'an (2018) revealed that students' 21st-century skills score is a predictor of their science achievement and a higher level of students' 21st-century skills are related to higher interest in physical science, mathematics, and engineering careers as suggested by Yerdelen et al. (2016), drawing from the results of their canonical correlation analysis involving middle school students. Similarly, in the modelling done by Han et al. (2021), the path analysis revealed significant direct effects of teacher self-efficacy on students' STEM knowledge achievement which was also significantly influenced by student STEM attitudes. The teacher outcome expectancy indirectly influences students' STEM knowledge achievement by affecting student STEM attitudes. When mediated by student STEM attitudes, 21st-century skills, and STEM career awareness have indirect effects on STEM knowledge. The teacher outcome expectancy showed a significant direct effect on student STEM attitude, while the teacher self-efficacy showed a significant direct effect on student STEM career awareness. On the other hand, both teacher outcome expectancy and self-efficacy have no significant effects on students' 21st-century skills (Han et al., 2021).

Arevalo and Ignacio (2018) found that although the majority of the Grade 10 students have an average level of science achievement and 21st-century skills, there was no statistically significant difference between male and female science achievement, while Kan'an (2018) found a significant difference between male and female students' 21st-century skills in favour of female students. In the STEM integration study involving a community service-learning model with human-centred design, Huang et al. (2022) found that there was no significant difference between males and females in terms of collaboration, creative thinking, and perseverance, and gender was not significantly related to these factors. Furthermore, Arevalo and Ignacio (2018) reported that technology integration could affect students' skills and achievement. In their study, the performance of high-achieving and low-achieving Grade 10 students in science was attributed to digital age literacy and inventive thinking. According to Kinboon (2019), students used technology to search for accurate and relevant information to solve real-life problems. This was also reported in the study by Baran et al. (2021) and by Rasul et al. (2016) wherein the students used the internet to get information about STEM projects. In the study by Huang et al. (2022), junior secondary school students learned the Internet of Things to design a community service-STEM integrated project.

In the analysis of 21st-century skills of Grade 12 students, Kan'an (2018) found that students from urban areas have statistically higher 21st-century skills mean scores than those from rural areas. Also, there was no significant difference between the jobs of educated and non-educated parents with respect to students' 21st-century skills. Due to cultural restrictions, Jordanian female students usually stay at home; thus, they may focus more on their studies and develop more 21st-century skills than their male counterparts. Moreover, technology and access to information and learning resources may be easier in urban areas, giving an advantage to students in urban schools than in rural schools. The jobs of both educated and non-educated parents have no direct bearing on science achievement as students, given their age, may have developed the ability to study with less parental support (Kan'an, 2018). In investigating the differences in communication, collaboration, creativity, and critical thinking skills, Khoiri et al. (2021) noted that there was no significant difference in the critical thinking of students from experimental and control groups. The researchers claimed that critical thinking is not influenced by students' backgrounds because problem-solving is a complex process that depends on the thinking habits of every individual. On the other hand, students from middle and rural areas have higher creativity and communication than those from urban areas, while students from rural areas have higher teamwork and collaboration than students from the two other groups (Khoiri et al., 2021). The researchers argued that creativity is independent of school background and mainly depends on the individual's previous experiences in producing new ideas. Students from urban areas have an advantage in communications due to access to technology and training (Kan'an, 2018; Khoiri et al., 2021).

Implications to Teaching and Learning

The significance of the 17 studies was grouped in the same manner as their results were classified. That is the implications of learning modules/packages, pedagogical approaches, and learning-related factors to the development of 21st-century skills and the improvement of science achievement.

Learning Modules

According to Usman et al. (2023), instructional materials designed based on the PBL principles promote and improve students' learning and achievement. In particular, the student as a game designer approach to learning chemistry can increase students' achievement, motivation, and 21st-century skills (Lay & Osman, 2018). In addition to integrated/interdisciplinary/thematic design, learning modules should allow students to learn and discover ideas/concepts through activities designed for collaboration and engagement through which they share or defend their ideas and formulate decisions based on their consensus. Learning modules should also encourage students to represent macroscopic concepts and experiences at the sub-microscopic and symbolic levels through learning activities. Learning activities should involve solving problems, formulating solutions, and designing, creating, and improving products for use in classroom and real-life situations (Tunkham et al., 2016). The activities should support students to connect learning contents with the real-world context (Asrizal et al., 2022) expressing and defending their ideas and opinions while constructing new knowledge and learning new skills by active participation in a meaningful learning experience. In line with this, Barquilla & Cabili (2021) suggested that any existing science modules should be evaluated using the 21st-century learning design rubrics to ensure that contents and activities, as well as the module design itself, support the development of 21st-century skills. Furthermore, Diez-Ojeda et al. (2021) argued that the development of the skills is more related to how the teacher implements the activity than the activity itself. Hence, teachers should be trained on how to develop and implement learning activities that would help students develop the targeted skills.

Pedagogical Approach

Pedagogical approaches that support the development of 21st-century skills while improving conceptual learning, such as PBL, project-oriented PBL, inquiry-based learning, and context-based learning, involve collaborative activities among students where they express their ideas and deliberate on possible solutions to a given problem. They also integrate life-related scenarios, along with mind mapping and inventive thinking, in learning activities to help students understand the connections of concepts and principles to real-life context applications (Khoiri et al., 2021). One such strategy is the STEM-based community service-learning model by Huang et al. (2022), which promotes 21st-century skills, particularly creative thinking, collaboration, and perseverance among students by researching and proposing solutions to a community problem. Thus, teachers should emphasise the connections of learning contents to everyday life scenarios and involve students in collaborative problem-solving where they will formulate ideas and express them into images, colours, and symbols in a systematic manner while working together (Sekarini et al., 2020), deliberating on proposed designs for a project that will resolve the given problem (Rasul et al., 2016). Completing such a project would reflect students' level of academic knowledge and 21st-century skills (Kinboon, 2019). Sharing of mental representations of a phenomenon, such as in the mind mapping by Sekarini et al. (2020), allows the students and their teacher to provide constructive criticism and offer suggestions during collaborative learning. This sharing and receiving of feedback enable students to improve their output, clarify thoughts, or correct their misconceptions (Demirçalı & Selvi, 2022). Similarly, teachers should employ socio-critical and problem-oriented learning processes (Hadinugrahaningsih et al., 2020) and socio-scientific STEM activities (Baran et al., 2021; Benek & Akcay, 2022; Hadinugrahaningsih et al., 2020) to help students realise interdisciplinary connections among the learning contents and understand science concepts and principles as they appear in nature, which in turn promotes the development of 21st-century skills.

Learning-Related Factors

Since 21st-century skills are predictors of students' achievement in science, integrating these skills into the science curriculum is beneficial (Kan'an, 2018). By assessing students' level of 21st-century skills at different time points within the academic year, teachers can see the student's progress in acquiring these skills, which may serve as a basis for a pedagogical approach to support student development. As Arevalo and Ignacio (2018) attributed the performance of high-achieving and low-achieving Grade 10 students in science to digital age literacy and inventive thinking, technology should then be integrated with pedagogical instruction to develop 21st-century skills and improve student achievement. Consistent with the literature, the results of path analysis by Han et al. (2021) revealed that teachers' efficacy and success beliefs are strong predictors of students' self-efficacy, motivation, and achievement. Teachers with strong self-efficacy are likelier to implement engaging and effective teaching strategies (Taştan et al., 2018). Hence, teachers should be continuously trained on content and pedagogical strategies. Although socio-demographic factors such as sex, school type, location, and parental involvement may affect the acquisition of 21st-century skills, the impact of these factors on students may vary depending on the prevailing conditions that directly influence learning. For instance, Diez-Ojeda et al. (2021) and Huang et al. (2022) did not find any significant differences in 21st-century skills between male and female students, while Kan'an (2018) found a significant difference in favour of female students. On the other hand, Arevalo and Ignacio (2018) attributed students' science achievement to digital age literacy and inventive thinking, which is supported by Kan'an (2018) and by Khoiri et al. (2021) asserting that access to technology, information, and learning resources may be easier in urban areas, giving advantage to students in urban schools than in rural schools. Teachers then should be aware which among these factors hinder students' progress and which factors support learning so that proper intervention can be given.

Conclusion

Seventeen studies were included in this systematic review, in which 13 primarily investigated the development of 21st-century skills among secondary school students, followed by the development of learning materials to enhance skills and knowledge acquisition. Nine of these studies employed a quasi-experimental method, followed by mixed-method (3 studies), and modelling/regression analysis (3 studies) while the rest are qualitative, nested mixed design, and action research. Eight of the 17 studies adapted a questionnaire on 21st-century skills with established reliability and validity by previous studies. These studies also developed and utilised achievement tests (5 studies), interview forms (6 studies), and observation sheets (5 studies) to attain their objectives. The remaining studies developed and validated their own instruments, rubrics, observation tools, and concept assessments. Reflective journals and field notes were also used.

The studies described teaching and learning modules as integrated, interdisciplinary, thematic, context-based, inquiry-based, inquiry-aided, problem-based, and problem-oriented learning, improved student achievement, and supported the development of 21st-century skills. Likewise, the studies that employed constructivist and constructionist pedagogical approaches have positive effects on student achievement and the development of 21st-century skills. Meanwhile, the studies that include socio-demographic factors in the investigation of either 21st-century skills or student achievement in science involved gender, school location, educated/non-educated parents' job, and teacher outcome expectancy and efficacy, suggested that, with the exception of school location and gender, the rest of the factors have no significant effect on 21st-century skills. Hence, the impact of these factors on students may vary depending on the prevailing conditions that directly influence learning.

Students who develop 21st-century skills such as critical thinking, communication skills, problem-solving, and ethical awareness are expected to be capable of discussing information and formulating creative decisions. They can use technology and social media to communicate effectively and achieve their aims. These notions are supported by inquiry-based, problem-based, problem-oriented, socio-critical/socio-scientific, or context-based learning approaches that encourage active learning where students involve themselves in role-play, argumentation, and other collaborative learning activities. Students are actively and pro-actively participating in knowledge construction and skills acquisition as they realise the interdisciplinary connections among the learning contents with real-life scenarios and research for information, deliberate on issues and propose solutions to a real-world problem. These entail the integration of chemistry topics with science, engineering, and technology, along with appropriate ICT, through learning activities in order to improve student achievement and support the development of 21st-century skills. Thus, teachers should be trained on how to develop and implement interdisciplinary/thematic learning activities that would help students develop the targeted skills and improve achievement.

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Research trends in modern physics education in Turkey

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ABSTRACT
This research involves a content analysis of studies on modern physics education conducted in Turkey between 2000 and 2023. In this context, 273 studies accessed in full text from different databases were examined. The studies were evaluated using the "Modern Physics Education Publication Classification Form" and analyzed using the content analysis method. According to the research findings, studies in the field of modern physics education in Turkey were mostly conducted between 2010 and 2020. The study objectives varied and quantitative research designs were preferred more. Purposive sampling was predominantly employed in the studies, with most samples consisting of high school and undergraduate students. The studies generally included sample sizes ranging between 31 and 100 individuals. The duration of the studies varied between 0 and 8 weeks. To enrich the data, various data collection tools were used. Frequency, percentage, and t-tests were commonly used for quantitative analyses, while content analysis was frequently preferred for qualitative analyses. Although different validity and reliability methods were used in the studies, not enough information was provided on this issue. The results of the studies examined have shown that there are positive developments as well as negative situations in modern physics education. However, these results were not sufficiently supported by the literature in the discussion section. Based on the findings of this research, it was recommended to use different analytical methods in modern physics education research, increase the sample size, enrich methods and intervention examples.

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Introduction

Modern physics began with Max Planck's blackbody radiation, followed by Einstein's theory of relativity, Heisenberg's uncertainty principle, De Broglie's matter wave, Schrödinger's wave mechanics, the Pauli Exclusion Principle, and Dirac equation. Modern physics is a subfield of physics that examines microscopic particles in terms of probability, observability, operators, eigenvalues, expected values, and wave functions (Beiser, 2003). Modern physics, which studies the behaviour and interactions of atoms, nuclei and fundamental particles within the scope of quantum theory, has brought about an understanding of uncertainty, probability and non-locality in the foundations of physics (Mufit et al., 2024; Müller & Wiesner, 2002). This understanding initiated the process of reconsidering the "fact" that each physical quantity in classical physics is defined independently of the environment, the subject, the observer and the measuring device, contains clear information and has a fixed and definite value up to a certain speed limit (Ayene et al., 2011; Pospiech, 2000). This process has enabled the development of theories in modern physics but has also opened up new ways of thinking and new possibilities in chemistry, biology, engineering, medicine and many branches of science (Stadermann & Goedhart, 2020). This enabled the development of many novel technologies, such as lasers, LCD and plasma screens, MRI and X-ray computed tomography devices, thermal cameras, nuclear reactors, superconductors, transistors, cell phones, and electron microscopes (Bouchée et al., 2021; Serway & Beicher, 2007). Additionally, modern physics also promises many future technologies, such as quantum computing, quantum computers, and quantum internet technology (Vermaas, 2017). Understanding all these rapid developments is important not only for physicists but also for engineers, biologists, chemists, philosophers, and everyone else. Therefore, there is a need for meaningful learning and teaching of modern physics (Bonacci, 2018). However, modern physics is a difficult, abstract and complex subject for students to learn and also a challenging subject or field for teachers to teach, as it covers microscopic particles, uncertainty, and probability states (Alstein et al., 2023; Çalışkan, 2002). However, the inclusion of more advanced mathematical equations in modern physics compared to classical physics (Abhang, 2005), the incomplete understanding of its philosophy (Bouchée et al., 2021), and the similarity of its concepts to classical physics (Stadermann & Goedhart, 2020) make the teaching-learning process of modern physics more challenging. According to Levrini and Fantini (2013), the main reason for these challenges is the failure to abandon the classical physics mindset instead of the unique thinking style of modern physics. Stadermann et al. (2019), who believe that these difficulties may stem from the modern physics curriculum, examined the physics curriculum of 15 countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom). They concluded that these curricula do not adequately emphasise the philosophy of modern physics, ignore the historical development of science, lack interdisciplinary understanding, and inappropriately treat certain concepts contrary to the nature of modern physics provide a couple of examples. Additionally, the relevant literature has found that textbooks and traditional teaching methods (Giliberti & Organtini, 2021; Kalkanis et al., 2003), the examples and analogies in textbooks (Levrini & Fantini, 2013), the persistence of the classical physics perspectives, and the emphasis on mathematical problem-solving (Baily & Fingelstein, 2010), teachers' inadequate subject mastery (Bouchée et al., 2021), oversimplify modern physics and lead to conceptual misunderstanding in modern physics. All these challenges contribute to conceptual misconceptions when learning modern physics (Müller & Wiesner, 2002; Obbo et al., 2024; Vakarou et al., 2024). Some of the prominent conceptual misconceptions highlighted in the relevant literature include perceiving wave functions as mechanical waves, explaining De Broglie waves with basic wave knowledge, explaining the wave-particle duality of electrons according to the Bohr Atom Model, considering the Heisenberg Uncertainty Principle as a measurement error stemming from external influences, simplifying modern physics mathematics to a basic level, and misinterpreting modern physics mathematical systems and algorithmic steps (Ayene et al., 2011; Dubson et al., 2009; Mannila et al., 2002; Müller & Wiesner, 2002; Sadaghiani & Munteanu, 2015; Vokos et al., 2000). Taber (2005) identified conceptual misconceptions about believing that quantum spin in modern physics represents actual motion. Additionally, Didiş et al. (2014) identified conceptual misconceptions among students in providing intuitive responses in explaining light, energy and angular momentum concepts and establishing contexts. In their study conducted with high school students, Rodriguez et al. (2020) also found that 40% of the students were still attempting to explain the particle nature of light in the photoelectric effect with classical physics. The most crucial step to eliminating all these conceptual misconceptions is to update the modern physics curriculum (Çalışkan, 2002). Michelini et al. (2016) strongly emphasize that the modern physics curriculum should be prepared and implemented separately rather than as a subfield of physics. Alongside updating the modern physics curriculum, the teaching-learning process should also be organised and managed in a way that can handle modern physics knowledge effectively (Bezen et al., 2021; Michelini et al., 2014). Teachers should facilitate the learning process by creating an appropriate learning environment rather than directly delivering modern physics knowledge. The relevant literature suggests various practices, materials, teaching methods, and techniques for learning or teaching modern physics. These include strategies for active learning and virtual laboratories (Mufit et al., 2024; Müller & Weisner, 2002), discussion and experimentation teaching methods (Baily & Finkelstein, 2015; Kersting et al., 2023), using simulations and animations in cooperative learning (Bungum et al., 2015), conducting theory-oriented experiments and discussing their results (Alstein et al., 2023; Bitzenbauer & Meyn, 2020), technology-supported active learning simulations (Swandi et al., 2020), e-learning based-STEM (Yusuf et al., 2018) problem-solving teaching methods, fostering mathematical thinking through analogies, and using different visual elements for the same content (Erol & Oflaz, 2020), and analysing multiple visual elements and original texts related to the topic (Levrini & Fantini, 2013). Other recommended practices include inquiry-based learning, 5E learning cycles, cooperative learning, and using interactive videos (Obbo et al., 2024; Rodriguez et al., 2020).

Aspden et al. (2016) underline the importance of highlighting modern physics concepts more frequently and adopting explanatory approaches instead of classical physics thinking and speaking styles to understand the true nature of modern physics. Doyan et al. (2021) support this idea and emphasize the importance of adopting a historical approach in the learning and teaching process of modern physics to instil in students the notion that modern physics has its own unique characteristics. Dekarchuk (2023) and Gilberti and Organtini (2021) who share similar views, emphasise that in order to understand modern physics, mathematical formulas, operations, experiments and interdisciplinary understanding should be included without trying to stick to models based on daily experience. Bunge (2003) suggests that there is no single common approach to teaching modern physics and highlights the need to sometimes continue from a historical development process perspective and at other times from the lack of consensus in current debates. Thus, students become intrinsically motivated towards modern physics and develop an understanding of "Why should I learn modern physics?" in their lives (Bungum et al., 2015). In order for all these elements and understandings stated for modern physics to be sustainable and developable, the "International Modern Physics and Education Research Seminar Series Symposium (IMPRESS)" emphasizes that studies conducted on modern physics education should be examined and trends should be determined (Kersting et al., 2023). Thus, the problems experienced in the curriculum, learning outcomes, content, learning-teaching process, technologies and daily life practices of modern physics can be determined, and appropriate solutions and different understandings can be developed. In this direction, when the content analysis studies conducted for modern physics education are examined, it is striking that the research is limited. Krijtenburg-Lewerissa et al. (2017) reviewed 74 articles on quantum physics published between 1997 and 2016, available in Scopus, Web of Science, and ERIC indexes. They analysed the articles in detail under students' learning difficulties, data collection tools, teaching strategies used, research methods, multimedia activities, and applications. They determined that students continued to interpret quantum physics with a classical physics understanding, and the data collection tools did not reflect the entirety of quantum physics. Furthermore, they found that the research studies were predominantly designed based on qualitative research designs, a non-mathematical conceptual understanding was mostly adopted in quantum physics education, and multimedia visuals were primarily used for undergraduate students. However, no study examining modern physics education in Turkey has been undertaken. There is a need for a comprehensive and holistic review of studies conducted in the field of modern physics education in Turkey. The results obtained from the research would help curriculum developers, teachers and students access the necessary information from a single source. Thus, it would serve as a guide in creating learning environments for students to develop a modern physics identity during the teaching-learning process of modern physics. Additionally, enabling students to acquire the skills of understanding modern physics theories in detail, engaging in discussions on their implications, providing necessary information, and interpreting their numerous problems may contribute to the understanding that "modern physics is important for everyone." The research results may encourage more high-quality and comprehensive studies to address the shortcomings in the field. In this context, the purpose of this research is to combine the results obtained from independent studies on modern physics education in Turkey. Accordingly, the main research problem was formulated as "How is the current state of the studies conducted in modern physics education shaped in Turkey?" In this respect, responses were sought to the following research questions:

1. What is the distribution of studies conducted in modern physics education according to their descriptive information regarding the research identity (e.g., publication type, publication year, publication language, and database)?
2. What is the distribution of studies conducted in modern physics education by their subject areas?
3. What is the distribution of studies conducted in modern physics education by their objectives?
4. What is the distribution of studies conducted in modern physics education by research design?
5. What is the distribution of studies conducted in modern physics education by sample types, sample levels, and sample sizes?
6. What is the distribution of studies conducted in modern physics education by intervention duration?
7. What is the distribution of studies conducted in modern physics education by data collection techniques\tools and types of data analysis?
8. What is the distribution of studies conducted in modern physics education by types of validity and reliability?
9. How have the results, discussions, and recommendations of studies conducted in modern physics education been shaped?

In this context, the research provides significant contributions to the field of physics education in terms of examining the studies conducted within the scope of modern physics education and determining the trends. The methodological contribution of the research is the development of the publication classification form in the research and the holistic and in-depth examination of the studies according to this form. It is thought that the detailed description of the findings obtained in the research will contribute to teachers, researchers, programme development specialists and will guide the development of different applications, materials, activities, etc. in the learning-teaching process of modern physics. The results obtained from the research will contribute to the understanding of "Modern physics is important for everyone" in recognising/defining the scope of modern physics in detail, discussing its inferences, providing information, and interpreting its problems. It is also thought that the suggestions regarding the research results will guide more qualified and comprehensive studies in eliminating the deficiencies in modern physics education.

Method

Research Model

This research is a bibliometric study examining studies conducted within the scope of modern physics education in Turkey. Bibliometrics is the process of examining journal articles, conference proceedings, book chapters and various publication types on any subject, discipline or field with quantitative and descriptive statistical analyses (Irwanto & Rini, 2024). Bibliometrics is divided into descriptive, evaluative and citation analyses (Kırık, 2024). Descriptive bibliometrics involves revealing the distribution and trends of the relevant literature according to years, subjects, languages etc. with descriptive statistics; evaluative bibliometrics involves revealing the interactions between authors, publications and countries, the interaction of authors and citation status and providing the measurement of the results (Yelman & İnal, 2024); and citation analysis on the one hand is the statistical analysis of the citations cited to the published studies (Kırık, 2024). In this direction, the method of the research was determined as descriptive bibliometrics.

Sample

A purposive sampling method (Yıldırım & Şimşek, 2006) was employed in selecting the sample of 273 studies for the research based on the following criteria:

- Studies conducted within the scope of education in Turkey
- Studies conducted with sample(s) selected in Turkey
- Studies conducted between 2000 and 2023
- Studies reported as theses, articles, or conference papers
- Studies including the following keywords either in English or Turkish: "modern physics, quantum physics, quantum mechanics, photoelectric event, Compton event, De Broglie matter wave, Heisenberg uncertainty principle, blackbody radiation, Einstein theory of relativity, Lorentz transformations, double slit experiment, ionization energy, Pauli exclusion principle, Michelson Morley experiment, tunnelling event, atom, atomic models, atom concept orbital, electromagnetic waves, x-ray radioactivity, nuclear energy, nuclear reactions"

Data Collection Tools

The Modern Physics Education Publication Classification Form (MPEPCF), developed during the research process was used to collect data in the study. The forms of studies conducted within the scope of the publication classification form were examined when developing the MPEPCF, and a new publication classification form was developed based on the purpose of this research. MPEPCF includes descriptive information about the research identity, topic, purpose, type, method, study group or sample, data collection tools, intervention duration, data analysis methods, validity and reliability methods, discussion, conclusions, and recommendations. For its validation, MPEPCF was presented to an expert in physics education, two experts in curriculum development and instruction, and two experts in measurement and evaluation. A draft form was created based on the expert opinions. Subsequently, the researchers conducted a pilot application of the draft form in 12 randomly selected studies. After the pilot application, to enhance the reliability of the form, consistency among researchers was examined. Necessary revisions and additions were made based on the shared opinions of the experts, and the final version of the form was created.

Data Collection

The data collection for the research began in April 2023 and continued until the completion of the study in December 2023. Priority was given to including newly published studies in the data. Studies included in the research were selected from the YOK National Thesis Centre, Tübitak Ulakbim, Sobiad, Doaj, Tei, Elsevier, Ebscohost-ERIC, Scopus, SpringerLink, Taylor & Francis, and Google Scholar databases. Studies on modern physics education were searched in databases using the keywords determined in Turkish and English. As a result, 303 studies were retrieved. However, sufficient information could not be obtained about the contents of 12 theses, 10 articles, and 7 conference papers due to their inaccessibility or unavailability in full text. In this context, attempts were made to contact the relevant authors, whereby the full texts of 283 studies were obtained. Upon examining the contents of the accessed studies, it was determined that 10 studies were not within the scope of modern physics education, and therefore, 273 studies were included in the research. However, some studies had the same title as conference papers, theses, or articles. To avoid repetition, only the article versions of the studies were included in the research.

Data Analysis

In the research, content analysis, one of the qualitative data analysis techniques, was used in the analysis of the data of the studies included in the research. Content analysis enables the objective and systematic determination of the explicitly stated characteristics of studies that cannot be directly measured or observed, allowing for inferences to be made about them (Cavitt, 2006). According to Yıldırım and Şimşek (2006), the primary goal in content analysis is to bring together similar data within the framework of specific concepts and themes, interpreting them in a way that the reader can understand. Thus, it serves as a guide for researchers in determining trends and areas of interest in the field. In this context, all the research studies included in this study were initially saved in data storage in PDF format. Subsequently, on a Microsoft Excel worksheet, the author names and study titles were entered in rows, while in columns, the main and subheadings of MPEPCF (e.g., database, publication year, publication language, subject area, purpose, data collection tool, and database) were determined and classified and a template was created. Studies were examined one by one according to this template and recorded in a Microsoft Excel worksheet. However, at these stages, it was determined that some studies included insufficient information, especially regarding the research methods, types of data collection tools, and data analysis methods. After all these processes, the data for each study were coded in a Microsoft Excel sheet and analysed using the SPSS statistical software package.

Validity and Reliability

To ensure the validity of the research, the process followed in each part of the study was explained in detail. To ensure coding reliability during the data analysis process, researchers independently reviewed the studies and created themes and codes. Meetings and discussions were held when there were differences between the two coders in the process of comparing the codes. When necessary, expert opinions (one in Curriculum and Instruction, one in Physical Education, and one in Measurement and Evaluation) were sought to reach a consensus. The coding reliability calculated using Huberman and Miles's (2002) formula (Reliability = Consensus / Consensus + Disagreement x 100) was 91%. Subsequently, the data obtained for each study were tabulated and presented in the findings section. Finally, the findings were presented again to the same experts and reported based on the feedback received.

Ethical Measures

For the ethical measures of the research, initially, an application was submitted to the Social and Humanities Ethics Committee of a state university in Turkey, and the research was deemed ethically appropriate with decision No. E-74009925-604.01.02-750991. Further, to avoid data redundancy in studies conducted within the scope of modern physics education, each reviewed study was coded as S1, S2...S273.

Findings

The findings obtained in the research are presented in order according to the research questions and tabulated in the form of frequency and percentage values.

Distribution of Studies Conducted in Modern Physics Education According to Descriptive Information Regarding the Research Identity

In this section of the research, information regarding studies, such as database, publication type, publication language, publication year, and years, was examined, leading to the findings presented in Table 1.

Table 1

Distribution of studies by publication years and databases

Database	f	%	Database	f	%
Tübitak Ulakbim	114	41.8	Springerlink	6	2.2
YOK	75	27.5	Taylor & Francis	5	1.8
ERIC	30	11.0	Doaj	4	1.5
Scopus	22	8.1	Sobiad	2	0.7
Science Direct	7	2.6	Tei	1	0.4
Google Scholar	7	2.6			

As seen in Table 1, 273 studies were conducted within the scope of modern physics education in Turkey and published in various databases. Most studies (f = 114) were published in Ulakbim, followed by YOK (f = 75), ERIC (f = 30), and Scopus (f = 22) databases, respectively.

Table 2

Distribution of studies by types of studies

Type	f	%
Article	189	69.2
Master's thesis	54	19.8
Doctoral dissertation	21	7.7
Conference paper	9	3.3

As seen in Table 2, the majority of studies on modern physics education were articles (f = 189), followed by Master's theses (f = 54) and doctoral dissertations (f = 21), respectively.

Table 3

Distribution of studies by publication language

Publication Language	f	%
Turkish	188	68.9
English	85	31.1

According to Table 3, the studies were conducted in Turkish (f = 188) and English (f = 85) languages.

Table 4

Distribution of subject areas of studies by year

Year	Subject Areas	f	%
2000	Compton effect (f=1)	1	0.4
2001	Compton effect (f=1), Photoelectric effect (f=1), Theory of relativity (f=1), Heisenberg uncertainty principle (f=1)	4	1.5
2002	Photoelectric effect (f=1), Heisenberg uncertainty principle (f=1), Double slit experiment (f=1), Radiation (f=1), Quantum mechanics (f=1)	5	1.8
2003	Blackbody light (f=1), X-Ray (f=1)	2	0.7

2004	Photoelectric effect (f=2)	2	0.7
2005	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=2), Compton effect (f=1), Doppler effect (f=1), Theory of relativity (f=2), De Broglie matter waves (f=1)	7	2.6
2006	De Broglie matter waves (f=1), Blackbody Radiation (f=1)	2	0.7
2007	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=2), De Broglie matter waves (f=1), Laser (f=1)	4	1.5
2008	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=1), Theory of relativity (f=2), Heisenberg uncertainty principle (f=1)	4	1.5
2009	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=1), Compton effect (f=2), Photoelectric effect (f:1), Electromagnetic wave (f=1), Theory of relativity (f=2), Radiation (f=1), Tunneling effect (f=1)	9	3.3
2010	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=1), Photoelectric effect (f:5), Heisenberg uncertainty principle (f=1), Double slit experiment (f=1), De Broglie matter waves (f=2), Blackbody Radiation (f=1), Radioactivity (f=1), Radiation (f=1), X-Ray (f=2)	15	5.5
2011	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f =2), Compton effect (f=2), Photoelectric effect (f:1), Doppler effect (f=1), Electromagnetic wave (f=1), Theory of relativity (f=3), Ionization energy (f=1), Double slit experiment (f=1), Blackbody Radiation (f=2), Radioactivity (f=3), Pauli exclusion principle (f=1), Energy levels (f=2)	20	7.3
2012	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=2), Photoelectric effect (f:2), Nuclear chemistry (f=1), Electromagnetic wave (f=1), Theory of relativity (f=2), De Broglie matter waves (f=2), Michelson Morley experiment (f=1), Pauli exclusion principle (f=1)	12	4.4
2013	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=1), Compton Effect (f=1), Photoelectric effect (f:1), Orbital (f=1), Theory of relativity (f=2), Heisenberg uncertainty principle (f= 3), Double Slit Experiment (f=1), Radioactivity (f=1), Radiation (f=1), X-Ray (f=1)	13	4.8
2014	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=4), Compton Effect (f=1), Photoelectric effect (f:3), Electromagnetic wave (f=1), Theory of relativity (f=2), Heisenberg uncertainty principle (f) =3), Double slit experiment (f=1), De Broglie matter waves (f=1), Blackgrass light (f=1), Spin (f=1), Nuclear energy (f=1), Tunneling event (f=1))	20	7.3
2015	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=2), Compton Event (f=2), Photoelectric event (f:5) Orbital (f=2), Electromagnetic wave (f=2), Theory of relativity (f=2), Heisenberg uncertainty principle (f=3), Double slit experiment (f=3), De Broglie matter waves (f=2), Blackbody Radiation (f=2), Radioactivity (f=3), Radiation (f=1), Quantum mechanics (f=2)	31	11.4
2016	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f =4), Compton effect (f=1), Photoelectric effect (f:2), Theory of relativity (f=2), Heisenberg uncertainty principle (f=3), Blackbody Radiation (f=1), Radioactivity (f=5), Pauli exclusion principle (f=1), Quantum number (f=1), Quantum mechanics (f=3), Redshift (f=1), X-Ray (f=2), Tunneling effect (f=1)	27	9.9
2017	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=4), Compton effect (f=1), Photoelectric effect (f:1), Theory of relativity (f=2), Ionization energy (f=1), Heisenberg uncertainty principle (f) =1), De Broglie matter waves (f=4), Blackbody Radiation (f=1), Radiation (f=1), Energy levels (f=1), Quantum mechanics (f=1), X-Ray (f= 1), Particle accelerator (f=1)	20	7.3

2018	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=1), Compton effect (f=5), Photoelectric effect (f:1), Orbital (f=1), Electromagnetic wave (f=2), Theory of relativity (f) =2), Ionization energy (f=1), Radioactivity (f=1), Pauli exclusion principle (f=1), Quantum number (f=2), Harmonic oscillator (f=1), Quantum paradigm (f=1)	19	7.0
2019	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f=4), Compton effect (f=4), Photoelectric effect (f:3), Electromagnetic wave (f=3), Theory of relativity (f=4), Heisenberg uncertainty principle (f=3), De Broglie matter waves (f=3), Blackbody Radiation (f=1), Radioactivity (f=2), Radiation (f=2), Energy levels (f=1), Quantum mechanics (f=1), Quantum paradigm (f=1), X-Ray (f=1)	33	12.1
2020	Photoelectric effect (f:1), Doppler effect (f=1), Theory of relativity (f=1), Heisenberg uncertainty principle (f=2), Radioactivity (f=1), Pauli exclusion principle (f=1), Quantum number (f=1)	8	2.9
2021	Electromagnetic wave (f=1), Relativity (f=2), De Broglie matter waves (f=1)	4	1.5
2022	Atom (e.g., Atom models, Atomic structure, and Atom concept) (f =1), Photoelectric Effect (f:1), Electromagnetic wave (f=1), Heisenberg uncertainty principle (f=2), De Broglie matter waves (f=1), X-Ray (f=2)	8	2.9
2023	Compton effect (f=2), Photoelectric effect (f:1)	3	1.1

When Table 4 is examined the most studies were conducted in 2019 (f = 33), followed by 2015 (f = 31) and 2016 (f = 27). The years in which the least studies were conducted were between 2000-2009. The number of studies has decreased in the last five years. The most preferred topic in the studies was the atom (atomic models, atomic structure, concept of the atom, etc.), followed by the photoelectric effect, Theory of Relativity, nuclear energy and the Compton Effect respectively. In recent years, different topics such as the Pauli Exclusion Principle, electromagnetic waves, quantum mechanics, Quantum number and the harmonic oscillator have also been included.

Distribution of Studies Conducted in Modern Physics Education by Subject Areas

In this section of the research, findings related to the subject areas of studies conducted in modern physics education are discussed and presented in Table 5.

Table 5

Distribution of studies according to their frequency of topic areas

Code	f	%
Atom (e.g., Atom models, Atomic structure, and Atom concept)	99	24.4
Photoelectric effect	34	8.4
Theory of relativity (Special and General Relativity)	34	8.4
Nuclear energy	33	8.1
Compton effect	28	6.9
Heisenberg uncertainty principle	27	6.7
Radioactivity	22	5.4
De Broglie matter waves	20	4.9
Electromagnetic waves	15	3.7
Blackbody Radiation	12	3.0
X-Ray	11	2.7

Radiation	10	2.5
Quantum mechanics	9	2.2
Double slit experiment	9	2.2
Orbital	6	1.5
Energy level	5	1.2
Quantum number	5	1.2
Pauli exclusion principle	5	1.2
Tunneling effect	4	1.0
Ionization energy	3	0.7
Doppler effect	3	0.7
Spin	2	0.5
Nuclear chemistry	2	0.5
Quantum paradigm	2	0.5
Particle accelerator	2	0.5
Laser beam	1	0.2
Michelson Morley experiment	1	0.2
Redshift	1	0.2
Harmonic oscillator	1	0.2

As observed in Table 5, most studies focused on atoms (e.g., atom models, atomic structure, and atom concept) (*f* = 99), followed by the Photoelectric effect (*f* = 34), Theory of relativity (*f* = 34), Nuclear energy (*f* = 33), Compton effect (*f* = 28), and Heisenberg uncertainty principle (*f* = 27). The least studied topics were laser beams, the Michelson-Morley experiment, the red shift, and harmonic oscillators.

Distribution of Studies Conducted in Modern Physics Education by Their Objectives

In this section, the objectives of studies conducted in modern physics education are identified, and the findings are presented in Table 6.

Table 6

Distribution of studies by their objectives

Theme	Code	f	%
Instructional Method and Technique Effectiveness	Computer-assisted instruction	19	7.0
	Constructivist approach	11	4.0
	Cooperative learning	9	3.3
	Argumentation	7	2.6
	Experimentation	6	2.2
	Writing for learning	5	1.8
	Blended (hybrid) learning	4	1.5
	Analogy	4	1.5
	Problem-based	2	0.7
	Drama	2	0.7
	Educational trip	2	0.7
	Peer teaching	2	0.7
	Conceptual map	2	0.7
	Roleplay	1	0.4
Material Effectiveness	Simulation/animation	5	1.8
	Conceptual change text worksheets	4	1.5
	3D drawing	4	1.5

	Modelling	3	1.1
	Pictures (photographs, caricatures, and more)	2	0.7
	Marbling art	1	0.4
Test-Scale-Questionnaire Development/ Adaptation	Multiple-choice achievement test	7	2.6
	Two-stage achievement test	2	0.7
	Three-stage achievement test	2	0.7
	Four-stage achievement test	1	0.4
	Scale and questionnaire development/ adaptation	3	1.1
Curriculum	Curriculum development	5	1.8
	Curriculum review or evaluation	3	1.1
Textbooks	Physics, chemistry, and science textbook review or evaluation	11	4.0
Cognitive Characteristics	Mental model	20	7.3
	Knowledge level	20	7.3
	Conceptual understanding	15	5.5
	Conceptual misconception	10	3.7
	Problem-solving skills	9	3.3
Affective Characteristics	Perception	10	3.7
	Awareness	5	1.8
	Attitude-anxiety relationship	3	1.1
	Interest-motivation	2	0.7
Situation Determination	General views on the subject	38	13.9
	Metaphor	8	2.9
Literature Review	Review	2	0.7
Structural Equation Modeling	-	2	0.7

As shown in Table 6, the main foci of the studies were the themes of instructional method and technique effectiveness, material effectiveness, test-scale-questionnaire development/adaptation, curriculum, textbook, cognitive and affective characteristics, situation determination, literature review, and structural equation modelling. In the theme of instructional method and technique effectiveness, the primary focus was on the effectiveness of computer-assisted instruction (f = 19) and the constructivist approach (f = 11), followed by cooperative learning (f = 9), argumentation (f = 7), and experimentation (f = 6) methods, respectively. Within the scope of material effectiveness, the effectiveness of simulation/animation (f = 5), conceptual change text worksheets (f = 4), and 3D drawings (f = 4) in learning was explored. Under the theme of test-scale-questionnaire development/adaptation, the focus was on developing achievement tests. These tests included multiple-choice, two-stage, three-stage, and four-stage achievement tests. Within the scope of the curriculum, the objectives of the studies focused on curriculum development (f = 5) and curriculum review/evaluation (f = 3). In the theme of textbooks, researchers have examined and evaluated physics, chemistry, and natural sciences textbooks (f = 11) within the scope of the research objectives.

As seen in Table 6, some studies also aimed to examine the cognitive and affective characteristics of students regarding modern physics topics. Among the cognitive characteristics aimed to be investigated, prominent ones included determining students' mental models (f = 20) and knowledge level (f = 20), followed by determining their level of conceptual understanding (f = 15) and conceptual misconceptions (f = 10), respectively. Regarding affective characteristics, the focus has been on examining perception, awareness, the attitude-anxiety relationship, and interest/motivation related to the subject. Other elements included determining the existing situation regarding modern physics education, literature review, and structural equation modelling.

Distribution of Studies Conducted in Modern Physics Education by Research Design

Studies in modern physics education included in this research were conducted using different research designs. In this context, the findings obtained are presented in Table 7.

Table 7

Distribution of studies by research design

Theme		Code	f	%
Quantitative	Experimental	True experimental	10	3.7
		Quasi-experimental	54	19.8
		Weak experimental	9	3.3
	Non-experimental	Descriptive survey	25	9.2
		Scale-questionnaire-test development/ adaptation	15	5.5
		Correlational survey	8	2.9
		General survey	4	1.5
		Comparative correlational survey	3	1.1
		Structural equation modelling	2	0.7
Qualitative	Interactive	Case study	82	30.0
		Phenomenology	8	2.9
		Unreported	2	0.7
	Non-interactive	Document analysis	14	5.1
		Literature review	2	0.7
Mixed		Explanatory design	3	1.1
		Exploratory design	4	1.5
		Convergent design	1	0.4
		Intervention design	2	0.7
		Unreported	14	5.1
Unreported	-----	Unreported	11	4.0

As observed in Table 7, among the studies using quantitative methods, 73 preferred experimental models and 57 preferred non-experimental models. Of experimental approaches, the quasi-experimental method (f = 54) was preferred more than other experimental methods. In non-experimental methods, descriptive survey (f = 25) and scale-questionnaire-test development/adaptation (f =15) were the most commonly used designs. Furthermore, 108 studies conducted in modern physics education preferred qualitative research methods. Among interactive qualitative methods, case study (f = 82) was preferred the most, followed by phenomenology (f = 8). In non-interactive qualitative methods, document analysis (f = 14) and literature review (f = 2) were preferred. Considering the mixed-method studies, exploratory design (f = 4) was preferred the most, followed by explanatory (f = 3), intervention (f = 2), and convergent (f = 1) designs, respectively. Another noteworthy finding here is that 14 studies opting for mixed methods did not specify which mixed-method design they used in the research process. Additionally, 11 studies did not report the research design they preferred during the research process.

Distribution of Studies in Modern Physics Education by Sample Types, Sample Levels, and Sample Sizes

Sample types, sample levels, and sample sizes of studies conducted in modern physics education were coded in the research. Descriptive statistics showing the distribution obtained after this coding are presented in Table 8.

Table 8

Distribution of studies by types of samples

Sampling Method		f	%
Random sampling	Simple random	39	13.6
	Unreported	4	1.4
Non-random sampling	Purposive		
	Criterion	31	10.8
	Maximum	23	7.7
	Stratified	8	2.8
	Typical case	5	1.7
	Homogenous	4	1.4
	Convenient	59	20.6
	Systematic	4	1.4
	Unreported	17	5.9
Unreported	---	93	32.5

According to the findings in Table 8, studies conducted in modern physics education mostly preferred simple random sampling (*f* = 39) in random sampling and purposive sampling (*f* = 71) in non-random sampling. In purposive sampling, criterion sampling (*f* = 31) was preferred the most, followed by maximum (*f* = 23) and stratified sampling (*f* = 8). However, 17 studies did not specify the type of purposive sampling. Additionally, 93 studies did not report any information about the type of sampling.

Table 9

Distribution of studies by sample levels

Sample Group	f	%
Primary school	1	0.3
Middle school	35	11.7
High school	65	21.7
Associate degree	4	1.3
Undergraduate (Education faculty)	148	49.3
Undergraduate (Not from education faculty)	9	3.0
Graduate	2	0.7
Teacher	17	5.7
Expert	4	1.3
Parents	3	1.0
Other	12	4.0

As seen in Table 9, in studies conducted in modern physics education, the sample group of education faculty undergraduate level (*f* = 148) was most commonly preferred, followed by high school (*f* = 65), middle school (*f* = 35), and teachers (*f* = 17). Graduate, parent, and primary school levels were the least preferred sample groups.

Table 10

Distribution of studies by sample size

Sample Size	f	%
1-10	28	9.3
11-30	55	18.3
31-100	103	34.3
101-300	67	22.3
301-1000	31	10.3
1001+	4	1.3
Other	12	4.0

As observed in Table 10, the studies were mostly conducted with sample sizes ranging between 31 and 100 (*f* = 103). Following this range, sample sizes ranging between 101 and 300 (*f* = 67) and between 11 and 30 (*f* = 55) were used. According to the research results, it was determined that studies with sample sizes exceeding 1000 were less common (*f* = 4) compared to others.

Distribution of Studies Conducted in Modern Physics Education by Intervention Duration

The intervention durations of studies conducted in modern physics education were analyzed, and descriptive statistics related to the coding after the analysis are presented in Table 11.

Table 11

Distribution of studies by intervention duration

Intervention Duration	f	%	Intervention Duration	f	%
Unreported	112	41.0	21-24 weeks	4	1.5
0-1 week	44	16.1	25-28 weeks	3	1.1
1-4 weeks	45	16.5	49-52 weeks	8	2.9
5-8 weeks	14	5.1	2 years	2	0.7
9-12 weeks	10	3.7	3 years	3	1.1
13-16 weeks	23	8.4	4 years	1	0.4
17-20 weeks	4	1.5			

As seen in Table 11, the majority of the studies examined within the scope of this research did not report the intervention durations. Among the studies that reported the intervention duration, the majority preferred the 0–1-week (*f* = 44) and 1–4-week (*f* = 45) ranges, followed by the 13–16-week (*f* = 23) and 5-8 week (*f* = 14) ranges. It was also determined that there were few long-term studies in the field of modern physics education.

Distribution of Studies Conducted in Modern Physics Education by Data Collection Techniques/Tools and Data Analysis Types

Studies conducted in modern physics education employed various data collection techniques/tools and data analysis types. The findings obtained are given in Tables 12 and 13.

Table 12

Distribution of studies by data collection tools

Theme	Code	f	%
Interview	Semi-structured interview	73	18.5
	Unstructured interview	6	1.5
	Structured interview	4	1.0
	Other	10	2.5
Observation	Unstructured observation	8	2.0
	Semi-structured observation	4	1.0
	Structured observation	4	1.0
	Other	4	1.0
Scale	Likert type	43	10.9
	Multiple-choice	14	3.5
	Other	9	2.3
Test	Multiple-choice	39	9.9
	Open-ended	31	7.8
	Other	19	4.8
Questionnaire	Likert type	35	8.9
	Open-ended	23	5.8
	Other	9	2.3
Alternative tools	Performance, portfolio, etc.	36	9.1
	Other	2	0.5
Documents	Books, developed activities, texts, etc.	22	5.6

As seen in Table 12, the data collection tools preferred in the research process of studies were interviews, observations, scales, tests, questionnaires, alternative tools and documents. The most preferred measurement tool was interviews (f = 93), followed by tests (f = 89), questionnaires (f = 67), and scales (f = 66). The least used data collection tool was observation.

Table 13

Distribution of studies by data analysis methods

Theme	Code	f	%
Quantitative	*Descriptive*		
	Frequency/percentage	105	23.0
	Mean/standard deviation	9	2.0
	Visualization with graphics	8	1.8
	Other	4	0.9
	Inferential		
	t-test	51	11.2
	Item analysis	48	10.5
	ANOVA/ANCOVA	37	8.1
	Non-parametric tests	18	3.9
	Factor analysis	13	2.9
	MANOVA/MANCOVA	12	2.6
	Correlation analysis	3	0.7
	Structural equation modeling	2	0.4

	Path analysis	2	0.4
	Regression analysis	1	0.2
Qualitative	Content analysis	97	21.3
	Descriptive analysis	27	5.9
	Document analysis	9	2.0
	Other	7	1.5
Unreported	-----	3	0.7

As seen in Table 13, studies conducted in modern physics education mostly employed frequency/percentage (*f* = 105) for quantitative descriptive values and the t-test for quantitative inferential values in data analysis. In qualitative analyses, content analysis (*f* = 97) and descriptive analysis (*f* = 27) were the most commonly used types of analysis. Another noteworthy finding is that three studies provided no explanation regarding the analysis methods.

Distribution of Studies Conducted in Modern Physics Education by Validity and Reliability Types

In this section, the validity and reliability methods used in studies conducted in modern physics education are presented, and the findings are given in Tables 14 and 15.

Table 14

Distribution of studies by validity types

Theme	Code	f	%
Design	Ensuring data diversity/collecting data from multiple sources	33	3.0
	Determining a purposeful sample	30	2.7
Study Group	Reporting the sampling method	85	4.1
	Describing the sample characteristics	75	10.4
	Using codes instead of participant names	72	6.5
	Participants' freedom to withdraw	23	2.1
	Describing the research population	14	1.3
	Longtime interaction	13	1.2
Research Process	Expert review	170	15.4
	Providing a detailed description regarding the intervention process	128	11.6
	Explaining the rationale for the method and relating it to the literature	73	6.6
	Describing assumptions and limitations	53	4.8
	Pilot application	51	4.6
	Describing the validity and reliability measures	43	3.9
Data Analysis	Providing a detailed explanation of the data collection process	132	12.0
	Describing the data analysis procedure	88	8.0
Unreported	---	18	1.6

According to Table 14, studies conducted within the scope of modern physics education utilized various validity types in research design, study group, research process, and data analysis themes. In the research design, ensuring data diversity (*f* = 33) and determining a purposeful sample (*f* = 30) were more prominently expressed in the study group. Reporting the sampling method (*f* = 85) and describing the sample characteristics (*f* = 75) were also mentioned. In the research process, expert review (*f* = 170) and detailed description of the intervention process (*f* = 128) were emphasized. In terms of data analysis, the preferred validity methods were mostly focused on providing a detailed explanation of the data collection process.

Table 15

Distribution of studies by reliability types

Theme	Code	f	%
Researcher	Calculating inter-coder consistency	78	15.4
	Separate analyses by two researchers	55	10.9
	Explaining the researcher's role	18	3.6
	Seeking expert opinion in comparing findings and results	16	3.2
	Internal audit among researchers with independent controls	10	2.0
Study Group	Direct quotations from participants' statements	62	12.3
	Participant control	27	5.3
Data Analysis	Employing variation in data analysis	32	6.3
	Data quality	18	3.6
	Considering code and category consistency	15	3.0
	Data analysis at different times	13	2.6
	Cronbach Alpha	51	10.1
	KR20-21	35	6.9
	Item total score correlation	4	0.8
	Test-retest	3	0.6
	Spearman Brown	4	0.8
	Parallel Test	4	0.8
	Kendall	3	0.6
Unreported	----	58	11.5

As seen in Table 15, the reliability methods of the studies reviewed within the scope of modern physics education were categorized under researcher, study group, and data analysis themes. In the researcher theme, calculating inter-coder consistency (f = 78) and separate analysis by two researchers (f = 55) were more prevalent, while in the study group theme, direct quotations from participants' statements (f = 62) were utilized more. In the data analysis theme, employing variation in data analysis, Cronbach's Alpha, and KR20-21 were the most preferred reliability methods. Additionally, 61 studies did not report any information on reliability methods.

Distribution of Studies Conducted in Modern Physics Education Based on Their Results, Discussions, and Recommendations

This section presents findings regarding the results, discussions regarding the results, and recommendations for future research based on studies conducted in modern physics education.

Table 16

Distribution of studies based on their results

Theme	Code	f	%
Instructional methods and techniques	*Positive*		
	Increase in academic achievement	59	9.6
	Concretisation of knowledge	43	6.9
	Development of positive emotions and thoughts	40	6.5
	Acquiring problem-solving skills	19	3.1
	Developing higher-order thinking skills	17	2.7

	Improving mathematical operation skills	10	1.6
	Relating knowledge to daily life	8	1.3
	Establishing relationships between concepts	7	1.1
	Commenting on reading passages	6	1.0
	Relating information across disciplines	5	0.8
	Reasoning about the topic	4	0.6
	Developing an understanding of modern physics thinking	2	0.3
	Interpreting visual materials	1	0.2
	Negative		
	Development of negative emotions and thoughts	5	0.8
	Inability to resolve conceptual misconceptions	3	0.5
	Inability to perform numerical operations in solving problems	2	0.3
	No change in emotions or thoughts	2	0.3
Materials	*Positive*		
	Concretisation of knowledge	10	1.6
	Development of positive emotions and thoughts	10	1.6
	More active participation in lessons	4	0.6
	Relating knowledge to daily life	4	0.6
	Developing higher-order thinking skills	3	0.5
	Increasing awareness concerning the subject	3	0.5
	Negative		
	Development of negative emotions and thoughts (disliking, difficulty, and more)	4	0.6
	Persistence of conceptual misconceptions	4	0.6
Curriculum	*Positive*		
	Adding current topics to the modern physics curriculum	2	0.3
	Incorporating the quantum paradigm into the modern physics curriculum	2	0.3
	Placing more emphasis on higher-order thinking skills in the modern physics curriculum	1	0.2
	Negative		
	Continuing with the classical physics understanding in the modern physics curriculum	2	0.3
	Including lower-order learning outcomes in the modern physics curriculum	2	0.3
	Updating frequently	2	0.3
	Inconsistencies between theory and practice	2	0.3
	Preparing the curriculum without considering the needs in terms of activities, content, and more	2	0.3
Textbooks	Lack of clarity and understandability of expressions	11	1.8
	Being unsuitable for the age and developmental characteristics	9	1.5
	Content not being supported with subject-related tables, figures, diagrams, and examples	7	1.1
	Not reflecting the understanding of modern physics in the content	5	0.8
	Insufficiency in the number of learning outcomes	4	0.6
	Being written in a non-scientific language	3	0.5
	Not reflecting the latest developments in the subject area	2	0.3
	Topics not supporting each other	2	0.3
Tests/Scales/ Questionnaires	Developing valid and reliable tests or scales	15	2.4
Cognitive	*Determining a Mental Model*		
	Maintaining a classical physics understanding	12	1.9
	Non-scientific explanations	10	1.6
	Non-scientific drawings	8	1.3
	Generating alternative concepts or thoughts	7	1.1
	Drawing appropriate models for the subject.	6	1.0
	Conceptual understanding and knowledge levels		
	Failing to relate to daily life	22	3.5
	Continuing with the classical physics understanding	17	2.7
	Operational inadequacy in quantum mechanics	16	2.6
	Failing to concretise concepts	15	2.4
	Failing to define concepts or formulas	8	1.3
	Knowing basic concepts	7	1.1
	Providing different examples related to the topic	2	0.3
	Conceptual Misconception		

	Failing to establish relationships between topics	10	1.6
	Explaining concepts with non-scientific expressions	7	1.1
	Incorrectly associating current examples with modern physics	6	1.0
	Failing to establish a connection from classical physics to modern physics.	5	0.8
	Misunderstanding in the philosophy of modern physics	3	0.5
	Problem-Solving Skills		
	Failing to understand the question content	8	1.3
	Failing to interpret the question content	7	1.1
	Failing to reach a conclusion	7	1.1
	Failing to explain the formulas	6	1.0
	Failing to perform operations adequately	5	0.8
	Solving context-based problems more easily	2	0.3
	Metaphor		
	Causing conceptual misconceptions	5	0.8
	Limiting the understanding of modern physics	3	0.5
	Facilitating the integration of information into daily life	3	0.5
	Developing creative thinking in modern physics	2	0.3
Affective	*Positive*		
	Feeling the importance of the subject	5	0.8
	Realising that the subject is intertwined with daily life	4	0.6
	Feeling that the subject is easy/learnable	3	0.5
	Having sufficient awareness about the subject	2	0.3
	Negative		
	Having negative prejudices regarding the subject	14	2.3
	Difficulty in developing an interest in the subject	10	1.6
	Thinking that the subject has a negative impact on health	9	1.5
	Not knowing the impact of the subject on daily life	5	0.8
	Developing positive feelings and thoughts towards the subject	4	0.6
	Having no awareness about the subject	3	0.5
Review	Providing insufficient information about the scope of their studies	2	0.3
	Providing little information regarding the data collection process of the studies.	2	0.3

As seen in Table 16, it was observed that positive or negative changes have occurred in participants as a result of the instructional methods and techniques employed in the studies. In positive developments, an increase in academic achievement (*f* = 59), concretisation of knowledge (*f* = 43), and the development of positive feelings and thoughts towards the subject (*f* = 40) were most frequently expressed. This was followed by acquiring problem-solving skills (*f* = 19), developing higher-order thinking skills (*f* = 17), improving mathematical operation skills (*f* = 10), and relating knowledge to daily life (*f* = 8). The negative side included the development of negative feelings and thoughts towards the subject, the inability to resolve conceptual misconceptions, and the inability to perform numerical operations in problem-solving. Similarly, the materials utilized in research studies brought about positive or negative changes in participants. Prominent positive developments include concretisation of knowledge (*f* = 10), development of positive feelings and thoughts (*f* = 10), and more active participation in lessons (*f* = 4). On the negative side, there were the development of negative feelings and thoughts towards the subject (e.g., disliking, difficulty, and more; *f* = 4) and persistence in conceptual misconceptions (*f* = 4).

In the table, positive changes in the curriculum theme included adding current topics to the modern physics curriculum, incorporating the quantum paradigm into the modern physics curriculum, and placing more emphasis on higher-order thinking skills in the modern physics curriculum. The negative side involved maintaining a classical physics understanding, including lower-order learning outcomes, updating frequently, and inconsistencies between theory and practice. The results obtained for modern physics topics in physics/chemistry/science textbooks were generally negative. Accordingly, the most frequently mentioned issues included the lack of clarity and understandability of the expressions in textbooks, being unsuitable for the age and developmental characteristics of students, content not being supported with subject-related tables, figures, diagrams, and examples, and not reflecting the understanding of modern physics in the content. According to the research results, many valid and reliable tests/scales/questionnaires have been developed in the studies. Additionally, many studies have found that participants have positive or negative perspectives in both cognitive and affective aspects.

Table 17

Distribution of studies based on their discussions

Code	f	%
The discussion is supported by the literature, but explanations of the literature are insufficient.	106	35.9
The discussion is supported by the literature, and explanations of the literature are sufficient.	97	32.9
The discussion is supported by the literature, but there are no explanations of the literature.	40	13.6
The discussion is supported by the intervention process of the research.	24	8.1
There is no discussion; only the conclusion is presented.	12	4.1
There is no literature in the discussion, only the researcher's interpretation.	11	3.7
The discussion is supported by the sample group characteristics.	5	1.7

Considering the discussion section of the studies on modern physics education examined in Table 17, most studies were supported by literature, but there were differences in the explanations of the literature. From these explanations, it was concluded that 106 of them were insufficient, 97 were sufficient and 40 did not provide any explanations. Another noteworthy finding was that 12 studies did not include any discussion.

Table 18

Distribution of studies based on their recommendations

Theme	Code	f	%
Investigating different variables	Interdisciplinary associations	18	2.8
	Examining affective characteristics	18	2.8
	Inquiry-based thinking	3	0.5
	Scientific literacy	3	0.5
	Retention of modern physics knowledge	3	0.5
	Relating the problems to daily life	2	0.3
	Development of scientific process skills	2	0.3
	Critical thinking	1	0.2
	Traditional problem-solving	1	0.2
	Academic achievement	1	0.2
Methods	More quantitative studies (e.g., true experimental)	11	1.7
	More qualitative studies (e.g., action, case, etc.)	10	1.6
	More mixed-method studies	4	0.6
Sample Groups	Secondary education	48	7.6
	Middle school	37	5.9
	Primary school	21	3.3
	Those studying in different departments of education faculties	8	1.3
	Those studying outside the education faculty	5	0.8
	Different countries	3	0.5
Sample Sizes	Larger sample sizes	19	3.0
	Smaller sample sizes	5	0.8
Instructional Methods and Techniques	Applying the same instructional method and technique to other modern physics subjects	36	5.7
	Using individualized instruction techniques more	33	5.2
	Placing more emphasis on problem-solving teaching methods	18	2.8
	Incorporating out-of-class instruction techniques	10	1.6
	Increasing teacher-student communication in the learning process	5	0.8

Materials	Animations/simulations	42	6.6
	Interactive experiments	36	5.7
	Visual elements (e.g., photographs and caricatures)	34	5.1
	Augmented reality experiments	15	2.4
	Using stories, brochures, and worksheets for different learning purposes	8	1.3
	Using experimental designs developed within the scope of the literature	6	0.9
	Using worksheets with graphical and visual content	5	0.8
	Incorporating writing activities for learning purposes	3	0.5
	Technological tools and equipment	2	0.3
Duration	Increasing the intervention duration	13	2.1
	Decreasing the intervention duration	3	0.5
Subject Content	Incorporating the philosophy of modern physics	19	3.0
	Relating topics to each other	11	2.1
	Placing more emphasis on problem-solving	8	1.3
	Relating more to daily life	7	1.1
	Including the history of science in the content	5	0.8
	Including current examples	3	0.5
	Reducing the content	2	0.3
	Simplifying numerical operation skills	2	0.3
	Interdisciplinary association	2	0.3
Curriculum	Developing a new curriculum related to modern physics	18	2.8
	Evaluating other curricula related to modern physics	11	1.7
	Including the modern physics philosophy in curricula	8	1.3
Textbooks	Increasing visuals	6	0.9
	Increasing content details	6	0.9
	Using a scientific language	6	0.9
	Organizing the content according to the history of science	4	0.6
	Including other modern physics topics in the content	3	0.5
	Including more examples related to daily life.	2	0.3
No recommendation	----	17	2.7

As seen in Table 18, when examining the suggestions related to the results of the studies, themes such as investigating different variables, research methods, sample groups, sample sizes, instructional methods and techniques, materials, duration, subject content, textbooks, curriculum, and recommendations emerged. In the theme of investigating different variables, interdisciplinary associations (f = 18) and examining affective characteristics (f = 18) come to the forefront. In the theme of method, it was suggested that more quantitative studies (f = 11) should be conducted. In the theme of the sample groups, it was recommended to conduct more research with secondary school (f = 48) and middle school students (f = 37), and it is noteworthy that conducting research with different countries was also recommended. In addition, it was suggested that a larger number of samples should be included in the sample groups. The instructional methods and techniques recommended for research included applying the instructional methods and techniques used in the intervention processes of the reviewed studies to other modern physics subjects (f = 36) and using individualized instruction techniques more frequently (f = 33). Regarding the materials to be used, there was a stronger recommendation for the use of computer-aided animations/simulations (f = 42) and interactive experiments (f = 36), followed by visual elements (f = 34) and augmented reality experiments (f = 15). Additionally, it was also indicated that the intervention duration should be increased. In the theme of subject content, it was suggested to incorporate the philosophy of modern physics. In the textbook theme, it was suggested to increase visual elements, increase content details, and use scientific language. In the theme of curriculum, developing a new curriculum related to modern physics was recommended. Another notable finding in the research was that 17 studies did not provide recommendations for modern physics education.

Discussion, Conclusion and Implications

In the research, 273 studies conducted between 2000 and 2023 and published in different databases were examined. Most studies were published in the Tübitak Ulakbim database (41.8%), in article format (69.2%), and in Turkish (68.9%). It was determined that the studies highly intensified between 2010 and 2019, but in recent years, there has been a decreasing trend in research activities. The main reasons for this decrease may include the abstract nature of modern physics concepts, the lack of direct observation in daily life, the persistent adherence to classical physics understanding, and the difficulty in acquiring technological devices for the teaching-learning process. Muştu and Şen (2019) note that simplifying the content in modern physics subjects not only hinders students' connected learning but also leads to a decreasing interest in the subject. Baily and Finkelstein (2010) note that the persistence of teachers and students in maintaining a classical physics understanding of modern physics topics and their failure to establish a wave-particle understanding of modern physics has also reduced the inclination towards engaging in modern physics studies. In this regard, Ensari and Bayrak (2023) indicate that there is less research on modern physics topics due to excessive conceptual misconceptions in students' basic physics knowledge. It was determined that the studies have concentrated on the atom, photoelectric effect, theory of relativity, and nuclear energy. The concentration on these topics could be explained by their status as fundamental subjects in modern physics, their significance for the understanding of modern physics, their greater relevance in daily life, and the increased support through computer-aided applications in the teaching-learning process. Baily and Finkelstein (2010) state that a clear understanding of the fundamental topics in modern physics is essential for students to make realistic interpretations in quantum mechanics. Atoms are a topic of focus for many researchers because they are taught in all educational levels, from primary school to university (Nakiboğlu, 2008). The fact that the theory of relativity acts as an important bridge in the transition from classical physics to modern physics (Dimitriadi & Halkia'a, 2012) and that the photoelectric effect is an interdisciplinary subject at the centre of explaining the nature of light and technological advances (Balabanoff et al., 2020; Jho et al., 2023) explains why more studies should be conducted on these topics. The reasons for the scarcity of studies on other modern physics topics in the research may include the more abstract nature of these topics, their prevalence in higher education levels, their involvement of more complex mathematical skills, their relatively lesser emphasis in the physics curriculum, and the lack of direct encounters with examples related to daily life. The reasons are also consistent with the relevant literature (Baily & Finkelstein, 2015; Hughes & Kersting, 2021; Huseby & Bungum, 2019; Kersting et al., 2023; Saglam & Eroglu, 2022).

Another dimension examined in the research was the objectives of the studies. The majority of the examined studies aimed at the effectiveness of instructional methods and techniques, followed by determining the current state and examining cognitive and affective characteristics. The relevant literature also supports the results of this research (Bonacci, 2018; Mannila et al., 2002; Stadermann & Goedhart, 2020). Levrini and Fantini (2013) suggest that, for the development of a modern physics understanding, it is essential to first determine students' views on modern physics, followed by the use of appropriate teaching methods and techniques. Baily and Finkelstein (2015) argues that students, through enriched learning environments, can develop reasoning skills in modern physics, allowing them to move away from classical physics understanding and intuitive physics thoughts. Therefore, it is essential to first characterise students' perspectives, followed by determining cognitive and affective characteristics, and then utilizing appropriate teaching methods and techniques (Bakri et al., 2023). Otherwise, students may develop ideas and beliefs that are not specific to modern physics (Şen, 2002). Another result obtained in the research is that the studies aim to examine and develop modern physics textbooks and curriculum. In their study examining the physics curriculum of 15 different countries, Stadermann et al. (2019) concluded that, for better teaching of modern physics, the physics curriculum should allocate more space to modern physics and delve into it more deeply. Similarly, Aktaş (2023) concluded in his study that modern physics is not given enough space in physics curricula and emphasised that physics curricula and textbooks should be revised and prepared according to the needs of the age in order to eliminate this problem.

An examination of the studies included in this research according to research designs indicated that quasi-experimental and descriptive survey designs were more commonly preferred in quantitative research. The research results were similar to the findings of existing content analysis studies in physics education (Arslan & Paliç, 2012; Bingöl & Baran 2023; Şenkal & Dinçer, 2016; Ünsal et al., 2018). The reasons behind opting for the quasi-experimental method more in quantitative research could be explained by easier and quicker access to samples, collecting data in a shorter time, and interpreting them quickly (Selçuk et al., 2014). Bitzenbauer and Meyn (2020) emphasize the need for more experimental studies with various learning activities for in-depth learning of modern physics independent from classical physics, supporting the results of the present research. Another extensively preferred quantitative research design was the descriptive survey method. Pereira and Solbes (2022) argue that the lack of a common method in experimental approaches of quantitative research in modern physics education prevents the formation of a distinctive understanding of modern physics. Therefore, they recommend reaching more samples and collecting more data through the survey method. Thus, by determining a general perspective and the current state regarding topics in modern physics, suitable instructional methods and techniques can be developed. This circumstance supports the research result. It was also determined that the studies examined in this research preferred the case study design more in qualitative research. Akaydın and Çeçen (2015) and Aktaş (2023) maintain that qualitative studies play a crucial role in presenting problems related to the subject more accurately, obtaining more in-depth information, and finding clearer responses to difficult questions. Qualitative studies should be given more place in modern physics education because qualitative approaches contribute more to the development of reading and analytical skills in students (Purwaningsih et al., 2024). According to Yılmaz (2015) and Doğan et al. (2023), only quantitative or qualitative studies are not sufficient to meet the needs of students concerning the subject in the teaching-learning process. Therefore, there is a need to increase mixed-method studies that utilise both qualitative and quantitative research methods together. This study also indicated that many researchers have preferred the mixed-method approach to conducting their studies. Utilizing mixed-methods research in modern physics can establish different contexts, promote the development of teachers' and students' perspectives and ensure consistency (Baily & Finkelstein, 2010). Mixed-methods research plays a crucial role in enriching research by replacing rigid boundaries and labels in quantitative and qualitative methods with permeable and inclusive categories (Johnson & Onwuegbuzie, 2004). Another notable result of the research was that 11 studies did not report the research design.

In the reviewed studies, researchers mostly preferred non-probability purposive sampling methods in sample selection. Due to the abstract nature of modern physics content, participants need to possess abstract thinking skills and master classical physics topics for a thorough understanding. According to Bitzenbauer and Meyn (2020), to make sense of modern physics, students need to have sufficient knowledge and inquiry skills in basic physics, especially regarding photons and atoms. Arbabifar and Nazerdeylamin (2024) Mastering the mechanics and electromagnetism subjects is a necessity for meaningful and permanent learning of modern physics. Therefore, working with sample groups possessing these skills enhances the validity of the research. As mentioned by Büyüköztürk et al. (2012), purposive sampling requires working with cases that meet specific criteria or possess certain characteristics. Some of the studies reviewed in this research have also preferred random sampling due to a lack of sufficient time and difficulties in reaching the intended sample. This result is consistent with the literature (Akaydın & Çeçen, 2015; Selçuk et al., 2014). Additionally, some of the examined studies on modern physics education did not mention the selected sample type.

Considering the sample sizes in the research, most studies carried out the research processes with sample groups ranging from 31 to 100 participants. However, the number of studies conducted has decreased, with an increase in sample sizes in study groups. Fraenkel et al. (2012) state that the sample size should be at least 30 in quantitative studies, as a sample size of 30 or more tends to show a normal distribution. In this research, the emphasis on quantitative studies could explain the preference for sample sizes ranging from 31 to 100. The selection of sample sizes of 101 and above in studies reviewed in the present research could be attributed to the studies' preference for the survey method and the need for a larger sample size for developing or adapting measurement tools. Selçuk et al. (2014) emphasize the importance of reaching a larger sample size in survey model research, as it involves investigating how the subject is distributed in terms of the sample. The small sample sizes observed in studies examined in this research may be associated with the prevalence of qualitative studies, especially those involving parents, administrators, and experts, where smaller sample sizes are common. Yıldırım (2023) In order for modern physics education to be meaningful and productive, research should be conducted with qualitative designs and small sample groups. Thus, more detailed and in-depth information about the learning-teaching process of modern physics can be obtained and necessary arrangements can be made in a short time. However, in qualitative studies, having a small number of samples is important for effective use of time in order to write down, clean, organize and analyze large amounts of data (Guisasola et al., 2023). Another finding obtained in the research was the variability in intervention durations of the studies reviewed, ranging from 0 to 4 and 5 to 16 weeks. The primary reason for this variability might be adjustments in intervention durations based on the objectives of the studies and challenges in creating suitable conditions for research. According to Baily and Finkelstein (2010), due to the abstract nature and complex philosophy of modern physics content, it is necessary to conduct longer-term studies. Bitzenbauer (2021) suggests that in modern physics, studies should be conducted over a longer period to facilitate the understanding of the paradigm, the qualitative acquisition of concepts, and achieving targeted development. This way, technological advancements in modern physics can also be understood more clearly.

In the studies reviewed within the scope of this research, the most preferred measurement tools in data collection were interviews, scales, tests, and questionnaires, followed by alternative measurement and evaluation tools. The preference for scales, tests, and questionnaires in data collection may be explained by their ease of use, cost-effectiveness, validity, and reliability in gathering data. Using scales and questionnaires in physics subjects allows for collecting the appropriate data in a shorter time, aiding in determining the general situation and outlining a roadmap (Arslan & Paliç, 2012; Resbiantoro et al., 2022; Ünsal et al., 2018). The reason for the more frequent use of interview types could be collecting more detailed data and adding new questions to the interview process when needed during the research (Guisasola et al., 2023). To obtain more detailed information about students' mastery of modern physics topics, interviews and alternative measurement and evaluation tools should be employed (Muştu & Şen, 2019). The least used data collection tools were observation types and documents. The main reason for this could be that both measurement tools involve a detailed and time-consuming analysis process. As a result of the research, the studies examined mostly preferred frequency/percentage, t-test, item analysis, and content analysis in data analysis methods. They also employed different quantitative and qualitative analyses. The efforts of researchers in the examined studies to determine the general state of modern physics education and obtain more detailed information about the content may explain the preference for quantitative descriptive analyses and content analysis (Guisasola et al., 2023). It could also be stated that the researchers conducted their analyses in line with their research objectives. The research results are parallel to the relevant literature. (Akaydın & Çeçen, 2016; Şenkal & Dinçer, 2016).

In the studies on modern physics education examined in the research, the most commonly utilised validity methods were expert review, detailed description of the research process, and detailed explanation of the data collection process. The reliability methods included inter-coder consistency calculation, direct quotation from participant statements, and separate analysis by two researchers. In this regard, it is possible to say that the validity and reliability methods in the studies may not have been conducted at an adequate level. Additionally, in some of the studies examined, it was found that the researchers used the validity and reliability evidence reported in previous studies without changing them in their own research (Guisasola et al., 2023). The research results consistent with the relevant literature (Arbağ & Ertekin, 2020; Öztürk, 2020).

The content analysis indicated that studies have reached different results in themes concerning instructional methods and techniques, materials, curriculum development, textbooks, tests/scales/questionnaires, cognitive characteristics, affective characteristics, and reviews. Although the results of the studies were generally positive, negative results were also obtained. In the themes of materials and instructional methods and techniques, the most positive results achieved included an increase in academic achievement, concretizing or understanding information, acquiring problem-solving skills, enhancing higher-order thinking skills, and developing positive emotions and thoughts. The negative aspects included developing negative emotions and thoughts and failing to eliminate conceptual misconceptions. Baily and Finkelstein (2010) suggest that despite the differences in instructional methods and techniques employed in modern physics education, students began to better understand the philosophy of modern physics, concretize knowledge, and improve their problem-solving skills through each intervention. Huseby and Bungum (2019) suggest that the teaching methods and techniques applied in modern physics education and the materials used should be structured in a manner that aligns with the understanding, nature, and philosophy of modern physics. Otherwise, continuing conceptual misconceptions in modern physics may lead to the development of negative emotions and thoughts. In the cognitive theme, other results reached include maintaining a classical physics understanding, failing to relate knowledge to daily life, continuing non-scientific explanations, and failing to develop thinking skills. In the affective theme, the result indicated that there were more negative emotions and thoughts towards modern physics. Zhu and Singh (2012) suggest that not understanding the nature of modern physics leads to conceptual, mathematical, and practical confusion, paving the way for the development of negative emotions and thoughts. Díaz et al. (2023) Inadequate teacher-student communication and interaction, materials that do not fully reflect the content, and little space given to scientific conversations can cause many negativities in the learning-teaching process of modern physics. Additionally, curriculum and textbooks that are not compatible with the nature of modern physics may lead to both cognitive and affective negative outcomes in students. In this regard, many studies reviewed in this research have examined modern physics curricula and textbooks, concluding that their contents were inadequate and not suitable for students' levels. Stadermann et al. (2019) and Aktaş (2023) emphasize the importance of considering student needs when preparing a curriculum and textbook for modern physics education, as neglecting student needs may lead to undesirable cognitive and affective outcomes.

In the studies reviewed, the majority of the discussions of the studies were supported by literature, but the literature explanations were insufficient or absent. Some studies only presented the results in the discussion section, while others did not include any literature support. Other studies structured the discussion process around the research's implementation and sample characteristics. The inadequacy or absence of the discussion section in the reviewed studies could be attributed to factors such as the unavailability of suitable resources within the study scope, the inadequacy of educators in the field of modern physics, discussions specific to the researcher being contradictory to the probabilistic world of modern physics, and a decrease in the number of studies conducted in the field in recent years. In their study, Fuchs and Peres (2000) argue that the interpretation of modern physics studies by the researcher would limit the unique world of modern physics, and therefore, there should be an 'interpretation without interpretation' in modern physics. Similarly, Laloë (2001) suggests that having various interpretations based on the researcher's attitude may lead to misunderstandings. Baily and Finkelstein (2010) note that teachers and students do not have consistent concepts and understandings within and across fields due to the nature of modern physics. Therefore, instead of referring to concepts and interpretations, interpretations should be made from a more general perspective or context. Giliberti and Organtini (2021) discussions on the learning-teaching process of modern physics should be within the framework of classical physics, quantum physics, quantum mechanics and quantum field theory. In this process, attention should be paid to the discussion of concepts, facts and measurement processes.

The recommendations regarding the results of the studies conducted in modern physics education were also examined in this research. Prominent recommendations in the studies included data collection tools, sample groups, instructional methods and techniques, materials, examining different variables, subject content, and curriculum themes. The research results are consistent with the literature (Baily & Finkelstein, 2010; Bitzenbauer, 2021; Pereira & Solbes, 202; Swandi et al., 2020). Swandi et al. (2020) suggest that since modern physics is the technology of the future, the targeted outcomes can be reached by providing students with an enriched learning environment and using technological materials. Mufit et al. (2024) and Kersting et al. (2023) concept teaching approach, group work, computer technologies, interdisciplinary applications and science trips facilitate the understanding of modern physics. Baily and Finkelstein (2015) emphasize that for effective and efficient modern physics education, determining students' cognitive and affective discourses is necessary at the outset. Afterward, the philosophy of modern physics, the history of science, and operational skills should be included more in the subject content. Additionally, students should be provided with opportunities to learn from each other. In the study, Aksakallı et al. (2016) concluded that the underlying problems related to modern physics stem from teachers not being up-to-date on modern physics topics, textbooks being scientifically inadequate, and the lack of learning environments that enable students to learn on their own. In this regard, the recommendation for providing seminars to teachers, organizing the curriculum or textbooks, and conducting long-term studies in enriched learning environments is similar to the findings of the present research. In a study on blackbody radiation, Balta (2018) concluded that teachers' knowledge of modern physics was not up-to-date and that students did not learn the subject in an acceptable way. In this context, the researcher suggests updating modern physics education, modern physics curriculum, and textbooks, and also recommends that teachers participate in various courses. Krijtenburg-Lewerissa et al. (2017) suggest developing an understanding of "How can I better learn/teach the nature and philosophy of modern physics?" for modern physics education to be more comprehensible.

Based on the results of the content analysis in the research, it could be recommended to conduct more qualitative and scientifically valuable studies on different topics of modern physics education. In future studies, to acquire the unique thought structure and understanding of modern physics, researchers could enrich their goals, prefer mixed research methods designed with quality approaches, enhance their intervention samples, increase sample sizes, and use different data analysis methods, significantly contributing to the field. Additionally, future research should place more emphasis on, diversify, and provide detailed information on validity and reliability measures. Considering the significance of the study results, reassessing the outcomes and making international publications would be important for shedding light on modern physics education. Finally, in this study, content analysis was conducted based on studies retrieved through selected databases and keywords. To make the research more comprehensive, the research process could include different databases, different keywords, and studies conducted in various countries. Furthermore, for a more detailed analysis of studies on modern physics education, content analysis could be conducted specifically for qualitative, quantitative, and mixed-method research alone.

Conflict of Interest

The authors have no conflicts of interest.

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A comparison between preservice science teachers' representational competence and fluency in chemistry and physics

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ABSTRACT
This study examined the representational competence and fluency of preservice science teachers (PSTs) enrolled in a science teacher education program. It compared how these skills influence the understanding of the same cohort of PSTs when teaching concepts in chemistry and physics. Utilising a quantitative descriptive comparative design, the research analyses the participants' ability to effectively use multiple representations (MRs)—comprising graphical, experimental, symbolic, and verbal modes—during lesson presentations. Data from 39 PSTs were collected through video recordings that demonstrate concepts using various representation modes in chemistry and physics. Chi-square statistical analyses revealed significant differences in PSTs' graphical and experimental competence, with no significant differences observed in symbolic and verbal representations. The findings underscore the need for improved pedagogical strategies to enhance representational skills in science education, emphasising the interconnectedness of representational competence and fluency. It calls for targeted approaches in teacher education programs to better equip future educators with the necessary skills to foster effective learning outcomes in science classrooms.

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Introduction

In science education, it is important for PSTs to use multiple representations (MRs) to understand various scientific phenomena, concepts and experiments. These representations can take the form of diagrams, graphs, mathematical equations, or verbal descriptions (Pande & Chandrasekharan, 2021; Tonyali et al., 2023). The ability to effectively navigate and utilise these diverse representations is crucial for PSTs' success in science. Many of them face challenges in interpreting and interacting meaningfully with MRs, which can hinder their understanding and problem-solving abilities (Jannah et al., 2022). They also experience difficulties in understanding basic concepts, analysing images, defining symbols, and calculating accurately (Erniwati et al., 2020).

To facilitate effective teaching and learning in the classroom, science teachers must cultivate diverse pedagogical strategies. When learning materials include MRs, they improve pupil achievement and retention and enhance their understanding of concepts (Alfianti & Kuswanto, 2024;

Hahn & Klein, 2023). When MRs are used in preservice science education, they enhance the understanding of physics concepts and aid the development of scientific literacy and critical thinking skills among future science teachers (Widodo et al., 2023).

The use of MRs in science education must be considered along with the development of PSTs' representational competence and fluency. Representational competence relates to "one's ability to use disciplinary representations for learning, communicating, and problem-solving" (Popova & Jones, 2021, p.733). It also demonstrates the ability to interpret and construct representations, and how and when to use them in a particular context. Furthermore, it goes beyond visual literacy to the interrelationship between representation and the phenomenon depicted. Representational fluency, on the other hand, refers to the ability of individuals to change between different forms of representations to make meaning and engage in problem solving (Handayani & Masrifah, 2024; Moore et al., 2013).

There is a lack of studies that specifically look at how PSTs integrate the use of MRs during their lesson presentations in teacher educations programs in South Africa. This study is focused on PSTs enrolled in such a program at a South African university and compares their representational competence and fluency in chemistry and physics in a Natural Science methods course.

Literature Review

Multiple Representations in Science Education

In science education, multiple representations involve analogies, tables, graphs, models, diagrams, simulations, and text, all of which are designed to enhance understanding and communicate scientific concepts (Daniel et al., 2018; Treagust et al., 2018). Integrating these representations can significantly enhance learners' comprehension and promote deeper learning. This review explores the role of multiple representations in science education, particularly examining their definitions, theoretical frameworks, pedagogical implications, and empirical studies that assess their effectiveness.

Learning from multiple representations occurs when individuals seek to understand information presented across various, distinct representations that differ in symbol systems, formats, or modalities (List et al., 2020, p. 2). These forms of representation are often described as semiotic resources, essential for meaning-making within a discipline (Volkwyn et al., 2020).

Cognitive and socio-cultural perspectives offer differing insights on multiple representations. Rau (2020, p. 17) noted that learners must develop verbal sense-making competencies, nonverbal perceptual fluency with multiple representations, and meta-representational skills. From a socio-cultural standpoint, they acquire representational practices through interactions within scientific, professional, or learning communities.

Through enculturation into scientific communities, preservice teachers can effectively utilise multiple representations and engage in disciplinary discourse. Science teaching must mirror the epistemic practices of the scientific community, using MRs to convey knowledge claims (Kozma, 2020). According to Tang et al. (2014, p. 306), "representations are artifacts that symbolise an idea or concept in science (e.g., force, energy, chemical bonding) and can take the form of analogies, verbal explanations, written texts, diagrams, graphs, and simulations." A combination of these different modes is essential for communicating scientific concepts within scientific discourse and during the process of science learning (Treagust et al., 2018).

Research by Abdurrahman et al. (2019) and Murni et al. (2022), reported in this journal, have highlighted the importance of different teaching strategies to enhance learners' critical thinking and conceptual understanding in science education. The former showed that a multiple representation-based worksheet improved junior high school pupils' critical thinking skills compared with a control group who received a traditional worksheet. The latter found that a structured inquiry-based reaction rate module, integrated with three levels of chemical representation, positively influenced senior high school students' mental models and overall learning outcomes. Both studies utilised a quasi-experimental design which illustrated that diverse teaching and learning approaches that use multiple representations can have constructive outcomes.

Zuhri and Wilujeng (2023) identified a significant gap in systematic research on multiple representation learning in primary science education. They emphasised the need to empower teachers to utilise both semiotic and epistemological representations to enhance students' conceptual understanding and pedagogical effectiveness. Their research demonstrated that diverse representations—such as text, diagrams and digital media—improve reasoning, problem-solving, critical thinking, and overall academic performance in science. Similarly, Yaman and Hand (2022) explored how preservice science teachers develop argumentative and representational skills using a mixed-methods approach to analyse 180 laboratory reports and 20 video recordings. They found that PSTs improved their integration of multiple representations across various levels, particularly in written arguments when they are given continuous opportunities to engage in the discourse and critical reflection.

Hansen and Richland (2020) examined how various visual representations in science education impact learning, particularly in understanding complex concepts such as mitosis and meiosis. The findings revealed that learners performed better with simultaneous representations, especially when self-explanation prompts were included to facilitate connections between the visuals. Kohl and Finkelstein (2017) posited that in physics representations are artefacts or tools that mediate students' cognitive processes, and are mainly verbal, mathematical, graphical, and pictorial. They are used to convey information and support knowledge construction and foster students' understanding of physics (Opfermann et al., 2017; Nieminen et al., 2017). Lesh and Doerr (2003) indicated that the goal of using MRs is to allow an individual to construct and deconstruct meaning as if they were a group of people working together around a table negotiating a stable version of knowledge.

In chemistry, Gilbert and Treagust (2009) identified three types of representations to express chemical ideas:

a) The phenomenological type which includes properties such as mass, density, concentration, pH, temperature, and osmotic pressure.

b) The model type which is used for causal explanations of phenomena such as solids and can be described in terms of packed atoms or molecules.

c) The symbolic type which involves the allocation of symbols to represent atoms, whether of one element or of linked groups of several elements.

Cheng and Gilbert (2009, p.55) have also suggested that "the successful learning of chemistry involves the construction of mental associations among the macroscopic, microscopic and symbolic levels of representation of chemical phenomena using different modes of representation". The symbolic language of chemistry education should be introduced in small quanta and supported by scaffolding, and reinforced through constant practise (Taber, 2009).

In reviewing the existing literature on multiple representations in science education, several potential gaps emerge that warrant further exploration. This includes longitudinal studies, differences in MR development across diverse groups, developing MRs across disciplines, etc. This study is focused on the interplay between representational competence and fluency in Physics and Chemistry in preservice science teacher education which is elaborated upon in the next section.

Representational Competence and Fluency in Science Teacher Education

Representational competence refers to the ability to comprehend and utilise a set of domain-specific representations, such as graphs, models, diagrams and equations, to communicate understandings effectively (Daniel et al., 2018; Parsons, 2018). This competence is crucial for learners as it encompasses not only the interpretation of these representations but also the skill of selecting appropriate representations to convey specific concepts or ideas. In this sense, representational competence is somewhat static; it reflects the capacity of learners to recognise, access and employ various representations in their learning activities.

Representational competence in chemistry education refers to the ability of students to understand and manipulate various representations of chemical concepts. This includes the ability to interpret and utilise different forms of representation, such as molecular models, chemical equations, graphical data, diagrams and symbols (Popova & Jones, 2021). In contrast, representational competence in physics education refers to the ability of pupils to use multiple representations—such as verbal descriptions, mathematical equations, graphs, diagrams, and physical models—to understand and solve physics problems (Küchemann et al., 2021). This skill is crucial because physics concepts often cannot be fully grasped through a single representation alone.

In contrast, representational fluency involves the dynamic process of navigating between different representations to deepen understanding of a concept (Hill & Sharma, 2015; Tang et al., 2019). This fluency allows learners to fluidly move from one representation to another—such as shifting from a graphical representation to an algebraic expression or a physical model—which facilitates a more comprehensive grasp of complex scientific phenomena. Representational fluency is critical for problem-solving and conceptual understanding as it enables learners to relate different forms of information and synthesise their knowledge in meaningful ways. This has also been shown to be significant in mathematics education as highlighted by Lesh, Post, and Behr (1987), whose work emphasised the importance of learners' ability to seamlessly translate between verbal, pictorial and symbolic representations.

Representational fluency in chemistry education pertains to the ability to interpret and use different types of representations, including symbolic, macroscopic, and particulate-level formats (Gkitzia et al., 2020; Hilton & Nichols, 2011; Farida et al., 2009). Learners exhibiting multi-representational fluency can seamlessly transition between various representations—such as linking chemical equations to observable phenomena or particle diagrams. Moreover, educational tools like animations and simulations further enrich this learning experience. In contrast, representational fluency in physics education refers to learners' ability to effectively interact with and shift between various forms of representation—such as graphs, equations, verbal descriptions, and diagrams (Ceuppens et al., 2018; Handayani & Masrifah, 2021, 2024). This skill enhances their comprehension of complex physical concepts and improves their problem-solving abilities. It emphasises the significance of not only understanding each individual representation but also being skilled at translating among them, which ultimately deepens their conceptual understanding.

Thus, while representational competence is foundational and refers to the basic ability to use representations effectively, representational fluency builds upon this foundation by emphasising the importance of adaptability and cognitive flexibility. Learners who exhibit high levels of representational fluency can engage more deeply with the material, fostering a richer and more nuanced understanding of scientific concepts. Together, these two constructs highlight the necessity of developing both the specific skills associated with using representations and the cognitive strategies required to move fluidly between them, ultimately enhancing educational outcomes in science learning.

Purpose and Research Questions

Recent developments in science education research have highlighted the importance of representational competence and fluency in promoting conceptual understanding. However, further research is needed to explore the interplay between these two constructs. This study aimed to investigate the links between representational competence and fluency within the context of science teacher education. Drawing upon theoretical frameworks, empirical evidence, and practical insights, we compared the same cohort of preservice science teachers' representational competence and fluency in chemistry and physics. This study seeks to illustrate effective pedagogical practices that leverage MRs to enhance learning outcomes.

The following main research question is proposed:

• How does the same cohort of preservice science teachers compare in terms of their representational competence and fluency in Chemistry and Physics?

A sub-question that elaborates on the main research question is stated as follows:

• What differences does the same cohort of preservice science teachers show in terms of their competence and fluency when using the graphical, experimental, symbolic and verbal representational modes in Chemistry and Physics?

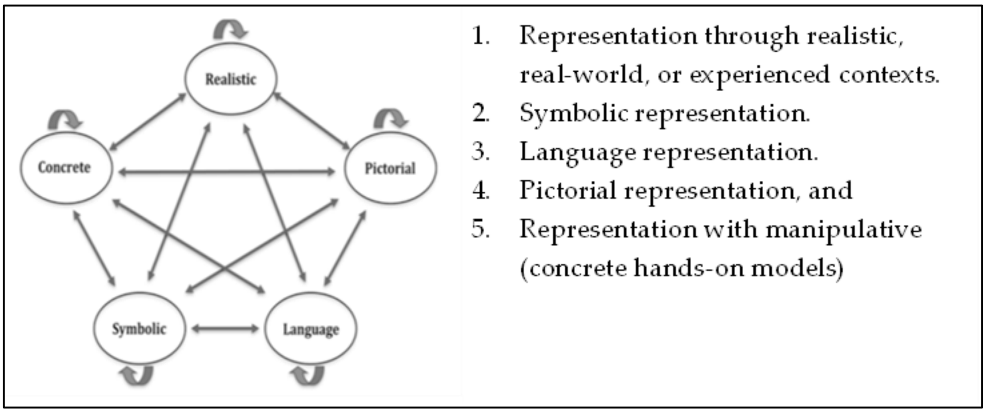
Measuring Representational Competence and Fluency

Numerous studies have sought to assess science students' representational competence (Kozma & Russell, 2005; Halverson & Friedrichsen, 2013; Mishra et al., 2018), primarily within specific contexts such as chemical or biological education. For students to effectively achieve specific objectives, they must be able to choose the appropriate representation for the task at hand (Prain & Tytler, 2013). In Science, Technology, Engineering and Mathematics (STEM) education, representational fluency is essential for engaging in professional discourse. Its promotion requires a collaborative effort among educators and researchers (Parsons, 2018).

Lesh and Doerr (2003) have shown that problem-solving in mathematics involves switching between different representations such as the spoken language, diagrams, equations, tables, etc. This is now referred to as the Lesh Translation Model (LTM) which consists of five nodes (Moore et al., 2018). These are illustrated in Figure 1 below:

Figure 1

The Lesh translation model (LTM)



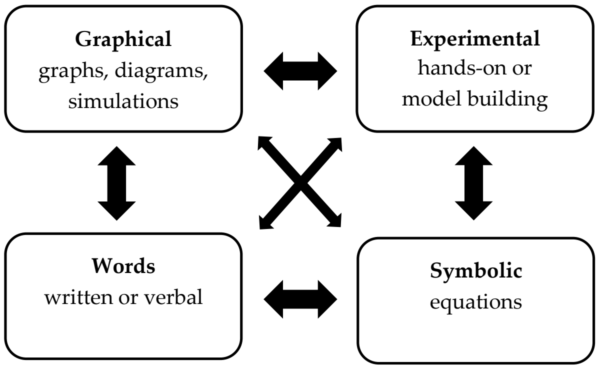
Note. Taken from Moore et al., 2018, p.20.

The LTM highlights that a deep understanding of a concept depends on using five different representations and being able to switch between them. By mastering these translations, learners can develop a more comprehensive grasp of ideas, preparing them to creatively and effectively address new problems. This multidimensional approach not only improves comprehension but also provides students with the skills to adapt their understanding to various contexts for a better learning experience.

This study has adapted the LTM and focuses on four representations and translations between them. These are shown in Figure 2 below:

Figure 2

The four representations adapted from the LTM



The adapted Lesh Translation Model framework provides a comprehensive structure that facilitates understanding and communication across multiple modes of expression—experimental, graphical, symbolic, and words. Each mode serves as a unique lens through which learners can engage with information, enhancing both comprehension and retention. A brief description of each mode is given below:

- Experimental Mode: This mode is centred around hands-on, experiential learning.
- Graphical Mode: This mode utilises visual representations to clarify and communicate information.
- Symbolic Mode: This mode relies on symbols and abstract representations to convey ideas and information.
- Words Mode: The traditional mode of communication that relies on verbal and written language to convey ideas.

The real strength of the adapted Lesh Translation Model lies in how these modes interact. By using multiple modes, educators can cater for diverse learning preferences and enable a more rounded understanding. For instance, a scientific concept can be learned through an experiment (experimental mode), visualised in a graph (graphical mode), expressed through a formula (symbolic mode), and then described in writing or discussion (words mode). When information is processed through various modes, it reinforces learning.

This adapted LTM has been used to compare the same cohort of PSTs' representational competence and fluency in chemistry and physics. Each lesson presentation in chemistry and physics was analysed in respect of the prevalence of the four modes and how they are integrated. This is expanded upon under the research procedure below.

Methodology

Research Design

This study uses a quantitative design which is nonexperimental, and specifically adopts a *descriptive comparative design* (Siedlecki, 2020). Characteristics of a sample population are compared and described without manipulating any variables. Depending on the data collected, the study can include descriptive and inferential statistics – the latter can be parametric or nonparametric (Siedlecki, 2020). The descriptive researcher's job is to focus on the most relevant features of a phenomenon as it exists in a real-world context (Loeb et al., 2017).

Furthermore, this study uses a quantitative research design because the data is numerical which allows for a more objective analysis (Privitera & Ahlgrim-Delzell, 2019). A quantitative study can also be conducted if the research questions, and hypotheses are narrow and measurable (Creswell, 2012). The numerical data that is collected is subjected to statistical analysis which allows for the hypothesis to be rejected when $p < .05$ (Lodico et al., 2010; Tavakol & Sandars, 2014).

Participants

The participants in this study are 39 preservice science teachers enrolled in a second-year level science methods course known as Natural Sciences Education. This is within a 4-year Bachelor of Education degree programme which would allow them to teach grades 4 to 7 once they qualify. The content covers biology, chemistry, geography and physics. This study explores the representational competence and fluency of the 2020 cohort and only focuses on chemistry and physics. These two disciplines were taught by the two researchers.

Data Collection

The second-year PSTs were required to present a physics model using an electricity kit they received. They had to demonstrate that it works and explain how it functions. The students had to submit a videorecording and upload it on the learning platform. Figure 3 below illustrates the use of a simulation to show light bulbs connected in parallel as presented by one of the PSTs. In chemistry, the same cohort of PSTs had to plan a lesson for a grade 7 or 8 class and practically demonstrate and explain the concepts which they chose for the lesson related to the curriculum. This had to be video recorded as well. Figure 4 shows the decomposition of water in the macroscopic, microscopic, and symbolic forms as presented by one of the PSTs. There were no restrictions placed on the PSTs to explain the concepts in both the physics and chemistry content. This allowed for a variety of representational modes to be used during the lesson presentation.

Figure 3

A typical use of a simulation to represent an electric circuit

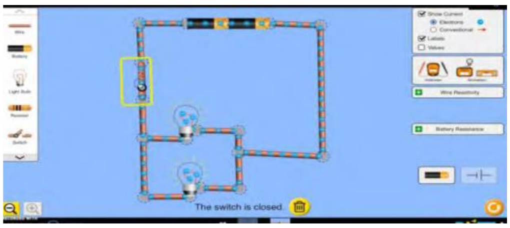
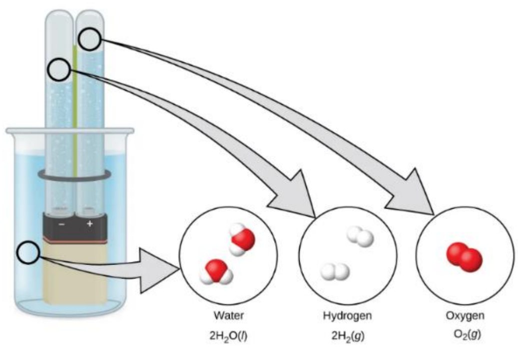


Figure 4

The decomposition of water



Note. Retrieved August 15, 2023, from https://openstax.org/books/chemistry-2e/pages/1-2-phases-and-classification-of-matter.

Sun and Van Es (2015) posited that video can capture the complexity of teaching, can be paused, and reviewed many times. Content presentation and pedagogical practices can also be analysed, whereas complex interactions in the classroom can also be observed (Dalland et al., 2020). The recorded lessons were transcribed after which coding was done of the competency and fluency relating to MRs during the lesson presentation.

Research Procedure

The lesson presentations and topic explanations in chemistry and physics provided by the PSTs were analysed based on their competency and fluency in each representational mode. This analysis was guided by the assessment rubric as developed by the researchers and presented in the Appendix. The competence and fluency in the different representational modes were categorised from low to high level and were assigned codes 1 to 3. The assessment rubric was developed based on the four representation categories in Figure 2 above. An explanation of the rating codes (1,2 and 3) follows while the inter-rater reliability is also indicated under the findings.

From the transcript each mode (graphical, experimental, symbolic, and non-specialist words) was coded as a 0 for no evidence, and 1, 2, or 3 for low-level to high-level of competence or fluency. Competence was analysed either as *inappropriate, partially appropriate,* or *appropriate* use of a specific representational mode as per the assessment rubric, whereas fluency was analysed either as the use of a mode that is *not linked, partially linked,* or *is linked* to other modes of representation.

A code 3 (high-level) was given to a mode of representation for competence and when it was used in conjunction with at least 2 other modes of representation which then promoted fluency. A code 2 (medium-level) was assigned when a partially adequate level of competence was evident, and it was linked to none or only one other representational mode. A code 1 (low-level) was allocated to a representation where no competence or low levels of competence was apparent for an attempt, despite this mode being linked to other modes of representation. A code 0 was given when there was no attempt made at using a specific representational mode.

The codes were captured on a spreadsheet which allowed then for the frequencies of each level for a particular representational mode to be tallied and converted into a percentage. This generated categorical data which allowed for the chi-square test to be applied as shown under data analysis.

Reliability and Validity

Reliability refers to the consistency of scores or a measure, whereas validity focuses on ensuring that the instrument accurately measures what it is supposed to measure (Lodico et al., 2010; Heale & Twycross, 2015). The inter-rater reliability is shown under the findings below.

Data Analysis

In this study, the non-parametric chi-square (χ^2) test is used because the nominal data obtained is in the form of frequencies, and the categories are mutually exclusive and independent (McHugh, 2013). Once the observed frequencies have been counted, they are used to calculate the chi-square statistic from a 4 X 2 contingency table. For a significance of $\alpha = .05$, and degrees of freedom, df = 3, the critical value from the chi-square table is 7.815. The null hypothesis is rejected if χ^2 is greater than the critical value, or if χ^2 is less than or equal to the critical value then we fail to reject the null hypothesis.

When the null hypothesis is rejected, it means that there is a relationship between the PSTs' representational competence and fluency in Chemistry and Physics. The extent of the relationship can be inferred from the extent to which the observed frequencies in a category exceed the expected frequencies and vice versa.

Findings

The content validity of the instrument used to assess the constructs of MR competence and fluency was done by two subject matter experts in Physics and Chemistry. Consensus was reached in terms of the instrument measuring competence and fluency in the different representational modes in Chemistry and Physics.

The inter-rater reliability was determined by calculating the Pearson correlation coefficient of the data. The data was coded independently by two science experts and yielded a value of r = 0.729. This indicates a strong positive correlation between the two sets of data which is illustrated in the scatterplot in Figure 5. The plot also shows a R^2 value of 0.53 which means there is 53% similarity between the data sets.

Figure 5

Scatterplot of data used to calculate Pearson correlation coefficient

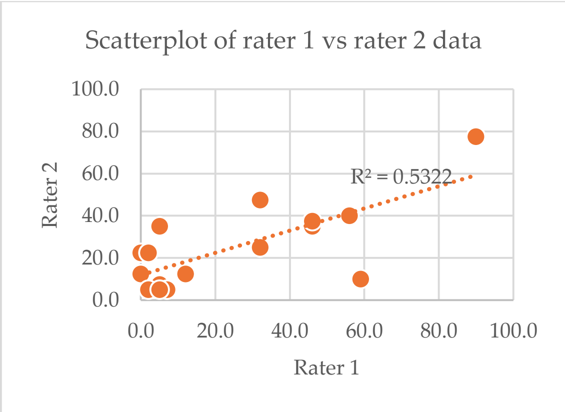


Table 1 shows that there were statistically significant differences between the same cohort of PSTs' representational competence and fluency in Chemistry and Physics on two of the representational modes. These were for the graphical and experimental modes, whereas there were no differences in relation to the symbolic and non-specialist words modes.

Table 1

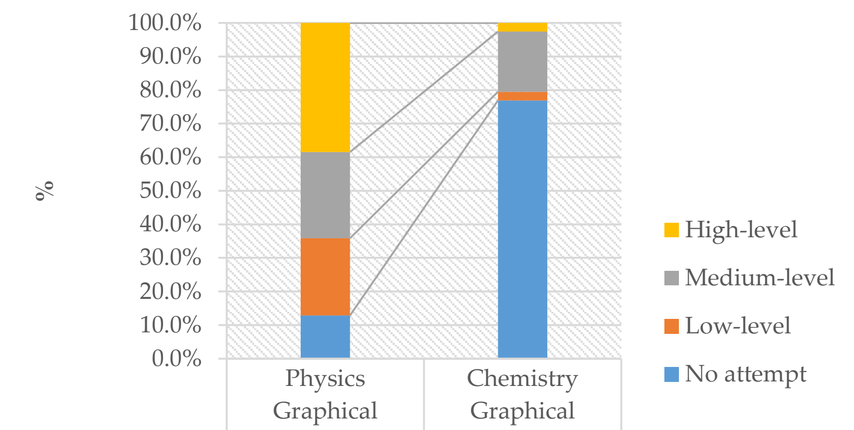
Chi-square statistics for different representational modes

Representational mode	χ^2	p – value	Significant ($p < .05$)
Graphical	37.04	$p < .001$	YES
Experimental	9.00	$p = .029$	YES
Symbolic	3.88	$p = .275$	NO
Non-specialist words	0.73	$p = .867$	NO

In Figure 6 the differences in the graphical representational mode for Chemistry and Physics are shown. The largest differences are in the no attempt, low-level and high-level categories.

Figure 6

Graph comparing graphical representation for Physics and Chemistry

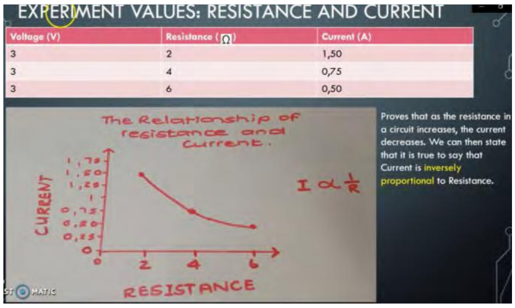


	Physics Graphical	Chemistry Graphical
High-level	38.5%	2.6%
Medium-level	25.6%	17.9%
Low-level	23.1%	2.6%
No attempt	12.8%	76.9%

A typical Physics example that illustrates a high-level of competence and fluency (code 3) is shown in Figure 7. Using a simulation, the student generated experimental data which were tabulated. A graph is then drawn to show the relationship between current and resistance in a direct-current electrical circuit. A symbolic representation of the relationship is then shown followed by an interpretation in words using the correct scientific terminology.

Figure 7

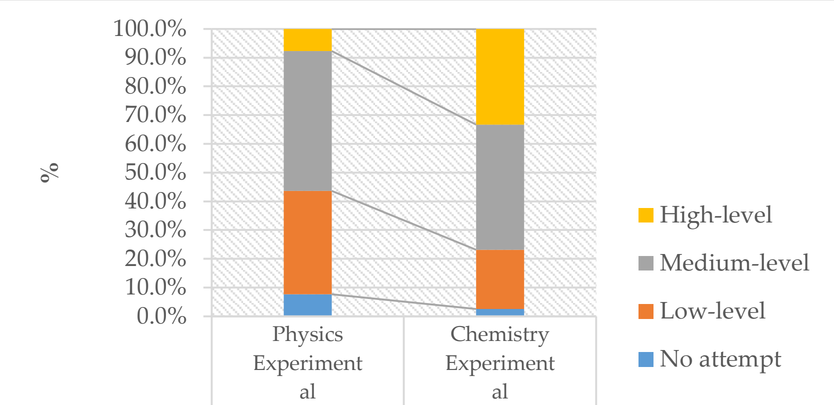
Translation from experimental data to graphical representation



In Figure 8 the differences in the experimental representational mode for Chemistry and Physics are shown. The largest differences are in the low-level and high-level categories. In Chemistry about 33% of the PSTs show a high level of representational competence and fluency, whereas in Physics 36% show a low level in the experimental representational mode.

Figure 8

Graph comparing experimental representation for Physics and Chemistry



	Physics Experimental	Chemistry Experimental
High-level	7.7%	33.3%
Medium-level	48.7%	43.6%
Low-level	35.9%	20.5%
No attempt	7.7%	2.6%

A typical Chemistry example that illustrates a high-level of competence and fluency (code 3) is shown in Figure 9. The students conducted an experiment to illustrate the pH of different solutions. A diagrammatic and symbolic representation of the concept is then shown which is accompanied by a verbal explanation using the correct scientific terms.

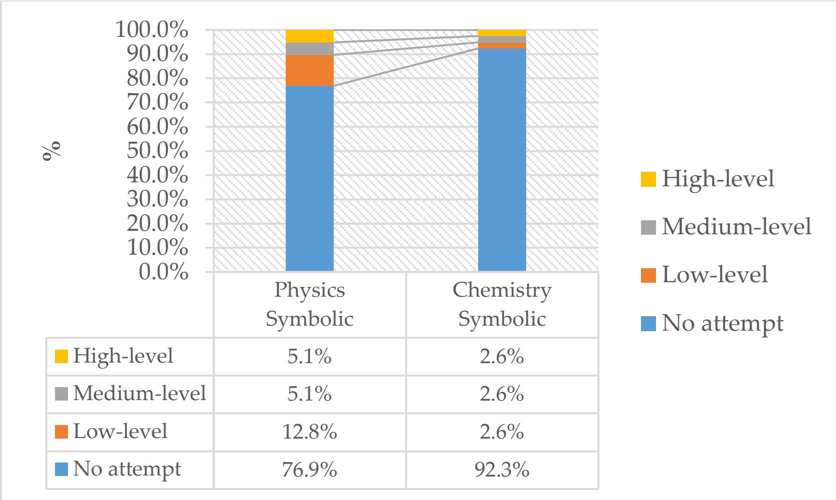
Figure 9

The experimental mode is integrated with the symbolic representational mode

Figure 10 shows that in both Chemistry and Physics there was a high percentage of PSTs who made no attempt to use the symbolic representational mode to explain concepts in these disciplines. As indicated above, the differences were not statistically significant.

Figure 10

Graph comparing symbolic representation for Physics and Chemistry

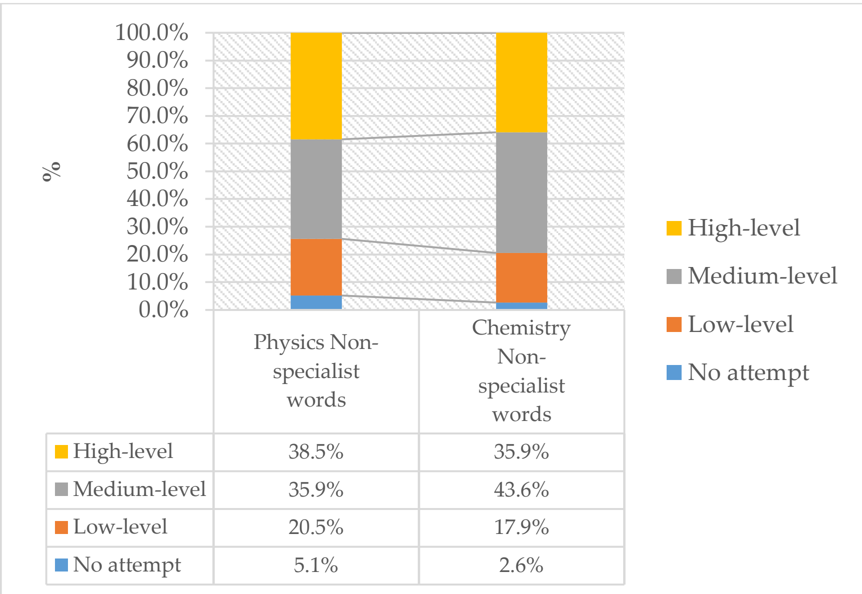


	Physics Symbolic	Chemistry Symbolic
High-level	5.1%	2.6%
Medium-level	5.1%	2.6%
Low-level	12.8%	2.6%
No attempt	76.9%	92.3%

The non-specialist words representational mode also yielded no statistically significant differences between Chemistry and Physics. The data and graph in Figure 11 clearly show that none of the categories contributed vastly different percentages.

Figure 11

Graph comparing non-specialist words representation for Physics and Chemistry



	Physics Non-specialist words	Chemistry Non-specialist words
High-level	38.5%	35.9%
Medium-level	35.9%	43.6%
Low-level	20.5%	17.9%
No attempt	5.1%	2.6%

Discussion

The chi-square analyses revealed significant differences in the modes of representation used by the same cohort of PSTs in physics and chemistry. Mathematical and graphical forms ($\chi^2 = 37.04$, $p < .001$) were favoured in Physics while phenomenological and model-based approaches ($\chi^2 = 9.00$, $p = .029$) were prevalent in Chemistry. This supports the notion that disciplinary focus influences representational preferences (Kohl & Finkelstein, 2017; Gilbert & Treagust, 2009). In both disciplines challenges were encountered with symbolic representations, which reflects broader difficulties related to task complexity and the ability to switch between representation types (Munfaridah et al., 2021;

Follmer & Sperling, 2020). This aligns with Hansen and Richland (2020), who noted that visual representations, particularly when paired with structured learning prompts, enhance understanding. The stronger competency observed among preservice teachers in Physics may stem from the discipline's reliance on graphical representations, particularly in areas like electrical circuits, although notable gaps in experimental skills indicate a need for pedagogical improvements in teacher education programs. This is in line with Yaman and Hand (2022) who encourage sustained engagements in representational practices.

No significant differences were found in the representational competence related to symbolic ($\chi^2 = 3.88$, $p = .275$) and verbal representations ($\chi^2 = 0.73$, $p = .867$), resonating with Chen and Gilbert (2009), who emphasized the importance of fostering mental associations across various levels of representation in Chemistry. It is particularly concerning that many participants did not attempt to engage with symbolic representations, suggesting a critical area for focus in teacher education programs. In addition, poor performance in verbal representation likely stemmed from a lack of disciplinary knowledge or misconceptions, rather than from representational challenges (Rau, 2020). Hill and Sharma (2015) suggested that students must not only choose appropriate representations but also integrate them effectively, as contextual factors such as task demands, and individual interests significantly influence understanding (Follmer & Sperling, 2020). These findings are consistent with Nichols et al. (2016), who stress that foundational competence in a single representation is crucial for successfully navigating and translating across multiple representations.

Overall, the study highlights the interconnectedness of representational competence, disciplinary preferences, and the challenges PSTs face in effectively integrating various representations, indicating a real need for targeted pedagogical strategies to enhance preservice teachers' ability to explain scientific concepts.

Conclusion

This study underscores the significant role that disciplinary focus plays in shaping the same cohort of PSTs' modes of representation in Physics and Chemistry. Their preference for graphical and mathematical forms in Physics contrasted with the phenomenological and model-based approaches favoured in Chemistry. This highlights the distinctive cognitive frameworks inherent to each discipline. Challenges were experienced in both Chemistry and Physics with symbolic representations, which can be attributed to the complexities of the tasks at hand. These findings reveal shortcomings related to representational competence and fluency in the South African context but also supports research findings internationally. It is evident that a lack of engagement with these representations points to a critical need for pedagogical interventions in teacher education programs.

Furthermore, the stronger competency in graphical representations in Physics observed among preservice teachers emphasises the necessity for enhanced training in experimental skills that complement theoretical knowledge. Notably, the lack of significant differences in symbolic and verbal representational competence raises critical questions about the underlying disciplinary knowledge of PSTs and suggests that misconceptions may hinder effective communication of scientific concepts.

Overall, our study advocates for a comprehensive approach to teaching that not only fosters foundational competence in distinct representation modes but also promotes the ability to translate and integrate these representations effectively. By addressing these challenges through targeted pedagogical strategies, we can enhance the representational competence and fluency of preservice science teachers, thereby improving their capacity to convey complex scientific ideas in their future classrooms. Future research should continue to explore the interplay between representation, discipline-specific pedagogy, and students' cognitive development, ensuring that teacher education evolves to meet the demands of modern science education.

Integrating technology into teacher education can further bridge the gap between theory and practice, utilising tools such as interactive simulations and digital visualisation software for real-time skill refinement. Future interdisciplinary research should explore the long-term effects of improved representational competence and fluency on science student achievement. This understanding is essential for refining teacher education curricula, and to ultimately prepare preservice teachers for contemporary challenges.

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Appendix

Assessment Rubric Developed By the Researchers to Measure Representational Competency and Fluency Levels

	Competency & fluency		
Representation mode	Low-level (1)	Medium-level (2)	High-level (3)
Graphical (Graphs / Diagrams/ Simulations)	Inappropriate graphical illustration that is not linked to the experimental, symbolic or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate graphical illustration that is partially linked to the experimental, symbolic or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate graphical illustration that is linked to the experimental, symbolic or word representation modes. Student demonstrates correct scientific understanding of concepts.
Experimental (Hands-on/model building)	Inappropriate experimental illustration that is not linked to the graphical, symbolic or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate experimental illustration that is partially linked to the graphical, symbolic or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate experimental illustration that is linked to the graphical, symbolic or word representation modes. Student demonstrates correct scientific understanding of concepts.
Symbolic (mathematical equations/ formulae)	Inappropriate symbolic illustration that is not linked to the experimental, graphical or word representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate symbolic illustration that is partially linked to the experimental, graphical or word representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate symbolic illustration that is linked to the experimental, graphical or word representation modes. Student demonstrates correct scientific understanding of concepts.
Words (verbal/written text)	Inappropriate use of words that is not linked to the experimental, symbolic, or graphical representation modes. Student demonstrates incorrect scientific understanding of concepts.	Partially appropriate use of words that is partially linked to the experimental, symbolic, or graphical representation modes. Student demonstrates partially correct scientific understanding of concepts.	Appropriate use of words that is linked to the experimental, symbolic, or graphical representation modes. Student demonstrates correct scientific understanding of concepts.

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Research-based learning: creative thinking skills of primary school pupils in science learning

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ABSTRACT
Creative thinking as a 21st-century skill is fundamental to human development and a catalyst for innovation. Researchers often study it because it encourages students to analyze, synthesize and evaluate information from various angles, which is essential for making decisions and solving complex problems. This study aimed to determine the difference in creative thinking skills between pupils who follow the research-based learning (RBL) and cooperative learning models. Data were collected from 60 primary school pupils using creative thinking skills instruments within a quasi-experimental design. Data analysis involved Analysis of Covariance (ANCOVA) to answer the research questions. The findings show that based on the results of the research and discussion, it can be concluded that the RBL learning model has a significant effect on learners' creative thinking skills in science learning. Where there are differences in creative thinking skills between pupils who follow the RBL learning model and those who follow the Cooperative Learning learning model, it can be seen from the results obtained in the experimental class and control class. Thus, RBL can be recommended for improving pupils' creative thinking skills rather than cooperative learning in science classes at the primary level.

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Introduction

Creativity and innovation are necessary to survive in the ever-changing modern world (Rumanti et al., 2023). The capacity for technological achievement, creativity, innovation diffusion, and knowledge generation are fundamental conditions for providing competitive advantage, economic growth, and sustainable development in the global arena (Khan et al., 2022). The 2016 Technology Achievement Index reported that Switzerland ranked 1st and Indonesia ranked 83rd out of 105 countries (Guz et al., 2017). The Frontier Technologies Readiness Index report in 2023 reported that the USA occupied position one and Indonesia occupied position 85 (WOF, 2023). One of the fundamental components of the UN's 2030 sustainable development agenda is the quality of education (Haleem et al., 2022). In education, it is necessary to develop generic competencies such as creativity and innovation (Vuk, 2023). Creative thinking helps professionals to succeed in complex problem-solving and decision-making processes and successfully adapt to the demands of everyday life (Khalil et al., 2023).

Creativity is a hot topic right now. Creativity is often equated with innovation as the spread of new ideas. Nevertheless, innovation arises from the belief that individuals can be persuaded to be creative (Anderson et al., 2014). However, some have also conceived of creativity as an innate and individualistic process that results in innovation. Creativity as an artistic practice has been attributed to the cognitive thought processes of individuals in a state of deep reflection (De Souza E Silva & Xiong-Gum, 2021). The evidence in the Faculty of Pedagogy at the Sofia University St. Kliment Ohridski-Bulgaria, where the teachers successfully developed students' skills from the 4C group through independent work (realized through research and creative tasks). Students involved in the study showed that independent tasks require creativity and innovative approaches as well as the development of learning skills (Batlolona et al., 2019). Students had enough to develop their creative skills through various forms of individual and group work, in line with the skills required for 21st-century teachers (Gyurova, 2020).

Creativity is also associated with other cognitive activities, such as leadership, critical thinking, decision-making, metacognition, motivation and behaviour (Karunarathne & Calma, 2024). Research suggests that teachers need to be trained and supported to equip students with strategies, approaches, resources and environments to promote creativity (Ruiz-del-Pino et al., 2022). In today's rapidly evolving and changing world, creative and productive people who can solve problems using different perspectives are needed (Wenno, 2021). In the world of education, productive teachers who never stop working and always renew themselves and their students to new things are needed (Batlolona, 2023). In this case, the education provided in schools must be open and make a difference (Malkoç, 2015). Creative thinking has acquired an important position due to its importance in preparing a new productive generation capable of taking the initiative (Tawarah, 2017). Global data shows that education in Latin American countries has shortcomings and is still far from reaching the highest levels when compared to developed countries (Hernandez-Leal, Duque-Mendez, and Cechinel, 2021).

The EU also recognizes the importance of creativity for the economy and science and social development, especially in reference to global challenges such as climate change. According to it, creativity is the main source of innovation and encouraging creativity is the goal of the European community (Andiliou & Murphy, 2010). Creativity is, therefore, a requirement for school graduates, yet in Germany, it is still not an integral part of school education (Semmler & Pietzner, 2018). Creative thinking is an essential skill for teachers, enabling them to adapt to the environment and curriculum, solve problems, design engaging lessons, manage the classroom, and develop a positive learning environment (Fredagsvik, 2023). It is important to incorporate creative thinking into classroom activities to achieve educational goals. Many students in the Asian region receive little exposure to creative teaching practices during their studies that must be why they are so successful and their hi-tech economies are so vibrant. It may be because traditional educational approaches are prioritized, which are structured around curriculum and academic outcomes, reducing the scope for originality and creative thinking that’s because they realise that one needs a solid base of factual knowledge before one can be creative and build on it. As a result, some may lack confidence in their ability to think creatively, thus limiting their ability to integrate creative thinking into the classroom effectively. Thus, students and teachers can benefit from continuous professional development, training programs, workshops, mentoring, and guidance from experienced teachers to enhance their creativity in designing and managing classroom activities. (Suchyadi et al., 2020; Siagian et al., 2023).

Undoubtedly, primary school children have different characteristics and learning processes than adults. The prioritisation scale in the USA for 21st-century skills includes life and vocational skills, learning and innovative skills, and information, media and technical skills. Innovative learning and skills emphasise the importance of problem-solving. For science education, problem-solving helps pupils make connections between science concepts by actively working to find solutions, rather than passively receiving information. This approach is effective after students have built a foundational knowledge base (Chen & She, 2015). The main goal of learning biological science in primary school is for children to gain a conceptual understanding of fundamental concepts, rather than simply memorizing a large number of biological facts, which is often seen as a limiting approach. However, one might question how understanding can be cultivated in the absence of factual knowledge (McDaniel et al., 2022). Research shows that biology, of all science subjects, has the most interest among school learners (Nwuba et al., 2023), while girls tend to like biology more than boys (England et al., 2019). Whereas the results of a different study from Finland on 3626 for pupils at the age of 15 years showed that more boys than girls were interested in basic processes in biology, while more girls than boys studied human biology and health education (Uitto et al., 2006). A number of studies on pupils' learning strategies have been conducted, focusing on learners' behaviours and thoughts that influence their cognition process in learning. Implementing modern learning designs can encourage pupils to utilize active learning strategies to learn biology. The application of active learning strategies can influence their biological conceptual understanding, attitude and motivation. Therefore, it is crucial to explore their biology learning strategies (Shen et al., 2018). One of the strategies that can be applied in increasing their conceptual biology to become better scientists in the future is research-based learning (RBL).

Research results that focus on creativity can create new products, which can then improve conditions in the socio-economic community and improve the identity of a nation. Innovation through quality research and patents also has an additional impact on improving the finances of business people which has a positive effect on improving the economy and welfare of the community. China is increasing its capacity in a range of disciplines to better understand the social impact of new fields, such as nanotechnology and artificial intelligence, and to drive innovation in digital health (Cao, 2023). China has successfully lifted its 700 million population through domestic innovation. South Korea and Israel have significantly strengthened their economies through intensive research and development, followed by successful integration into global markets. Israel, in particular, serves as an exemplary case of how a country with largely arid lands has become one of the largest exporters of agricultural commodities. This transformation has been driven by ongoing innovation and uninterrupted research efforts. Additionally, North America and Western Europe account for a majority of global research, comprising 46.1%, while East Asia and the Pacific follow with 40.6% (Acharya & Pathak, 2019).

RBL is a learning model for students to learn new skills and knowledge by working on a project (Thiem et al., 2023). A key aspect of RBL is that students are required to take an active role in their learning, meaning that students can identify and explore problems and questions, conduct research, and develop solutions themselves. Previous research shows that RBL increases students' research skills and interest in pursuing a research degree in the future (Camacho et al., 2021). RBL can improve retention and develop scientific character. In addition, RBL helps students contribute to faculty research productivity when integrated into academic activities, arouses subject motivation, and develops an understanding of research methods (Fuller et al., 2014). RBL, a synonym of inquiry-based learning, which links research and teaching in the academic environment (Yeoman & Zamorski, 2008).

RBL is a student-centred pedagogy where students conduct research projects under the guidance of a supervisor: they pose and frame research questions, review literature, collect and analyse data, propose answers and explanations, and communicate the results. RBL facilitates active student engagement and promotes deep learning (Archer-Kuhn et al., 2020). Effective RBL learning experiences are largely evidenced in science, technology, engineering, and mathematical disciplines, thus leaving room for further research in other disciplines (Wessels et al., 2021). Research results show that RBL is challenging for undergraduate students but also beneficial in developing their work readiness and professional identity skills. It is demonstrated by the experiences of academics and undergraduates in two business faculties, one in Australia and the other in Finland (Bowyer & Akpinar, 2024). Proponents of research-based learning have pointed out the need to develop enthusiasm for critical questioning, resourcefulness and creative solutions in undergraduate students (Guinness, 2012). One of the most advanced ways is RBL, where students actively participate in the research process. The purpose of RBL is not only to improve students' research competence but also to improve their general professional qualifications by teaching them key competencies such as communication, presentation, and problem-solving skills. Therefore, RBL is considered a 'panacea' to address the various demands in basic education and higher education. The purpose of this study is to determine the difference in creative thinking ability between students who follow the RBL learning model.

RBL has proven its superiority in overcoming various learning problems related to cognitive aspects, behaviour, and affective experiences for pupils. Some of the related reports include learning outcomes and academic performance (Worapun, 2021); critical thinking and self-regulation (Reyk et al., 2022; Salvador & Buque, 2024); Critical thinking (Usmeldi et al., 2017); scientific questioning and experimental skills of primary school pupils) (Khumraksa & Burachat, 2022), scientific process skills (Usmeldi, 2016; Behrmann, 2019); analytical thinking skills (Suyatman et al., 2021); creative thinking (Khwanchai et al., 2017; Supit & Winardi, 2024); attitude (Dvorak et al., 2021; Usmeldi, 2016); problem solving (Suyatman et al., 2021). With this information in mind, there is still a lack of studies that reveal the effect of RBL on creative thinking variables. The potential of RBL to creative thinking skills is very limited, in addition to the lack of related research results, and this model is rarely widely known in the community. The information that has not been revealed must be followed up in research. Thus, the question that needs to be answered in this study is whether RBL influences students' creative thinking skills in science learning for primary school pupils.

Aims

This study aimed to analyze the effect of the RBL learning model on students' creative thinking skills in Biology science learning in primary schools.

Rationale

The goal of science education in primary schools is to introduce pupils to basic science concepts that are relatable to their everyday lives. This means that the content should focus on the real-world experiences of the students and connect with their existing knowledge. In particular, the biology curriculum for primary schools encompasses factual, conceptual, procedural, and metacognitive knowledge (Jeronen et al., 2017). To effectively teach biology to primary school pupils, it is essential to employ a strategy, approach, or learning model that is appropriate for their developmental level.

In Indonesia, many schools still implement the 2013 curriculum, although some have switched to the Merdeka curriculum. The Government, through the Ministry of Education and Culture, highly recommends the 2013 curriculum. This curriculum requires teachers to fully and consistently apply the Scientific Approach. The Scientific Approach is aligned with the scientific method, which involves collecting data through observation or experimentation, followed by processing the information, analyzing it, and testing hypotheses (Emden, 2021). Learning Biology through a scientific approach encourages students to think like scientists, helping primary school pupils develop higher-order thinking skills, including creativity and innovation in achieving the learning objectives set by their teachers. In teaching Biology, in addition to adopting the scientific approach, teachers have the flexibility to choose learning models that align with the subject matter, student characteristics, and the scientific approach. One effective learning model for this purpose is the Research-Based Learning (RBL) model. The RBL model is grounded in the philosophies of constructivism, behaviorism, and cognitive learning. Its main characteristics include helping pupils construct their understanding, build on prior knowledge, foster social interaction, and achieve meaningful learning through real experiences (Estuhono & Efendi, 2024). This student-centered learning model integrates research activities and can be implemented both inside and outside the classroom or in laboratory settings (Kerimbayev et al., 2023).

Research activities conducted within the RBL (Research-Based Learning) model offer a unique experience for primary school pupils in science-biology education. These activities highlight the importance of research for aspiring scientists and stimulate students' curiosity and creative thinking skills. Pupils are likely to find joy in engaging in hands-on learning activities that incorporate scientific practice and evidence, rather than relying solely on lectures or group discussions commonly used in traditional learning environments.

This enthusiasm among pupils is anticipated to foster the development of creative thinking skills, encouraging them to adopt various perspectives when presenting scientific explanations or devising problem-solving solutions. The lack of scientific information and studies examining the impact of RBL on pupils' creative thinking in science-biology education underscores the necessity of research in this area, especially for primary school pupils.

Research Question

Does the RBL learning model influence the creative thinking skills of primary school pupils in Science-Biology learning?.

Methods

Research Design

This type of research is *quasi-experimental and* conducted under conditions that do not allow controlling or manipulating all relevant variables (Harris, 2006). The research design used in this study was *pretest-posttest control group design*. This research design involves two classes, namely the experimental class and the control class. Before treatment, both groups were given a *pretest,* and after treatment, both groups were given a *posttest*. The design of this study is presented in Table 1.

Table 1

Pretest-posttest control group design

Group	Pretest	Treatment	Posttest
A	T_1	X	T_2
B	T_1	Y	T_2

Note. Description: A = Experiment Class, X = Application of *Research-Based Learning* Model, B = Control Class, Y = Application of *Cooperative Learning* Model, T_1=*Prestest* administration, T_2= *Posttest* administration

Population, Sample and Procedures

The population in this study were pupils of class IV primary school cluster V Inamosol sub-district, which amounted to 79 pupils. The sample in this study amounted to 60 children, consisting of 30 as a control class and 30 as an experimental class. determination of the experimental class and control class is based on the results of the lottery. The implementation of learning was carried out eight times in class meetings. The biology topics taught were: 1) Plant parts and their functions; 2) Classification of animals based on the type of food; 3) Cycle of living things and efforts to preserve it; 4) The life cycle of animals and how to keep pets.

The independent variable (X) is the RBL model, while the dependent variable (Y) is the ability to think creatively. The techniques used in this study were direct and tests to obtain scores of creative thinking (an initial test and a final test). The instrument used was a description test.

Learning with RBL was carried out in the experimental group, while the control group used the learning model used by the teacher, namely the Jigsaw cooperative learning model. Learning refers to the theme of Caring for living things, with subthemes 1) animals and plants in my home environment (2 lessons), 2) diversity of living things in my environment (3 lessons), and 3) let us love the environment (3 lessons). Before the treatment, each group took a pretest of creative thinking skills. 2) Learning in the experimental and control groups was conducted with the same teacher, teaching materials, and all learning-related matters except for the learning model. The time allocation for learning is 105 minutes. The subject matter that was taught included 1) the structure and function of plant organs, 2) types of animals based on their food, 3) and the cycle of living things. The lesson plan was developed by researchers referring to the thematic curriculum in the fourth grade of primary school using the learning model used in this study. Of course, in developing learning, it must refer to the Core Competencies, which have then been translated into basic competencies (KDs). There are 2 basic competencies used as a reference, namely KD. 3.1 Analyse the relationship between the form and function of body parts in animals and plants (cognitive aspects) and KD 4.1 Present reports on observations about the form and function of body parts in animals and plants (psychomotor aspects). From the KD, indicators of competency achievement and learning objectives are formulated and arranged in learning activities 8 times.

Learning with RBL was carried out following the syntax of the RBL learning model. The learning steps consisted of 5 phases, namely 1) formulating problems, 2) reviewing theories, 3) planning investigations, 4) researching and analysing data, and 5) explaining research results. Before formulating the problem, pupils were given readings about the subject matter. The content of the subject matter was related to the theory or basic concepts according to the subject matter being taught. When planning the investigation, the teacher gave directions to the pupils to prepare tools and materials and understand research procedures by reading several times. If it was clear enough, they were asked to conduct research according to the research procedures the teacher had designed according to their learning needs. The results of the research were entered in the existing observation table. The group discussed entering data into the formats according to the teacher's instructions. In class, groups were asked to explain the research results they obtained in front of the class.

Instrument

The test used in this study is a test of creative thinking skills based on the subject matter of plant parts and their functions, the classification of animals based on the type of food, and the life cycle of living things. A valid and reliable creative thinking skills test instrument was used to collect creative thinking skills data. Data collection was done twice, namely pretest and posttest, on the three learning models. The scoring key was modified from Treffinger et al. (2002), with a range of 0-4. The assessment key was developed from each indicator of creative thinking skills. The creative thinking skills assessment rubric is presented in Table 2.

Table 2

Scoring rubric of creative thinking skills

Indicator	Criteria	Score
Fluency	Mentioning/writing five or more ideas, suggestions or different alternative answers	4
	Mentioning/writing three ideas, suggestions or different alternative answers	3
	Mentioning/writing some ideas, suggestions or alternative answers that are not very different	2
	Mentioning/writing one idea, suggestion, or alternative answer	1
	Not answering or giving a wrong answer	0
Originality	Mentioning/writing several interesting, unique ideas that are logical, relatively new and relevant to the given problem	4
	Mentioning/writing several interesting, unique ideas that are logical, relatively new, but not quite relevant to the given problem	3
	Mentioning/writing quite interesting, unique ideas that are quite logical, relatively new and quite relevant to the given problem	2
	Mentioning/writing an ordinary idea that is logical and relevant to the given problem	1
	Not answering or giving a wrong answer	0
Elaboration	Explaining several logical details of an existing idea so that the formulation of the idea becomes clearer and can be applied more easily	4
	Explaining one logical detail of an existing idea so that the formulation of the idea becomes clearer and can be applied more easily	3
	Giving several logical details of an existing idea but not quite relevant to the concept of the main idea, so does not make the idea clearer.	2
	Not adding any details of an existing idea so that the formulation of the idea cannot be applied well	1
	Not answering or giving a wrong answer	0
Flexibility	Writing several alternative answers that are very logical and relevant to the given problem from different points of view	4
	Writing a few alternative answers that are quite logical and relevant to the given problem from different points of view	3
	Writing several alternative answers that are quite logical but less relevant to the given problem from different points of view	2
	Writing one alternative answer that is quite logical and relevant to the given problem with only one point of view	1
	Not answering or giving a wrong answer	0

Note. Modified from Treffinger et al. (2002)

Data Analysis

The creative thinking test data is obtained, processed and analyzed to be able to answer the formulation of problems and research hypotheses. The data analysis used is hypothesis testing regarding differences and population averages. The test used is the ANCOVA test. The ANCOVA test was used to determine whether or not there is a significant difference (convincing) between the two *mean* (average) samples. Before hypothesis testing was carried out, the prerequisite analysis tests were carried out, namely the normality test and the homogeneity test. Prerequisite test analysis consists of a normality test in which the data were analysed first to determine the normality of the research data, to test whether the creative thinking ability data (*posttest*) obtained from the control group and the experimental group came from a normally distributed population or not. Then, the homogeneity test was carried out after the normality test. The homogeneity test was used to determine whether the variances of the two groups have the same population (homogeneous) or not.

Furthermore, if the population data is normally distributed and the data is homogeneously distributed, the ANCOVA test is carried out with a significant level of 0.05. This hypothesis testing aimed to determine whether the average value of the creative thinking ability of experimental class students was higher than the control class. The experimental class used the RBL learning model, while the control class used the cooperative learning model.

Findings

The data report of the findings showed that RBL greatly contributed to improving the creative thinking skills for each indicator, namely fluency (F), flexibility (Fe), originality (O), and elaboration (E) of pupils when compared to the cooperative class. This can be found in Figure 1.

Figure 1

Description of students' creative thinking skills for each indicator in rbl and cooperative classes

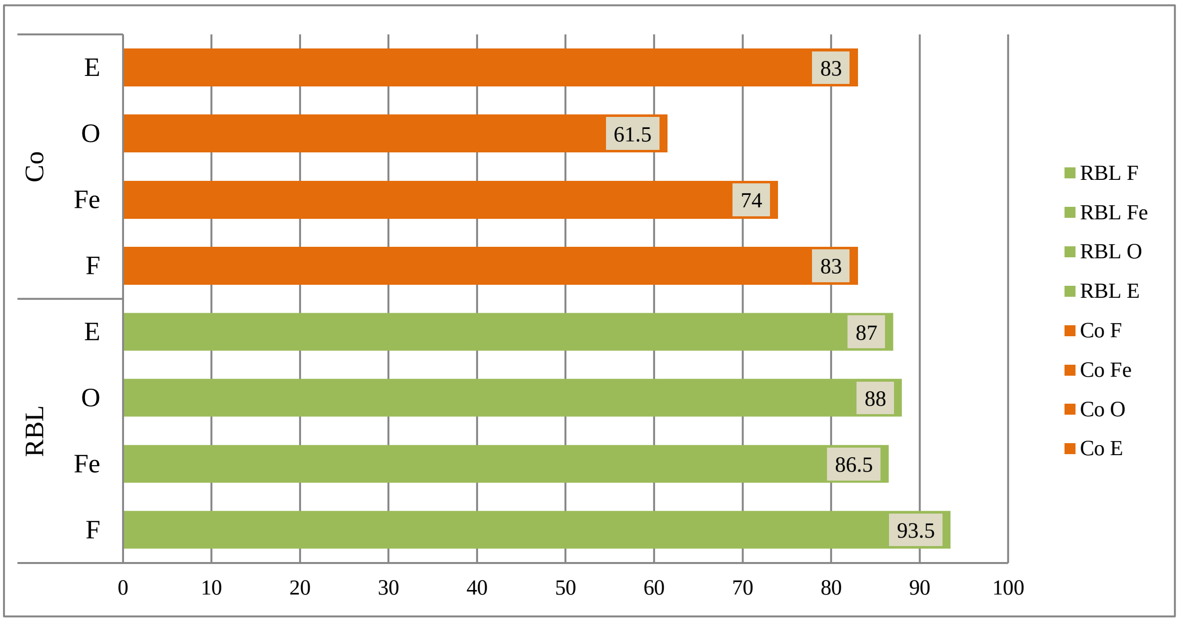
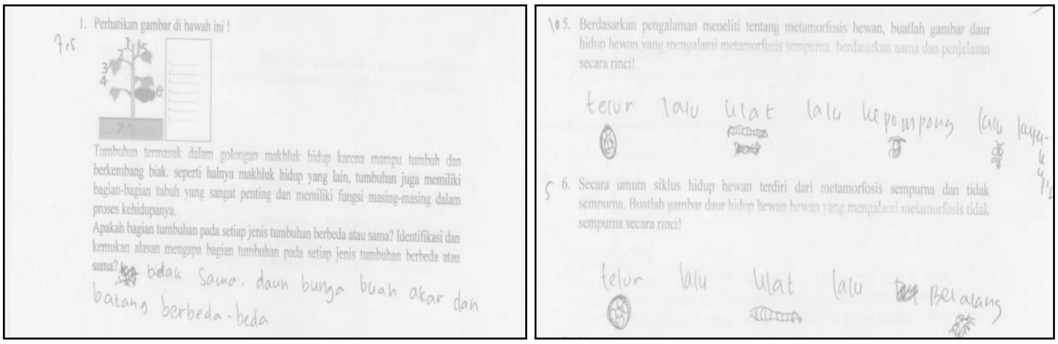


Figure 1 shows that the most prominent indicator of creative thinking skills in both learning models is fluency. This means that students can provide more than one solution to the problems given related to plant organ material. Students can describe or write their ideas creatively when they are taught with two different learning models. They use imagination in describing one of the life cycles that experience perfect metamorphosis in butterflies. Some of the students' work on their worksheets are shown in Figure 2.

Figure 2

a) Results of Creative Thinking Answers in the Flexibility (RBL) and b) Elaboration (Cooperative



(a) (b)

Based on the results of the *pretest* and *posttest* calculations of the experimental group and control group consisting of 60 attachment pupils, the data obtained are as shown in Table 3.

Table 3

Results of pretest and posttest data calculation

Frequency distribution	Experiment		Control	
	Pretest	*Posttest*	*Pretest*	*Posttest*
Lowest score	24	68	24	48
Highest score	64	92	72	76
Mean	45.20	79.80	47.16	64.83
Median	42.00	80.00	46.00	64.00
Standard deviation	11.17	7.61	11.12	7.18

Before researching the experimental group and control group, a *pretest* was conducted to determine the initial ability of the pupils. from the pretest results, the average score of the experimental group is 45.20, and the control group is 47. Table 4 shows that there were changes after the intervention. The biggest change occurred in the experimental group, namely the increase in the average value from 45.20 to 79.80, which is 34.6. Similarly, the control class experienced an average increase from 47.16 to 64.83, which is 17.67. It means that the increase in the average value after being given treatment in the experimental class is higher than in the control class.

The data on the creative thinking ability of the two groups in this study are normally distributed and homogeneous, so the data testing on the creative thinking ability of the two groups is continued in the next data analysis, namely hypothesis testing using one-way ANCOVA test using the assistance of the IBM SPSS for windows programme, namely by comparing the calculated significance of each independent variable with the dependent variable with a significance level of 5%. Decision-making for the ANCOVA test follows the following guidelines: If the Significance (Sig) value is less than 0.05, then Ha accepted; otherwise, if the Sig value is greater than 0.05 then Ha rejected. Therefore, there is a difference in creative thinking skills between students who follow the RBL learning model and students who follow the CL learning model. The results of the hypothesis test is presented in Table 4.

Table 4

Hypothesis test calculation results

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3501.255[a]	3	1167.085	21.515	.000	.535
Intercept	16368.576	1	16368.576	301.752	.000	.843
Class	606.998	1	606.998	11.190	.001	.167
Prekbk	21.783	1	21.783	.402	.529	.007
class * prekbk	124.094	1	124.094	2.288	.136	.039
Error	3037.728	56	54.245			
Total	320321.000	60				
Corrected Total	6538.983	59				

Tests of Between-Subjects Effects

Dependent Variable: creative thinking skills posttest

a. R Squared = .535 (Adjusted R Squared = .511)

The results of the study in the *Test of Between-Subjects Effects* table obtained sig. in the class row of 0.001> 0.05 so that it was declared H_a accepted. This shows that there are differences in creative thinking skills between students who follow the RBL learning model and students who follow the *Cooperative Learning* model [F (1,56) = 11.190, p = 0.001, np^2= 0.535].

Discussion

Based on the research results obtained during the implementation of the *pretest* for students in the primary school cluster V Inamosol sub-district before learning activities, it shows that the average value of experimental class students is 45.20 with the highest score of 64 and the lowest score of 24 while the average value of the control class is 47.16 with the highest score of 72 and the lowest score of 24. The *posttest* was carried out after learning activities were carried out, where the two classes had been given material about plant parts and their functions, types of animals based on their food and animal life cycles and how to care for animals based on learning competency indicators using the RBL learning model for the experimental class and the CL learning model for the control class. The *posttest* results of creative thinking skills show that the average value of the experimental class is 79.80, with a highest score of 92 and the lowest score of 68, while the average value of the control class is 64.83, with a highest score of 76 and the lowest score of 48. This shows that pupils have well understood the learning competency indicators.

The learning process that took place in the experimental and control classes was carried out based on the Learning Implementation Plan (RPP) that had been designed and carried out for eight meetings. In the learning process that took place in the experimental class, the researcher showed the material (types of plants, types of animal food, types of animals) which made students interested in observing and knowing more about the material being studied. Then, the researcher asked questions about the material shown and provided opportunities for the children not only to answer but match each other's answers and discuss differences. Furthermore, the researcher explains the material that has been shown and other things related to the material. It makes pupils focus and look for information related to the material to re-discuss their answers. Furthermore, the researcher provides an opportunity for students to choose material (plants in the surrounding environment, plants that animals can eat, animals in the surrounding environment) and make a list of questions related to the selected material. It makes pupils curious so that they eagerly choose material and ask questions. Furthermore, the researcher divides the children into groups, gives directions on research procedures, and helps students prepare tools and materials. It makes them work together in teams to make research plans. Furthermore, they conduct research and present the results thereby practising what has been obtained and find what they are looking for. Then, students make reports and present the results so that learners are more thorough, creative and brave in conveying what has been obtained both in writing and orally.

The data above shows that RBL is superior to cooperative research because the RBL model can make innovations in each specific field, and also contributes to the creative and analytical abilities of learners. The research process can help learners to manage their knowledge, shape learning autonomy behaviour and understand the learning environment. In conducting research, a researcher needs to process and present data systematically. Therefore, learners in courses designed for research-based learning are instructed to process information to synthesize problems, select methods to find solutions, systematically design data collection processes, and present research results scientifically (Worapun, 2021). RBL is beneficial to the development of teaching skills between students and teachers. In addition, it trains both learners' and teachers' active learning skills and brings satisfaction to learning (Salvador & Buque, 2024). RBL can increase cognitive, affective and psychomotor, which is effective for increasing pupil engagement (Wessels et al., 2021). The results of an RBL study for Computational Engineering undergraduate students at Tecnologico de Monterrey, Mexico City Campus showed that students were able to work in teams for a semester. Most teams, guided by the instructor, were able to develop high-quality monographs and sketches suitable for their team's proposed research paper (Noguez & Neri, 2019).

RBL is different from cooperative learning even though both are student-centered models. RBL focuses on research, while cooperative learning focuses on cooperation between students in groups to complete group assignments. The concept of research in primary school pupilss can be designed simply by presenting phenomena that exist in their environment, in addition to providing stimuli in the form of questions that help students think to solve problems by conducting investigations. The research procedure is explained in detail to students, so that they understand the research procedure. The most important thing here is that students realize the importance of the research, why, for what and how to do it.

In the cooperative learning model pupils learn in small groups of 4-6 students heterogeneously, providing opportunities for them to work together, positive interdependence among students and be able to take responsibility independently (Mallick et al., 2023). Previous findings Janah & Subroto (2019) stated that RBL is superior to a cooperative learning model. The teacher conveys learning objectives and motivates pupils then the teacher presents information through media or learning resources. In conclusion, the learning outcomes in experimental group differ from control group. from the learning source after the teacher organises students into groups and guides them in working on problems. Then, the teacher evaluates the learning outcomes achieved. This means that passive students in the group only follow active students, so only active students understand the problems given by the teacher better.

With the application of the RBL model, students feel happy and interested in participating in learning; students are also more creative, critical and confident in conveying ideas and solving problems. This is evidenced by an increase in motivation and science learning outcomes (Tupan et al., 2024) and an increase in students' analytical thinking skills (Liline et al., 2024). In contrast to the above research, this study states that RBL is a learning model that has an influence on students' creative thinking skills where RBL is able to improve students' creative thinking skills significantly; this can be seen from the average value of the experimental class *posttest* which is 79.66 or in the high category (Zubaidah et al., 2017), this proves that the RBL model is a learning model that affects students' creative thinking skills. From some of the findings and explanations above, it is evident that there is an influence of the RBL model on students' creative thinking skills.

RBL can help students and teachers innovate in experimentation. This is how new practices are integrated into existing practices in school learning. With RBL implementation, students improved by 67%, compared to Cooperative, which was only 40% (Siegel, 2005). Research results (Gillies, 2023) showed that RBL consistently demonstrated that students achieved higher learning outcomes when compared to peers taught with a cooperative approach. RBL will help students develop an understanding of the content, but also dialogic practices that will help them to engage in constructive discussions and facilitate critical thinking in learning. When teachers dialog with students, they not only provide different models and scaffolds but also provide feedback to help students develop clearer and deeper understanding.

The results of the ANCOVA test analysis on the creative thinking ability of the experimental class and control class based on *pretest* and *posttest* data of 60 students, obtained a significance value of 0.001 ($p = <0.05$) so it can be concluded that the hypothesis stating the effect of the RBL model on creative thinking ability is accepted. This is evidenced by the frequency distribution data of the *posttest of* creative thinking skills, where in the experimental class, there were 7 students in the medium category and 23 students in the high category. In contrast, in the control class, there were 3 students in the low category, 23 students in the medium category and 4 students in the high category. In addition, descriptive data of the research results that followed the RBL learning model showed an average value of 79.80 or in the high category, while the control class was 64.83 or in the low category. In addition, the percentage of creative thinking skills in the experimental class for *flexibility* indicators 86.5, *originality* 88, *elaboration* 87, and *fluency* 93.5, while the percentage of creative thinking skills in the control class for *flexibility* indicators 74, *originality* 67, *elaboration* 61.5, and *fluency* 83 means that the experimental class has higher creative thinking skills than the control class.

In RBL, students were assisted in improving creative thinking skills through activities carried out by the teacher. The progress of creative thinking skills can be measured, and progress from each indicator can be measured. Students must think directly in making their ideas. The selection of essential problems must be considered because to provide solutions to agreed problems, and questions are designed to stimulate student thinking to create various ideas so as to improve the fluency aspect (Yustina, 2022). The problems chosen by students are problems that exist in the surrounding environment. Research results Leasa et al. (2023) stated that projects implemented based on problems from the surrounding environment have a relationship with students' creative, critical, and metacognitive thinking. Science learning is closely related to the creative process and does not focus on one method but uses different scientific (Markula & Aksela, 2022). The phases of creative thinking skills help students develop ideas both individually and in groups. Students explore knowledge to understand basic concepts related to problems related to the material through various sources and write the results in the form of summaries or concepts (Batlolona et al., 2020). This situation is in line with Jean Piaget's theory which states that students will compile their knowledge after understanding concepts through various learning sources (Hammond, 2014).

Conclusion

Based on the results of research and discussion, it can be concluded that the RBL learning model has a significant effect on young children’s creative thinking skills in science learning where there are differences in creative thinking skills between students who follow the RBL learning model and students who follow the *Cooperative Learning* model. It can be seen from the results obtained in the experimental class and control class. Based on the results of the research that has been obtained, suggestions that can be proposed are that in the learning process, the RBL learning model should be considered for frequent use in order to help students hone their creative thinking skills so that students are able to face the challenges of 21st-century learning. For further research, it is recommended to use observation sheets to determine the achievement of the learning process when activities take place, make a questionnaire that is useful for knowing how students perceive learning activities using the RBL learning model, manage time well so that all stages in the RBL learning model are carried out and completed on time.

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Appendix 1

Student Worksheet for Learning with Rbl Model in Fourth Grade of Elementary School Students

Activity Title: Simple Research on Vegetative Organs of Plants

Activity Objective

1. Identify the structure of plant vegetative organs
2. Explain the function of plant vegetative organs
3. Analyze the function of plant vegetative organs for human life

Activity steps

1. The teacher divides students into groups
2. Each group is given an LKPD (student worksheet)
3. Students read the discourse provided several times and then formulate a problem.
4. Students observe the plant stem types in the school environment and fill in the observation table.
5. Students answer the questions provided to exercise creative thinking skills.
6. The time to do the activity is 40 minutes
7. Follow all learning instructions according to the activity steps.

Phase 1 Formulating the Problem

Each group is asked to write down some questions about vegetative plant organs. Then, they think of a hypothetical answer to the question.

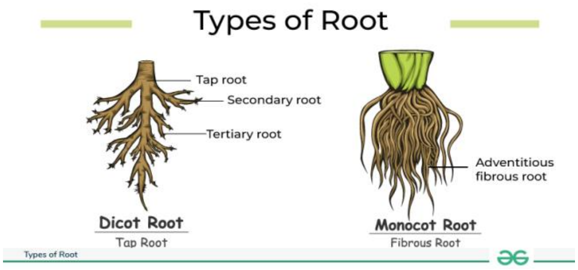
No.	Question	Provisional Answer

Phase 2 Reviewing Theory

Read the discourse below on Vegetative Organs of Plants

Vegetative Organs of Plants

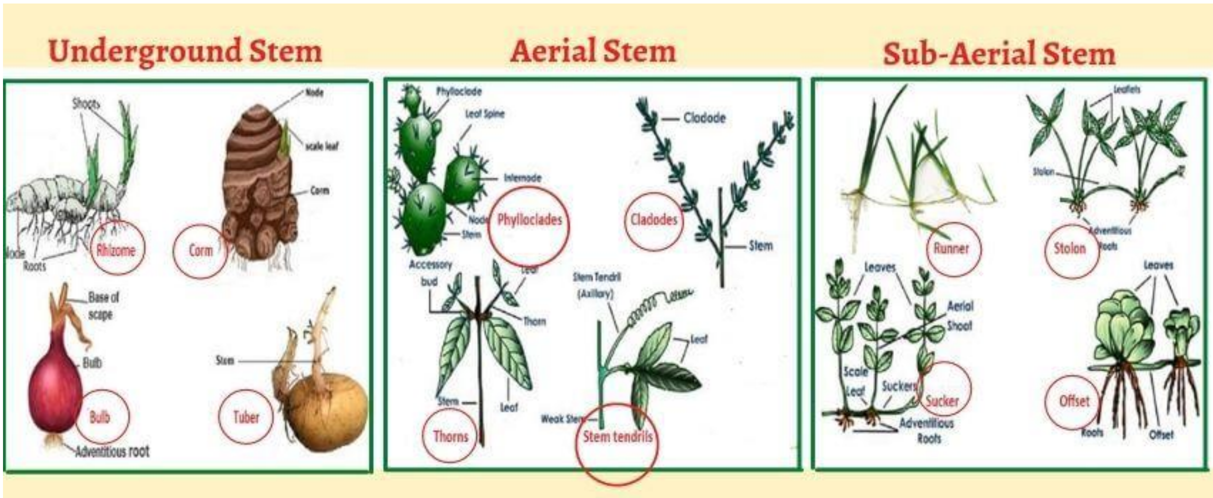
Plants are included in living things because they can grow and reproduce. Plants consist of vegetative organs and generative organs. Plant vegetative organs include roots, stems, and leaves. Roots are part of the plant that grows downward in the soil as a reinforcement and absorber of water and food substances and storage of food reserves. The root structure consists of the root shaft, root hood, root branches, and root hairs. Plant roots can be fibrous roots and taproots.



Source: https://www.geeksforgeeks.org/tap-root-diagram/

Leaves are the green part of the plant. The main function of leaves is as a place for photosynthesis. Chlorophyll is one of the main ingredients plants need to carry out the photosynthesis process. After getting chlorophyll and sunlight, plus water and minerals from the soil, plants can make their food through the process of photosynthesis. Leaves also act as a means of breathing plants through stomata.

The stem is the part of the plant that stands above the roots, where twigs and leaves grow. The stem serves as a means of transporting water and food substances and storing food reserves. There are two vessels in a stem: wood vessels (xylem) and vessels tapis (phloem). Wood vessels (xylem) transport water and nutrients from roots to leaves. Vessel tapis (phloem) is useful for transporting photosynthetic products from the leaves to all parts of the plant. The types of stems can be seen in the following figure.



Source: https://smartclass4kids.com/plant-stem/

Phase 3 Planning Investigations

The research will be conducted by observing plant organs in the environment around the school. Each group will observe the shape of the roots, stems, and leaves of plants found in the environment. Each group can use at least 5 types of plants in the neighborhood. During the observation, students are accompanied by the teacher.

Phase 4 Researching and Analyzing Data

Each group can pick the stems and leaves of plants in the environment and bring them to class to make careful observations. The observation data can be written in the following table.

Table of Plant Organ Shape Observation Results

No.	Plant Name	Root Shape	Leaf Shape	Rod Shape

Table of Plant Organ Function Observation Results

No.	Plant Name	Root Function	Leaf Function	Trunk Function

Afterward, the group discusses the following questions:

1. Plants should have 3 main vegetative organs: roots, stems, and leaves. Think of 4 possibilities of what happens to a plant that only has 2 vegetative organs.
2. Plant organs can be utilized for human life. Write down 4 forms of utilization of plant roots for human life.
3. Describe the shape of the stem organs in all the plants observed. Is the shape of the stem the same or different? Give your group at least four reasons.
4. Is the shape of the leaf organ observed in all the plants the same or different? Why is this the case?
5. Think of four possibilities of what would happen if no plants were around!

- **Phase 5 Explaining Research Results**

In this phase, the teacher organizes students to present the research results in class. The teacher's role is to facilitate this activity so that students' work can be appreciated. After that, the teacher guides students to make conclusions at the end of the lesson.

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Development of a four-tier diagnostic test for misconceptions in natural science of primary school pupils

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ABSTRACT
This study aimed to develop a standardised instrument for diagnosing science misconceptions in primary school children. Following a developmental research approach using the 4-D model (Define, Design, Develop, Disseminate), 100 four-tier multiple choice items were constructed. Content validity was established through expert evaluation by six science specialists. The study was conducted using stratified purposive sampling on 140 pupils from public and private primary schools with 'very good' and 'good' ratings in Surakarta, Indonesia. The instrument's construct validity, reliability, and empirical validity were assessed using Aiken's V, Pearson's Correlation Coefficient, and Cronbach's alpha, respectively. Difficulty index was also calculated. The final version comprised 61 valid and reliable items with Aiken's V ranging from 0.79 to 0.92, Pearson's Correlation ranging from 0.17 to 0.58, and a Cronbach's alpha coefficient of 0.86. Item difficulty ranged from 0.014 to 0.62, with 27 and 34 items falling into the moderate and difficult categories, respectively. This instrument demonstrates potential for effectively detecting science misconceptions in primary school learners. Based on these findings, teachers, policymakers and parents can take targeted action to address misconceptions. This may involve evaluating science textbooks, enhancing teacher training, and fostering discussions with science experts. Additionally, parental involvement in reinforcing science concepts is crucial.

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Introduction

Science constitutes a body of knowledge comprising a collection of facts, concepts, laws, principles, theories and models (Chiappeta & Koballa, 2010). Knowledge frameworks concerning learning and scientific practice are now influencing policy initiatives that have an impact on primary school science teaching (Abell & Lederman, 2007; Nugroho et al., 2021). Desstya & Sayekti (2020) stated science is one of the subjects taught in primary schools in Indonesia for several reasons. Science is universally beneficial as fundamental scientific principles drive technological advancements, facilitating easier lifestyles globally. Science dispels myths and unscientific beliefs, promoting rational understanding. Science underpins various professions by revealing logical foundations, for example, doctors rely heavily on scientific knowledge based on medical and biological research. Science fosters critical thinking and problem-solving skills, essential for intellectual development. Science instils positive characters and attitudes (refers to traits, attitudes and behavior that demonstrate good qualities) nurturing curiosity about phenomena in the surrounding world. Everyday occurrences expose primary school children to scientific phenomena, from observing light and optics, heat and temperature when boiling water. Children initially encounter science through daily experiences, which, if not aligned with accurate scientific concepts, can lead to misconceptions (Canada et al., 2017). Misconceptions denote inaccurate understandings, misapplications of concept names, or incorrect classifications of examples (Bou'-Jaoude, 1991; Ajayi, 2017; Berg, 1991; Chang, 2010). They impede knowledge development and scientific thinking (Bou-Jaoude, 1991), significantly impacting learning success (Bou-Jaoude, 1991), and hindering the learning process (Bau-Jaoude, 1991). Misconceptions are prevalent among teachers, lecturers, students (at both school and university levels), and researchers.

Numerous studies have documented science misconceptions among primary school learners (Nurjani et al., 2020; Deringol, 2019; Bar et al., 2016; Kambouri, 2010; Narjaikaew, 2013; Sahin et al., 2008; Smolleck & Hershberger, 2011; Stein et al., 2008), necessitating teachers' intervention. Addressing misconceptions promptly is crucial to remove conceptual barriers to science learning (Soeharto et al., 2019; Nurhasanah et al., 2022). Early detection of science misconceptions is accordingly essential to mitigate their negative impacts. Diagnostic tests are valuable tools for identifying misconceptions (Directorate General of Ministry of National Education; Directorate of Junior High School Development, 2007). Various diagnostic tools have been developed and employed to pinpoint science misconceptions. Soeharto et al. (2019) revealed that found that a number of concepts in physics (33 concepts), chemistry (12 concepts), and biology (15 concepts) commonly causing misconceptions. Furthermore, it found that the types of diagnostic tools used include interviews (10.74%), simple multiple-choice tests (32.23%), multiple-tier tests (33.06%), and open-ended tests (23.97%). Each diagnostic tool possesses its strengths and limitations. Multiple-tier tests, consisting mainly of multiple-choice formats, are widely used for detecting science misconceptions (Soeharto et al, 2019). Despite the efficiency of multiple-choice tests as evaluation tools (Kusumawati & Hadi, 2018), they have drawbacks. Although comprehensive and objective, multiple-choice questions suffer from limitations such as increased error variance due to guessing, lack of insight into respondents' thought processes, and constraints on answer options (Caleon & R. Subramanium, 2010; Suwarna, 2014). Multiple-choice tests including two-tier and three-tier formats, were developed to address these shortcomings and provide more nuanced assessments.

The two-tier type is a two-level multiple-choice test that presents answer choices and reasons for their selection. This instrument has been developed by several researchers (Nasir et al., 2023; Soeharto, 2021; Sadevi, R.A & Sayekti, I.C, 2023). Questions in this type of test often be unclear to distinguish between correct and incorrect answers due to conceptual difficulty or misconceptions. These questions typically necessitate thorough preparation and specialised assistance (Rintayati, Lukitasari, & Syawaludin, 2021).

The three-tier test is a multiple-choice test comprising three levels of answers: answer choices, reasons, and confidence levels in answering a question (Caleon & Subramanium, 2010; Mubarokah, Mulyani, Indriyanti, 2018). However, this test type's weakness lies in potentially low interpretation proportions (that means it is difficult to distinguish whether an incorrect answer is due to misconception, ignorance, or simply guessing, especially if the participant's level of confidence is low) for those who lack conceptual understanding and excessively high proportions for those who do understand. Consequently, distinguishing between respondents with misconceptions and those lacking conceptual understanding remains challenging (Diani et al., 2019). This challenge complicates determining appropriate corrective approaches for learners with misconceptions versus those simply lacking understanding. Hence, there is a need to develop a multilevel multiple-choice test in the form of a four-tier multiple-choice test. This four-level diagnostic test, as proposed by Maharani et al.

(2019); Salamah et al. (2020); Rohmanasari & Ermawati (2019), and Putica, B. (2022) comprises four levels: the first level containing answer choices, the second level containing the confidence level in the chosen answers, the third level containing reasons for selecting the answers in the first level, and the final level containing the confidence level in the written reasons. In this study, the investigation focuses on answers and reasons using closed options to maintain pupil engagement with the material being assessed.

Yuberti et al. (2020) developed a four-tier diagnostic test to identify misconceptions at the junior high school level. The test focuses on exploring the concepts of work and simple planes. Habiddin & Page (2019) developed a four-tier multiple-choice test for university students, concentrating on the concept of chemical reaction kinetics. Saputra et al. (2020) devised a four-tier multiple-choice test for high school students, delving into fluid mechanics concepts. These tests, developed by Yuberti et al. (2020) and Saputra et al. (2020), feature four levels, consisting of answers to the question, confidence level in answering, reasons for answering, and level of confidence for the answer/reason respectively. This diagnostic instrument offers various advantages, such as including the level of confidence in answering and the opportunity to give reasons separately (Tumanggor et al., 2020; Celikkanlı, Kızılcık, 2022), facilitating easier implementation and access (Nurhidayatullah & Prodjosantoso, 2018). Kartimi et al. (2021) developed a four-tier diagnostic test to identify primary school children's misconceptions regarding the concept of energy. Comprising six questions for fourth graders, this test contributes to alternative ways to identify and analyse misconceptions. Other advantages of this four-tier multiple-choice test include its practicality in implementation and scoring, as well as the efficiency of time and energy used (Agustin, 2020). However, the weakness of this test is that it cannot be used to determine the factors that contribute to those misconceptions. Among the existing types, the four-tier multiple choice at the first level is a multiple-choice question with four distractors and one correct answer key. The second level is the level of confidence in choosing answers. The third level is the reason for choosing an answer.

However, the four tiers have not been able to determine the sources causing misconceptions. Therefore, the development of this type of four-tier multiple-choice test requires modification to address the aspects contributing to misconceptions. Understanding the sources of error is crucial as it informs the design of effective learning interventions. This aligns with research by Inggit et al. (2021), suggesting that proper learning strategies should be tailored to address misconceptions and their underlying causes. Further research analysing factors contributing to learners' misconceptions is warranted (Sheftyawan, Prihandono, & Lesmono (2018). Previous studies have demonstrated that four-tier multiple-choice tests have been extensively developed to detect science misconceptions at middle school, high school this term means something a bit different in various systems, and tertiary levels, focusing on specific topics. While this instrument has been adapted for use at the primary school level, its usage remains limited and requires further refinement. Among the existing four tiers, none have been able to pinpoint the sources of experienced misconceptions (Salamah, 2020). Thus, modifying the format of the four-tier multiple-choice test is essential for effective use and for better identification of factors contributing to students' misconceptions. The four-tier multiple-choice test developed for primary school learners serves as a novel instrument for detecting science misconceptions. From the child's perspective, this instrument fosters critical, analytical, and reflective thinking skills. In tiers 1 and 2, they are prompted to analyse scientific situations, concepts, problems, and evaluate decisions. Meanwhile, tiers 3 and 4 encourage them to reflect on their understanding. From the teacher's standpoint, this instrument provides valuable insights into the sources of misconceptions, enabling the preparation of tailored follow-up plans for science learning.

Therefore, the development of an instrument to detect science misconceptions in the form of a four-tier multiple-choice test is essential due to its numerous benefits. This test can identify misconceptions accurately, allowing pupils to determine answers to explored concepts, provide reasons for their choices, demonstrate confidence in their responses, and identify the sources of their answers. Hence, this study aims to develop such an instrument that meets the requirements of validity, reliability, and difficulty index. Consequently, this research addresses the following questions: a) How are the characteristics of the Four-tier Diagnostic Test for Misconceptions; (b) How is the validity and reliability based on experts assessment; c) How are the validity, reliability and difficulty level of the instrument in empirical tests?

Methods

Participants

The participants in this study were 140 fifth-grade primary school pupils aged 11 to 12 years, comprising 76 boys and 64 girls. The sample was obtained through stratified purposive sampling, involving public and private schools with 'very good' and 'good' quality school accreditation (Cohen, Manion, & Morrison, 2018), in five sub-districts in Surakarta, Central Java, Indonesia, to ensure the representation of various sample characteristics.

Development Framework

This research follows a Research and Development (R&D) approach. The development model used was the 4-D model developed by Thiagarajin, Semmel & Senmel (1974), which consists of defining, designing, developing and disseminating stages. The 4-D model was chosen for its simplicity in the product development process (Irawan et al., 2017), and its detailed steps allow for systematic use. The defining stage involved the analysis of pupil characteristics, misconceptions and available diagnostic instruments. During the design stage, the instrument was developed by devising constructs for each question item, determining core competencies and basic competencies, and developing indicators of competency achievement. The developing stage involved developing the instrument for expert review, with all validated and revised items then tested on pupils. In the dissemination stage, the instrument for identifying science misconceptions was disseminated to primary school teachers.

Instrument

Question Item Constructs

The questions were based on the standard content of the fifth-grade science curriculum, covering the following topics: locomotory organs of animals and humans and their functions, respiratory organs of animals and humans and their functions, digestive organs of animals and humans and their functions, circulatory organs of animals and humans and their functions, the relationship between ecosystem components and food webs in the surrounding environment, heat transfer, effect of heat on changes in temperature and shape of objects, the water cycle and its impact on events on Earth and the survival of living things, and matter in daily life based on its constituent components (single and mixed substances). Ten to eleven questions were developed for each topic.

Item Format

Initially, this misconception detection instrument consisted of 100 four-tier multiple-choice questions. The first tier presented answer choices for the concept asked, the second tier provided reasons for choosing the answer, the third tier indicated the level of confidence in answering, and the fourth tier identified the source of the answer. Before constructing question items, it was necessary to create a content outline based on basic competency and competency achievement indicators that had been developed.

Scoring Procedure

The maximum score for correct answers in each tier is 1.

Data Analysis Technique

To ensure the validity and reliability of the instrument for detecting misconceptions in science, the Aiken's V formula (Aiken, 1985) was employed for validity analysis. The formula is as follows:

$$V = \frac{S}{[n(C-1)]} \qquad (1)$$

Where :
S : R - lo
V : Validity Index
R : The Score Given by The Experts
lo : Lowest Validity Score
c : Highest Validity Score
n : Total Number of Experts

The validity criteria for this instrument were determined based on the number of validators involved in the study. Six validators participated, including one professor specialising in physics education, two individuals with doctoral degrees in research and evaluation in chemistry and biology education, and three individuals with Master's degrees in physics and biology education. The validation sheet included multiple categories (five in this study), and the significance level was set at $p < 0.05$. According to these criteria, the V-value was established at 0.79. Items with a minimum V of 0.79 were empirically tested to assess validity between items. Validity calculations were performed using SPSS 23 software, determining bivariate correlations between item scores and the total construct score. An item was considered valid if the bivariate correlation score exceeded 0.5 (Perinetti, 2019).

Reliability refers to the consistency and trustworthiness of a test instrument, which is deemed reliable if it produces consistent results under identical conditions. Reliability was assessed by administering the instrument to 60 respondents. Cronbach's alpha method was employed to test instrument reliability, conducted using SPSS 23 software. The results indicated high reliability, with a coefficient exceeding 0.7 (Gelişli et al., 2017).

The difficulty index was established with the following ranges: 0.80 to 1.00 (easy), 0.30 to 0.79 (moderate), and 0.00 to 0.29 (difficult). The formula used to calculate the difficulty index is as follows (Jandaghi, 2011; Jandaghi & Shaterian, 2008).

$$p = \frac{B}{JS} \qquad (2)$$

Where:
p: The difficulty Index
B: The number of student who answered correctly
JS: The number of student taking the test

To categorise respondents' answers into the category of misconceptions or not, the grouping criteria based on the three-tier multiple-choice test outlined by Gurel, Eryilmaz, and McDermott (2015) were utilised. These criteria, presented in Table 1, were selected because the fourth tier in the multiple-choice test developed in this study pertains to identifying the source of answers chosen in the previous tiers or to pinpoint the source of misconceptions.

Table 1

Criteria for grouping students'answer choices

First Tier	Second Tier	Third Tier	Category
Correct	Correct	Confident	Understand the concept
Correct	Incorrect	Confident	Misconception *(false positive)*
Incorrect	Correct	Confident	Misconception *(false negative)*
Incorrect	Incorrect	Confident	Misconception
Correct	Correct	Unconfident	Consecutive guess, Lack of confidence
Correct	Incorrect	Unconfident	Lack of concept understanding
Incorrect	Correct	Unconfident	Lack of concept understanding
Incorrect	Incorrect	Unconfident	Lack of concept understanding

Note. Source from Gurel et. Al (2017) with author's modification.

Findings

Table 2 shows distribution of valid and invalid questions

Table 2

Distribution of valid and invalid questions

Evaluation of question quality	Question Number	Numbers of Questions
Valid	2,3,4,5,6,7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 35, 36, 37, 38, 39, 41, 42, 45, 47, 48, 50,51, 53, 54, 55, 57, 58, 59, 61, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 75, 77, 78, 79, 80, 81, 82, 84, 85, 87, 89, 90, 92, 93, 96, 98, 99.	73
Invalid	1, 16, 20, 21, 22, 27, 33, 40, 43, 44, 46, 49, 52,56, 59, 60,62, 74, 76, 83, 86, 88, 91,94, 95, 97, 100	27
Total		100

The Aiken's V coefficient for valid questions ranged from 0.792 to 0.917, with an average score of 0.793. Subsequently, after identifying 73 valid questions based on experts' judgment, these questions were administered to a sample of primary school children. The test results yielded scores ranging from 2 to 4. These scores were utilised to calculate the bivariate correlation between each question's score and the overall total score using the SPSS program. The correlation values are presented in Table 3.

Table 3

Pearson's correlation value of each item

Items	Pearson's Correlation	Result	Item Number	Pearson's Corelation	Result	Item Number	Pearson's Corelation	Result
1	0.206*	Valid	25	0.446**	Valid	49	0.092	Invalid
2	0.321**	Valid	26	0.421**	Valid	50	0.500**	Valid
3	0.331**	Valid	27	0.182*	Valid	51	0.043	Invalid
4	0.437**	Valid	28	0.403**	Valid	52	0.513**	Valid

Items	Pearson's Correlation	Result	Item Number	Pearson's Corelation	Result	Item Number	Pearson's Corelation	Result
5	0.308**	Valid	29	0.462**	Valid	53	0.199*	Valid
6	0.142	Invalid	30	0.576**	Valid	54	-0.288**	Valid
7	0.262**	Valid	31	0.213*	Valid	55	0.392**	Valid
8	0.431**	Valid	32	0.457**	Valid	56	0.023	Invalid
9	0.068	Invalid	33	0.331**	Valid	57	0.526**	Valid
10	0.194*	Valid	34	0.422**	Valid	58	0.356**	Valid
11	0.182*	Valid	35	0.535**	Valid	59	0.440**	Valid
12	-0.021	Invalid	36	0.274**	Valid	60	0.284**	Valid
13	-0.072	Invalid	37	0.230**	Valid	61	0.054	Invalid
14	0.189*	Valid	38	0.310**	Valid	62	0.514**	Valid
15	0.221**	Valid	39	-0.038	Invalid	63	0.352**	Valid
16	0.230**	Valid	40	0.276**	Valid	64	0.295**	Valid
17	0.168*	Valid	41	0.254**	Valid	65	0.215**	Valid
18	0.394**	Valid	42	0.368**	Valid	66	0.407**	Valid
19	0.338**	Valid	43	0.296**	Valid	67	0.480**	Valid
20	0.142	Invalid	44	0.100	Invalid	68	0.240**	Valid
21	0.363**	Valid	45	0.112	Invalid	69	0.311**	Valid
22	0.410**	Valid	46	0.461**	Valid	70	0.255**	Valid
23	0.441**	Valid	47	0.274**	Valid	71	0.457**	Valid
24	0.498**	Valid	48	0.500**	Valid	72	0.325**	Valid

Based on Table 3, it is evident that out of the 73 questions, 61 were deemed valid, indicating their suitability for measuring the intended competency (Nunnally, 1978). However, 12 questions were deemed invalid. The criterion for validity determination was set at a minimum score of 0.164, calculated using the two-tailed r table with a significance level of 5% and 140 samples. The valid items ranged in scores from 0.168 to 0.576.

Reliability

Cronbach's alpha was found to be 0.863, indicating high reliability.

Difficulty Index of Questions

From the study results, among the 61 valid and reliable questions, 27 fell into the "moderate" category with scores between 0.30 and 0.69, while 34 questions were categorized as "difficult" with scores ranging from 0.00 to 0.29. None of the questions were classified as "easy." Consequently, eight questions required correction and modification to enhance their quality and acceptability. The responses to select questions among the 61 valid and reliable items were scrutinised to identify any misconceptions, and the findings are elaborated upon in the subsequent section.

Disseminating

During the dissemination phase, the tool for pinpointing misconceptions in science was distributed to 38 primary school teachers through instructional workshops and mentoring sessions aimed at addressing science misconceptions in their pupils. These teachers were selected from various public and private schools across five sub-districts (Banjarsari, Serengan, Pasarkliwon, Jebres, Laweyan) including Gading Public Primary School, Islamic Primary School Sunan Kalijaga, Mijipinilihan Public Primary School, Muhammadiyah 10 Primary School, Islamic Bakti 1 Primary

School, Baturono Public Primary School, Kleco 2 Public Primary School, Mojosongo 2 Public Primary School, Al Firdaus, Ar Risalah, Kemasan 1 Public Primary School, and Islamic Sunniyah Primary School. The selection process employed purposive random sampling.

Schematically, the entire process of developing this item is presented in Table 4.

Table 4

Stage of the item development process

Stage	Process	Results
1. Initial Developed 100 item	Expert validation, and validity analysis using Aiken V	73 valid items 27 non valid items
2. Continued 73 valid items	Tested on 140 students, validity analysis (used *Pearson's Correlation)*, reliabilitas (by coefficient of Cronbach's alpha)	61 valid items 12 non valid items
3. Final Obtained 61 valid items	difficulty index.	61 valid items (27 questions in the "moderate" and 34 questions in the "difficult" category)

Discussion

Content validity assesses the extent to which elements in a measurement instrument are relevant and representative of the construct being measured (Bahri, 2019; Ishartono et al. 2024). It is a pivotal step in instrument development, as it precedes the testing of construct validity. An instrument must pass the content validity test before undergoing other validity assessments (Ihsan, 2015). Following the validation and reliability assessment of the instrument, it was utilized to detect student misconceptions. For instance, the analysis of responses to question number 1 is presented below.

Item 1 as presented in Table 5 is an example of a valid item in this study.

Table 5

Example of item 1

Irwan works as a porter at a market. Every day he lifts many heavy sacks of rice and vegetables. One day, Irwan's arm muscles got tight and swollen, so Irwan's friend had to help him lift a sack of rice. The muscle disorder that Irwan suffered from is called… a. stiff b. atrophy c. hypertrophy d. tetanus
Reason a. The muscle disorder occurred because Irwan did continuous and excessive activities b. The muscle disorder occurred because Irwan had poliomyelitis c. The muscle disorder occurred because Irwan made a sudden stomping motion d. The muscle disorder occurred because Irwan never had exercise
Your level of confidence in answering a. confident b. unconfident
The source of your answer

a. I have ever helped/cared for a friend with the same condition as Irwan b. I have experienced the same condition as Irwan c. I have seen other people experience the same thing as Irwan d. I have seen a video of a person having the same problem as Irwan

Based on Table 5, it is evident that Sample Item 1 aims to diagnose whether there are misconceptions among students regarding the understanding of locomotory organs of animals and humans, their functions, and the maintenance of human locomotory organs' health. In this topic, the developed competency involves identifying symptoms and bone abnormalities in humans. The question presents a discourse and assesses students' understanding of muscle disorders. The student answered the question in the following order: B. Atrophy, A. The muscle disorder occurred because Irwan did continuous and excessive activities, A. Confident, and B. I have experienced the same condition as Irwan. According to the reference category of students' understanding presented in Table 5, this student is included in the category of misconception (false negative) because the answer in the first tier is wrong, the answer in the second tier is correct, and he/she answered the question confidently. Further analysis revealed that the student's misconception stemmed from personal experience. This finding aligns with research by Lin et al (2016), which suggests that personal experience can contribute to students constructing their own knowledge. However, some of the students' daily experiences can lead to misconceptions, as observed in a study conducted by Mutsvangwa (2020). Daily experiences form students' initial knowledge, which may not always be accurate due to the variability and inaccuracies in the sources of students' information and experiences.

Table 6

Example of item 36

To make a sharp and beautiful kris, a kris blacksmith needs to design, combine the elements of beauty, and carve it. In order to make a good and artistic kris, the blacksmith burns the alloy into the flaming fire to make it heated, so it can be carved. The alloy becomes heated because of... a. transmission b. radiation c. convection d. conduction
Reason a. heat travels through the metal b. heat travels through the air c. particles in the metal move from one end to the other d. heated over the fire
Your level of confidence in answering… a. confident b. unconfident
The source of your answer… a. teacher's explanation b. a story book or textbook c. I saw a metal being burned / a kris making myself d. I listened to my mother's/father's/sibling's story

As indicated in Table 6, Item 36 serves to diagnose whether pupils harbour misconceptions when appraising the effect of heat on changes in temperature and shape of objects in daily life. In the first tier, the majority of pupils selected option 'D) conduction'. The question scenario presents a situation where a kris blacksmith heats an alloy in a flaming fire to facilitate carving, with the correct answer being 'D. conduction'. In the second tier, the correct answer is identified as A (heat travels through metal). The responses from the first to the third tier are correct, incorrect, and confident, respectively. Consequently, it falls into the category of misconceptions (false positive). In the fourth tier, it is evident that the source of the misconception is attributed to the teacher's explanation.

Table 7

Example of item 16

Every human should try to keep their digestive organs healthy by consuming healthy and nutritious food so that the digestion process can run well. In the human digestive system, absorption of nutrients in food occurs in the… a. mouth b. oesophagus c. stomach d. small intestine
Reason a. The process of breaking down of food and absorption of nutrients in food occurs mechanically and chemically in the mouth b. The process of breaking down of food and absorption of nutrients in food occurs mechanically and chemically in the oesophagus c. The process of breaking down of food and absorption of nutrients in food occurs mechanically and chemically in the stomach d. The process of breaking down of food and absorption of nutrients in food occurs mechanically and chemically in the small intestine
Your level of confidence in answering… a. Confident b. Unconfident
The source of your answer… a. teacher's explanation b. a story book or textbook c. I saw a video d. I listened to my mother's/father's/sibling's story

As delineated in Table 7, item 16 is designed to identify misconceptions pertaining to the digestive organs of animals and humans, their functions, and methods to maintain their health. In the first tier, the correct response to the question, "Every human should strive to maintain the health of their digestive organs by consuming nutritious food, thereby facilitating efficient digestion. In the human digestive system, the absorption of nutrients from food occurs in the…" is 'D (small intestine)'. For the rationale (second tier), the correct response is 'D (the process of food breakdown and nutrient absorption occurs both mechanically and chemically in the small intestine)'. It can be observed that the pattern of the response is incorrect, incorrect, and confident, indicating a misconception. The source of the misconception is identified in the fourth tier (C. I saw a video).

This instrument was utilised to assess the level of understanding of 140 elementary school pupils, who were subsequently categorised into aspects: understanding concepts, misconceptions, guessing, and lack of understanding concepts. The results revealed that 11 % (n=16) demonstrated a clear understanding of the concept, while 34% (n=47) exhibited misconceptions. A further 12% (n=7) appeared to be guessing, and the remaining 43% (n=60) showed a lack of understanding of the concept. In addition, the study identified specific misconceptions among the pupils, categorised by the topic of the material. These findings are succinctly presented in Table 8. This research thereby contributes to a more nuanced understanding of the factors influencing the comprehension of digestive health among students.

Table 8

Summary of students' misconceptions

No	Topics	Percentage (%)
1	Locomotory organs of animals and humans and their functions	23.51
2	Respiratory organs of animals and humans and their functions	30.44
3	Digestive organs of animals and humans and their functions	43.24
4	Circulatory organs of animals and humans and their functions	55.55
5	Relationships between ecosystem components and food webs	32.33
6	Heat transfer concept	24.33
7	The effect of heat on changes in temperature and shape of objects	24.33
8	Water cycle and its impact on events on earth and the survival of living things	15.34
9	Matter in daily life based on its constituent components (single and mixed substances)	50.44

Table 8 shows that the topic of animal and human circulatory organs and their functions has the highest percentage of misconceptions. This highlights that the concept is complex and requires greater attention in the learning process. For instance, common misconceptions include misunderstandings about the role of the heart, blood vessels, and the differences between blood circulation in humans and animals, as also reported by Setiabudi, Mulyadi, Puspita (2019). The instrument developed in this study has a reliability score of 0.863, indicating a very high level of consistency, making the measurement results trustworthy. High reliability in such instruments is crucial for identifying misconceptions, as also emphasized by Sadler, et al. (2019). They developed diagnostic tools for science concepts based on mental models and reported a reliability threshold above 0.80 as the ideal standard for internal validity.

The results of this study are in line with Caleon & Subramaniam (2017), which developed diagnostic instruments on human physiology material, such as the blood circulatory system, which is often a source of misconceptions due to understanding the contents of textbooks or less interactive learning media. This research recommends the use of visual media and a simulation-based approach to minimize student misconceptions. The results of this research have significant implications for the development of teaching materials for teachers. Teachers need special training to detect student misconceptions early on, especially at the primary school level. This is as suggested by Furtak et al. (2020), who emphasized the importance of misconception-based scaffolding in improving the quality of science learning. Treagust (2018) also believes that in developing assessment for science subjects, they should not only be relied on in terms of content but also explore students' misconceptions comprehensively. Treagust emphasized that the use of multiple-choice diagnostic tests designed specifically for abstract concepts, such as the circulatory system, can help teachers understand thinking patterns and design more effective teaching strategies.

The four-tier diagnostic test instrument developed in this study is believed to be capable of identifying misconceptions and their underlying causes among primary school students. This instrument has four tier explored concept, provide reasons for their choices, demonstrate confidence in their responses, and identify the sources of their answers. This statement aligns with Gurel et al. (2015), highlighted that assessment tools are particularly effective in thoroughly identifying misconceptions. Similarly, Kaltakci-Gurel et al. (2016) developed a four-tier assessment focused on electricity in physics, discovering that it successfully revealed misunderstandings stemming from the misinterpretation of textbook material and poor teaching practices. This underscores the necessity for educational resources that can enhance students' conceptual comprehension. Treagust et al. (2017) further validate the usefulness of diagnostic assessments in the early detection of student misconceptions. According to Treagust, utilizing four-tier assessments encourages students to engage in analytical thinking, particularly regarding intricate scientific subjects such as human body systems or changes in matter. The advancement of this assessment tool carries important implications for science education at the primary level, particularly in improving instructional effectiveness through the early identification of misconceptions. This supports Cheung et al. (2017), who proposed that four-level test evaluations can help bridge the gaps in students' misunderstandings.

For primary school teachers, instruments produced in this research is considered comprehensive. They must be prepared to identify the types of understanding or misconceptions of their pupils. If students exhibit misconceptions, the teacher can immediately identify the source and address it. The approach to this depends on each factor. If the source of the misconception is the teacher's explanation, then the teacher must design learning that applies models, approaches, methods, and strategies that align with the characteristics of the material. Moreover, teachers must master the material thoroughly, not only by exploring the material independently but also through various professional activities, such as scientific activities or forums, as a suggested by Mitkovska (2010). Essentially, teachers are required to continually broaden their horizons to ensure the effective delivery of science learning in the classroom. When considering factors such as a storybook or textbook, watching a video, or listening to a parent's or sibling's story, parental involvement at home is crucial. Parents must accompany children in reading books or watching videos, ensuring the story's plot is coherent, or providing insight into the pictures in the accompanying book. The same applies to storytelling to children. Parents should narrate phenomena in a comprehensive and uninterrupted manner. This demonstrates that parents' basic knowledge significantly influences the misconceptions experienced by students, as conveyed by Lestari (2019). If parents possess a good basic knowledge of science material, they will be competent and capable of providing explanations and assistance to their children. They serve as their children's teachers at home. This underscores the need for parental involvement in understanding science concepts.

Conclusion and Implications

The findings of this study indicate that the Four-tier Diagnostic Test for Misconceptions comprised 61 valid and reliable items with Aiken's V ranging from 0.79 to 0.92, Pearson's Correlation ranging from 0.17 to 0.58, and a Cronbach's alpha coefficient of 0.86. Item difficulty ranged from 0.014 to 0.62, with 27 and 34 items falling into the moderate and difficult categories, respectively. This instrument demonstrates potential for effectively detecting science misconceptions in primary school learners. The process involved the analysis of scientific situations, concepts, and problems, the evaluation of decisions, and the identification of the sources causing misconceptions. In conclusion, teachers and policymakers can undertake several measures to address the sources contributing to misconceptions. These may include evaluating the textbooks used in teaching, enhancing the teaching skills of teachers, or facilitating more frequent discussions with individuals who possess a deeper understanding of the topics. This study underscores the necessity of parental involvement in understanding science concepts. It recommends further research to investigate the factors causing misconceptions from various aspects.

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Pre-service physics teachers' conceptual understanding of kinematics graphs in Tanzania

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ABSTRACT
Tanzanian secondary school students have consistently performed poorly in the topic of motion in a straight line, which involves kinematics formulas and graphs. Despite instruction, many struggle to plot and interpret these graphs, largely due to limited conceptual understanding among both learners and teachers. This study examines the conceptual understanding of kinematics graphs among pre-service physics teachers in selected Tanzanian teacher training colleges. Using a mixed-methods approach with a sequential explanatory design, the study involved 225 pre-service teachers from two colleges. Data were collected through a validated kinematics graph concept inventory and interviews, then analyzed using SPSS version 22, Excel, and thematic analysis technique. The findings revealed five key challenges: difficulty interpreting slopes of graphs that do not start at the origin, representing stationary objects on the graph, calculating total distance when motion involves both forward and backward directions, interpreting areas under acceleration-time graphs, and converting between kinematics graphs. These challenges underline the need for learner-centred teaching strategies to enhance students' conceptual understanding and performance. The study recommends that physics educators in Tanzania recognize and address these specific difficulties when teaching kinematics graphs to students.

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Introduction

The topic of kinematics is significant in learning physics and mathematics because it consists of concepts that build the foundation required by students to learn the next concepts (Amin et al., 2020; Planinic et al., 2013). An inadequate understanding of kinematics concepts may result in poor understanding of further concepts (Manurung et al., 2018). According to Ole & Gallos (2023), kinematics is one of the fundamental topics in physics which need to be covered by students in many countries. Some kinematics concepts include position, displacement, speed, velocity and acceleration. According to Amin et al. (2020), kinematics concepts tend to be presented as formulas and displayed in the form of graphs. Kinematics graphs have velocity, position and acceleration as the ordinate and time as the abscissa (Beichner, 1994). The knowledge of kinematics graphs plays an important role in graph constructions that are not necessarily related to kinematics. Researchers in mathematics, science and educational psychology use kinematics graphs to explore learners' graphing abilities (Susac et al., 2018). Graph constructions, presentation and interpretation are integral to teaching and learning physics (Beichner, 1994). Through graphs, the use of complex formulas can be minimised and some equations can be obtained from graphs.

However, many students have difficulties with kinematics graphs even after learning relevant concepts. The study by McDermott et al. (1987) revealed two kinds of difficulties learners encounter with kinematics graphs. The difficulties include challenges in connecting graphs to physical concepts and misconceptions in connecting graphs to the real world. In addition, Beichner, (1994) pointed out seven misconceptions learners were facing when dealing with kinematics graphs. These included learners seeing the graph as a picture, confusion between slope and height, confusion of variables, difficulty in determining the slope of the line, confusion of area under kinematics graphs, and confusion between area, slope and height. Also, Hernández et al. (2021), Phage et al. (2017), & Núñez et al. (2022) found that very few students could associate the slope with velocity or acceleration. Furthermore, Antwi (2015) reported four difficulties learners had with kinematics graphs: difficulties in describing the shapes of kinematics graphs, calculating slopes from curved graphs, interpreting areas under kinematics graphs and converting between kinematics graphs. Similarly, they have difficulties in separating the meanings of position, velocity, and acceleration versus time graphs (Antwi et al., 2018; Maries & Singh, 2016; Zavala et al., 2017).

In Tanzanian, kinematics graphs are taught to Form Two students with average ages of 13 and 14 years under the topic called motion in a straight line. Motion in a straight line is one of the physics topics in which candidates' performance in both Form Four and Form Two national examinations is low, hence negatively affecting the overall performance in physics (Mbwile & Ntivuguruzwa, 2023a, b). Results from the National Examination Council of Tanzania (NECTA) show that students' performance on the topic in Form Two National Assessments (FTNA) was weak for the past five years (NECTA, 2017-2021). For example, from 2017 to 2021, the top score was 20.9% in 2018. Results are considered to be good, average and weak if their average percentage lies in the interval of 65-100, 30-64, and 0-29, respectively (NECTA, 2018).

The weak performance of candidates in the topic of motion in a straight line contributes to their poor performance in physics. For example, results from the basic education statistics in Tanzania indicate that the average performance in the Certificate of Secondary Education Examination from 2017 to 2019 was below 50% (Ministry of Education, Science and Technology, 2019, 2020). Weak performance in the topic of motion in a straight may be attributed to directly or indirectly to students' and teachers' difficulties in interpreting kinematics graphs (Mbwile et al. 2023a). Also, since students' and teachers' difficulties are often comparable to other with similar characteristics (Mubarokah et al., 2018), pre-service physics teachers from training colleges may have similar difficulties. Little is known in the Tanzanian context about specific challenges learners, teachers and pre-service teachers face when working with the topic of motion in a straight line, specifically in kinematics graphs. According to Kirya et al. (2022), Mbwile et al. (2023b) & Mohammad et al. (2020), challenges facing learners on a specific area of the topic or subtopic can be identified by using assessment tool called concept inventory. Therefore, this study aimed to use the available kinematics graphs concept inventory to identify challenges facing pre-service physics teachers when working with kinematics graphs in teachers training colleges

Research Question

What could be the challenges facing physics pre-service teachers from teachers' trainging colleges when interpret kinematics graphs?

Methodology

Research Approach and Design

A sequential explanatory design was adopted during the process of data collection. This is a design in a mixed research approach whereby the outcomes of data collection in a quantitative research approach inform data collection methods in a qualitative approach (Bowen et al., 2017; Creswell & Clark, 2017). Thus, in this study, the outcomes from testing pre-service physics teachers were used to structure and administer interview questions to some of them.

Research Participants

The study sampled 225 pre-service physics teachers from two teachers' training colleges in Tanzania. Half of the respondents were first-year and the other half were second-year diploma pre-service teachers majoring in physics, education, and one more science subject. The average ages of respondents ranged from 21 to 23 years while 45 were females and 180 were males. To avoid selection bias, first-year and second-year pre-service teachers were randomly picked by using YES/NO cards. Pre-service teachers who picked NO cards were excluded from the test. Similar sampling was used to obtain participants for interviews whereby only pre-service physics teachers who sat for the test were considered for Interviews.

Instruments and Validation

The study used a validated physics teachers' concept inventory for interpreting kinematics graphs and interviews. A kinematics graphs concept inventory with set of 25 multiple-choice questions used for testing learners' understanding of kinematics graphs was adopted from one of the already published inventories (Mbwile et al., 2023a). Also, interview questions used to assess pre-service teachers' conceptual understanding of kinematics graphs more deeply were constructed by considering the outcome of test result analysis. Interview questions were peer-reviewed by two PhD physics students at the University of Rwanda and cross-checked by two physics experts found in Iringa-Tanzania. The kinematics graphs test as indicated in the Appendix section was given to 225 pre-service physics teachers to test their conceptual understanding of kinematics graphs. After analysis of test results, 20 pre-service physics teachers (10 from each teachers' training college) who sat for the test were involved in interviews. Interviews were conducted to understand the conceptions of pre-service teachers more deeply.

Data Analysis Procedures

Quantitative data were analysed by using Statistical Package for Social Science (SPSS) version 22 and Excel Sheet. SPSS was so useful in obtaining descriptive and inferential statistics such as mean score, standard deviation, frequencies of choice selection, and normality of the test. The Excel Sheet was used to compute marks of participants and displaying statistical charts. Qualitative data analysis was carried out by following six stages of thematic analysis (Braun & Clarke, 2006). The researcher had an opportunity to familiarise with data by reading and listening to recorded voices, followed by generating initial codes through data reduction for efficient analysis and then organising codes into broader themes. Thereafter, themes were reviewed through examination, defined and named to indicate what was interesting about the themes, and the final report about pre-service teachers' conceptual understanding of kinematics graphs was written by using themes that made a meaningful contribution to the research objective.

Ethical Considerations

The study adhered to ethical issues, including obtaining research permits from the University of Rwanda in Rwanda and the Ministry of Education, Science and Technology in Tanzania. Also, participants gave their consent for their willingness to contribute to the study by signing consent forms. Furthermore, sources of information were acknowledged by citing inside the main text and putting their bibliography in the reference section. Moreover, real names were avoided by using arbitrary coding instead. For example, X and Y were used for the sampled colleges while T1 to T20 represented pre-service physics teachers who participated in a focus group discussion.

Findings

The general performance of pre-service physics teachers when tested for conceptual understanding of kinematics graphs, revealed the mean, standard deviation, and distribution of scores using the Shapiro-Wilk normality test as indicated in Table 1 below.

Table 1

Mean, standard deviation, and Shapiro-Wilk normality test

Category	N	Mean	Standard Deviation	Significance	Normality test
Test	225	36.53	9.19	0.278	Normal Distribution

Table1 shows a p-value of 0.278 which means the test scores were normally distributed. Although the test was administered to learners who were taught kinematics graphs in previous years, a mean performance of 36.53 is below 50%. Pre-service teachers' mean performance below 50% despite learning the topic in previous years aligns with Beichner (1994) who found a mean score of 40% despite the prior exposure students had about kinematics graphs. Arguing along the same lines Setyono et al. (2016) showed that the ability of learners to interpret kinematics graphs was still low, with an average percentage of 48%. Also, the study by Amin et al. (2020) revealed the achievement of students in answering each kinematics graph question was 20.99 % and 11.91% for the highest and lowest performance respectively. The findings agree with NECTA (2019, 2020) indicating students' what level? performance on Motion in a straight-line topic (comprising kinematics graphs and formulas) in FTN was 11.7% and 12.5% in 2019 and 2020 respectively. These performances are lower than what was revealed from the findings. The difference may be attributed to the nature of the participants whereby teacher trainees were better compared to secondary school students.

Meanwhile, results from pre-service physics teachers' frequency of choice selections for each of the 25 test items and interviews were so useful in identifying challenges facing them on kinematics graphs. The revealed challenges include difficulties in interpreting the slope of the line graph which does not start from the origin, presenting the stationary position of the object on the graph, and calculating total distance when forward and backward directions are involved. Other challenges include difficulties in interpreting the area under acceleration time graphs, and converting from one graph to another. The summary of the frequency of choice selection for each of the 25 test items is indicated in Figure 1 below.

Figure 1

Pre-service teachers' frequency of choice selection for each question (N=225)

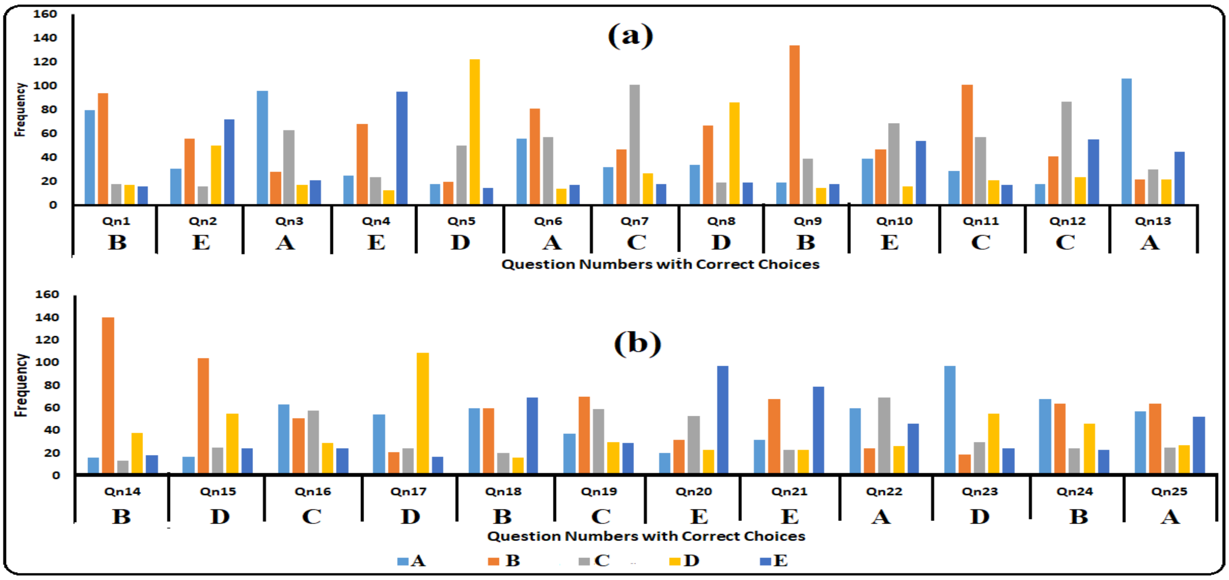


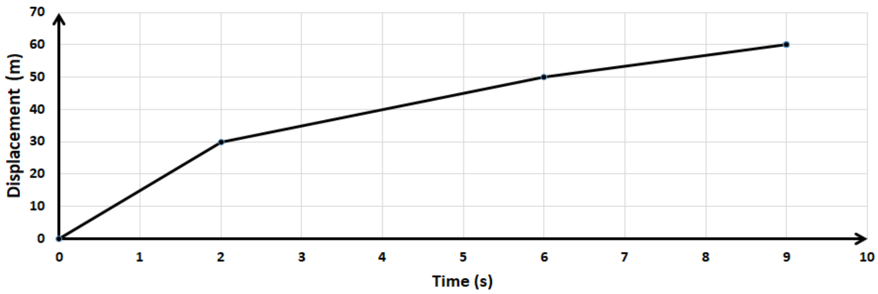
Figure 1 shows how 225 pre-service teachers selected multiple choices for all 25 questions. In each question, there was a correct choice and one or more distractors representing students' misconceptions. Identified challenges through frequency of choice selections and interviews are described in the following sub-sections.

Interpreting Slope

It was noted from test findings that pre-service physics teachers had difficulties interpreting the slope of line graph which does not start from the origin. Figure 2 below shows an example of a test item number 10 where pre-service teachers were asked to find the velocity of an object at a time (t) = 4 seconds.

Figure 2

An example of an item for testing slope



In the Figure 2 above (the Figure representing question 10), pre-service physics teachers were required to divide of the total displacement covered between time (t) = 2 seconds to t = 6 seconds with its corresponding time. The total displacement covered was 20 metres (50m-30m) and the corresponding time was 4 seconds (6s-2s). The division between displacement and time (velocity) is

5m/s. This velocity is constant at any point between 2 seconds and 6 seconds. However, the majority of pre-service teachers were dividing displacement-coordinate (40m) with time-coordinate (4s). The majority got 10m/s as a correct response instead of 5m/s.

Similarly, in question number 16, distractor A was more popular than the correct answer C because they were students were dividing vertical coordinate with horizontal coordinate instead of dividing total displacement with its corresponding time. The challenge was that, many pre-service teachers were assigning coordinate values directly to the slope which is valid only if the line representing slope starts from origin.

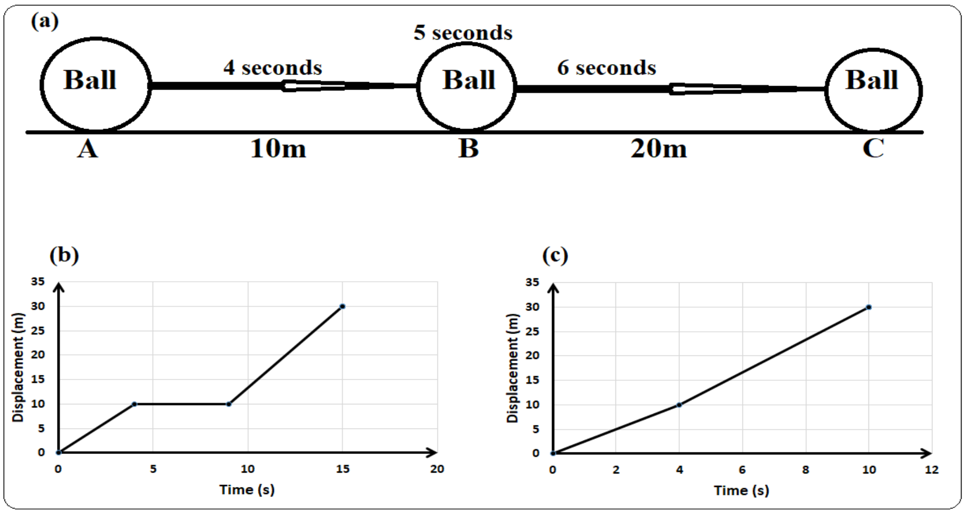
Findings from pre-service teachers' interviews supported findings from testing as 17 of 20 pre-service teachers had views of dividing displacement-coordinate with time-coordinate. For example, pre-service teacher T5 from Teachers' College X contended that "to *get the velocity of a point, someone is required to read properly the coordinates of the displacement axis and that of the time axis. Thereafter, calculate the velocity (slope) of an object at a given time by taking the ratio of distance coordinate and time coordinate".* The quotation above signifies little understanding of slope concepts among pre-service physics teachers. These findings could be valid if the line which represents slope could start from the origin. It signifies the challenge pre-service teachers had with the slope of kinematics graphs.

Presenting the Stationary Position of an Object on a Graph.

Findings show that pre-service teachers had little understanding of stationary objects being presented on the position-time graphs. Although pre-service teachers were able to identify the stationary positions of the object on the already drawn graphs, results from pre-service teachers' interviews revealed the challenge of presenting the stationary position of an object on a graph. Figure 3a is an example of a test item where pre-service teachers during oral interviews were asked to present the position-time graph of a ball moving from point A to B for 4 seconds, stopping at point B for 5 seconds, and finally moving from B to C for 6 seconds. Many pre-service teachers (13 of 20) responded by drawing the position-time graph as indicated in Figure 3c below instead of 6b.

Figure 3

An example of item for presenting stationary objects and responses



In Figure 3 above, many pre-service teachers were drawing the wrong Figure 3c because were neglecting time spent by an object while at a stationary position. To draw the required graph as indicated in Figure 3b, they were required to use the time spent to cover the total displacement which was 30 meters plus the time spent when an object was at a stationary position. In contrast, many used only the time related to distance covered.

Furthermore, oral interviews revealed similar misconceptions as quoted from pre-service teacher T14 of Teachers' College Y who contended that "*if you want to draw a position-time graph, do not consider the time spent by the object when it was not moving. Thus, from the Figure we are given, only 10 seconds which comprises 4 seconds covered from A to B and 6 seconds covered from B to C will be used in drawing the position-time graph*". It is obvious from the excerpt that, those pre-service physics teachers had little understanding of the concepts of stationary objects. Their challenges do not rely on the distance covered by an object but on failing to include the time spent by an object when at rest.

Finding Distance in Positive and Negative Directions

Findings revealed that pre-service physics teachers had difficulties in calculating the total distance travelled for position-time graphs when positive and negative directions are involved. Figure 4 below represent an example of a question where pre-service teachers were asked to calculate the total distance travelled by an object from time = 0 Hours to time = 20 Hours.

Figure 4

An example of an item for calculating distance in opposite directions

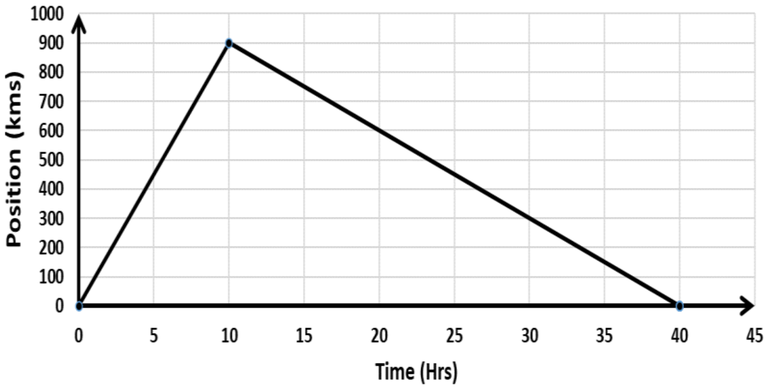


Figure 4 represent question number 19 where pre-service physics teachers were required to calculate the total distance covered by adding the distance in the positive direction (900 km) and the distance in the negative direction (300 km). After adding the two distances were expected to get 1200Kms as the correct answer. Nevertheless, many pre-service teachers got 600 km because were subtracting distance in the negative direction from distance in the positive direction. Pre-service teachers getting 600 km instead of 1200 km, signifies their difficulties in interpreting the distance covered in the positive and negative directions. Pre-service teachers need to know that the total distance is calculated by adding different distances covered in position-time graphs without regarding their directions.

Also, in question 15, the distractor B was more popular than the correct answer D because learners subtracted forward direction of 20 m from backward direction of 60m and got 40m. The correct answer D which few participants got 80m is obtained by adding forward and backward directions the two distances.

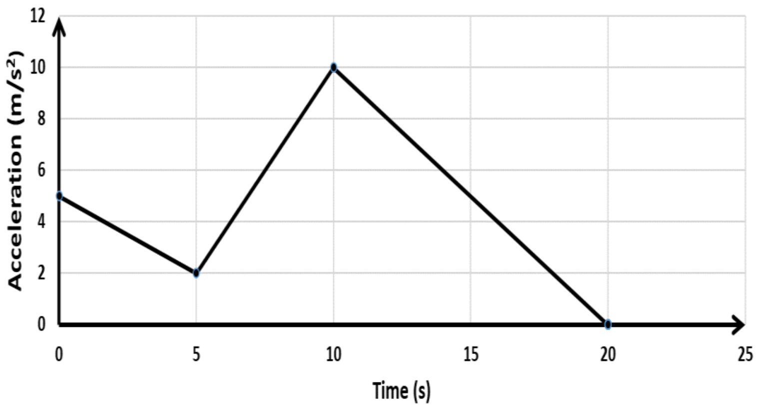
Findings from pre-service physics teachers' interviews complemented findings from the test. For example, when pre-service teachers were asked to explain how can they calculate the total distance for objects moving forward and backward directions in position-time graphs, the response of pre-service teacher T8 from Teachers' College X was *"the total distance is calculated by subtracting the total distance covered in the negative direction from the distance covered in the positive direction and vice-versa. It depends on the numerical value, the direction with a higher numerical value will subtract the direction with a lower numerical value"*. This passage above entails pre-service teachers' misconceptions they had concerning the movement in the opposite directions. The point to note is that going somewhere and coming back to where you were before does not mean that you have not covered any distance but means twice the distance has been covered.

Interpreting Area Under Kinematics Graphs

The findings have revealed that pre-service physics teachers had challenges interpreting areas under acceleration-time graphs. They tend to confuse between area under the acceleration-time graph with the area under the velocity-time graph. Figure 5 is an example of a test item for testing the ability of pre-service teachers to interpret the area under the acceleration-time graph.

Figure 5

An example of an item testing area under acceleration-time graph



In Figure 5 above, pre-service physics teachers were required to use the relationship which exists between acceleration, velocity and time ($Acceleration = \frac{\Delta Velocity}{time}$) to get the meaning of area under the acceleration-time graph. Since the area under the acceleration-time graph is the product of acceleration and time, the resulting product is the change in velocity. However, the majority of pre-service physics teachers associated the area under the acceleration-time graph with the total distance covered under the graph. Many pre-service teachers opted for the total distance covered under the graph which is related to the area under the velocity-time graph but not the acceleration-time graph. This shows the challenges pre-service physics teachers had with kinematics graphs areas.

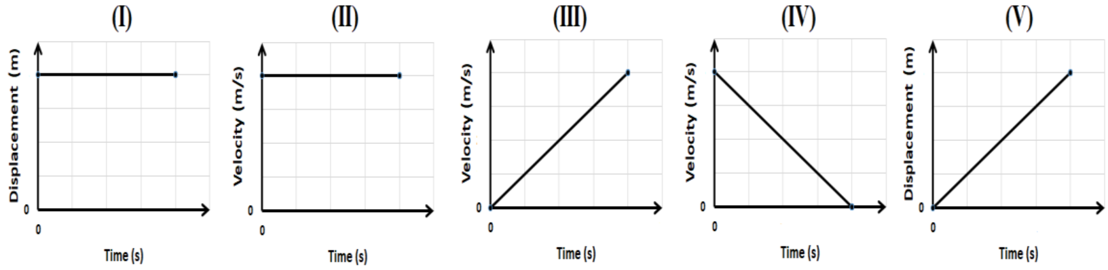
Interviews from pre-service teachers revealed similar findings to that of the test. For example, Pre-service teacher T15 from Teachers' College Y, when asked the meaning of area under the acceleration-time graph, T15 contended that *"the area under acceleration-time graphs is equal to the total distance covered under the graph"*. This excerpt indicates confusion between areas under-acceleration-time graph with that under the velocity-time graph. It seems pre-service physics teachers were familiar with the area under velocity-time graphs and know little about area under acceleration-time graphs.

Converting between Kinematics Graphs

Findings revealed that pre-service teachers had misconceptions about converting from one kinematics graph to another. They had challenges of identifying whether the graph can change its shape when variables of acceleration, position and velocity interchange at a given time. Figures 6 below represent an example of a test item for testing the ability of pre-service teachers to convert between kinematics graphs. They were asked to select two graphs which represent motion with constant velocity as indicated below.

Figure 6

An example of item for testing converting between kinematics graphs



Pre-service teachers were expected to select the choice having one velocity-time graph with constant velocity (graph II) and one displacement-time graph with constant velocity (graph V). Only 18.67% of pre-service teachers were able to get the correct answer. 51.6% got it wrong because they selected the choice with displacement-time graph having an object at stationary (graph I) and the velocity-time graph with constant velocity (graph II). The findings indicate that they were confused between stationary object in the position-time graph with constant velocity in the velocity-time graph because the two graphs look similar.

Similarly in question number 23 where students were required to convert position to velocity-time graphs. The popular destructor was A while correct options was D. Examination of distractor A more closely is that, physical structure of the its figure resembles to the structure of the figure in from the questions. Learners could not notice the change in the shapes of graphs when variables of position-time graph were interchanged with variables of velocity-time graph. Generally, pre-service teachers had difficulties in converting between kinematics graphs.

Discussions

This section expands on the results by thoughtfully addressing them in relation to the pertinent literature. Engaging pre-service physics teachers from teachers' training colleges to answer kinematics graphs conceptual questions has no doubt that, it revealed several challenges facing them. Pre-service teachers' difficulties with slope by reading directly the axis coordinates for the lines which do not start from the origin and assigning them values to slope were reported by Beichner (1994) who found that students were directly reading coordinate values from the axis and assigning them to the slope. This worked well in finding the slope of the line passing through the origin but fail when the line does not pass through zero. However, Amin et al. (2020), Antwi (2015), McDermott et al. (1987), Núñez et al. (2022), & Phage et al. (2017) showed that many students were unable to associate the slope with velocity and acceleration.

Inadequate skills in locating the object at stationary were reported by McDermott et al. (1987) who asserted that, when college students were asked to draw the position-time graph of a stationary object, some draw only a line starting from the origin rather than a horizontal line. Also, Alimisis &

Boulougaris (2014) reported that when students were given position-time graphs with forward and stationarydirections, their interpretation was good. However, when they were given a question which required them to draw the position-time graph with forwarding and stationary positions, it was hard to locate the stationary position. Moreover, Amin et al. (2020) stated that students often make mistakes when plotting graphs of rest objects. The mistake occurs because learners demonstrate the movements observed directly without noticing the time axis.

The challenge of calculating total distance in opposite direction aligns with Alimisis and Boulougaris (2014) who said it was difficult for students to find the total distance for a person walking at constant speed straight from a certain point to the wall and coming back to that point. In addition, findings align with McDermott et al. (1987) who argued by giving an example that, students were unable to translate forward and backwards from the position-time graphs.

As this study reports the confusion between area under velocity time graphs and acceleration-time graphs, the report by Antwi (2015), Antwi et al. (2018), Beichner, (1994), McDermott et al. (1987), & Phage et al. (2017) also have reported difficulties in interpreting areas under kinematics graphs. However, these reports indicate that students are failing to interpret areas under kinematics graphs because they do not understand different areas under graphs, including curved areas.

The revealed findings about students' difficulties in converting between kinematics graphs aligns with previously findings. Beichner (1994) revealed some confusion among learners when could not notice the change in the shapes of graphs when variables of position-time graph, velocity-time graph, and acceleration-time graph were interchanged. Moreover, Antwi (2015), Antwi et al. (2018) & McDermott et al. (1987) reported that students had difficulties converting between position, velocity, and acceleration time graphs. Generally, it is very important for physics educators in Tanzania to address these challenges accordingly when teaching kinematics graphs to students.

Conclusions and Implications

The challenges revealed in this study include difficulty in interpreting slope of the line graph which does not start from the origin, presenting the stationary position of the object on the graph, and difficulty in calculating total distance when forward and backward directions are involved. Other challenges include difficulty interpreting the area under acceleration time graphs and difficulty converting from one graph to another. The challenges identified require teachers to find proper learner-centred teaching and learning methods that will address those challenges and raise the performance of students on kinematics graphs and physics in general. Based on these findings and the conclusion made, the study recommends that physics teachers themselves need to know the challenges when teaching kinematics graphs to students.

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Appendix

Kinematics Graphs Concept Inventory

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGY
PHYSICS EXAMINATION FOR PRE-SERVICE TEACHERS
KINEMATICS GRAPHS QUESTIONS
TEACHERS' COLLEGE____________

INSTRUCTIONS

1. Choose the correct choices for all 25 multiple choice questions
2. All answers must be written in the box provided for each question
3. Each question carries four marks (4%)

Time 90 minutes (1.5 hours)

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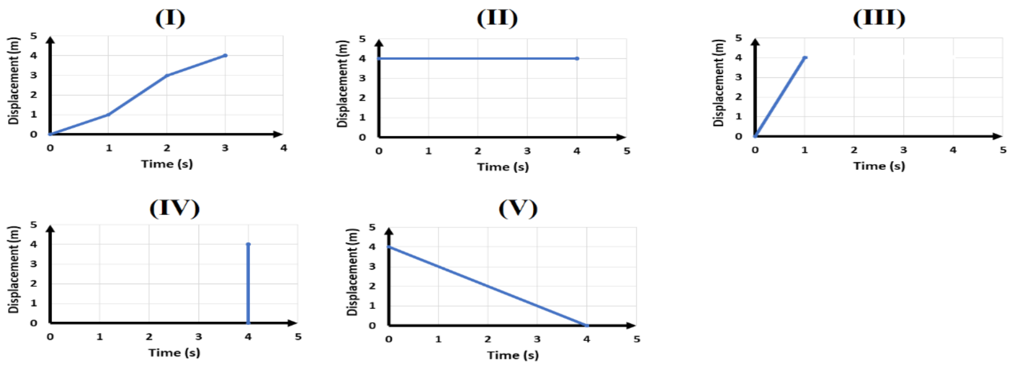
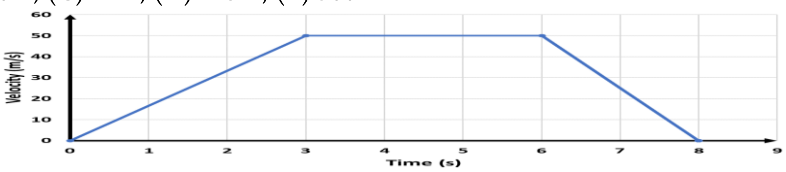
1. The displacement versus time graph for five objects is given below. Which object is moving fast in the forward direction with constant velocity?
(A) II, (B) III, (C) I, (D) V, (E) IV

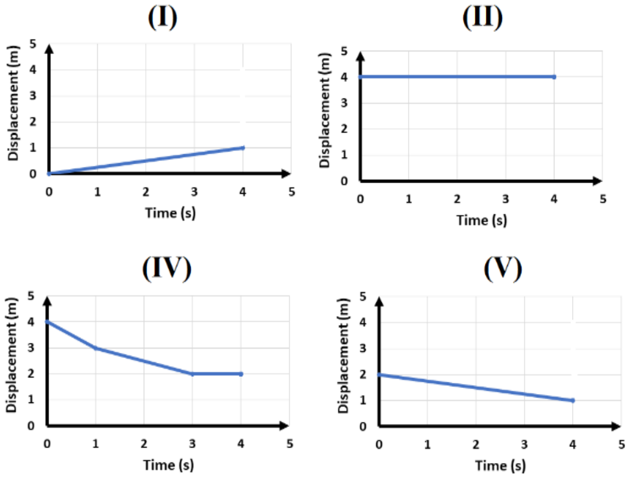


2. An object starts from rest and then moves as shown in the area of the figure below. The total distance travelled by the object is
(A) 550m, (B) 400m, (C) 24m, (D) 275m, (E) 300m

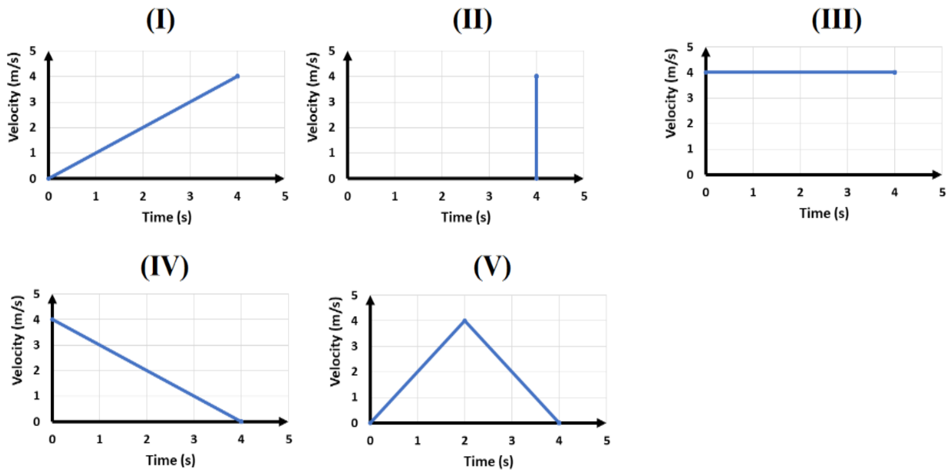


3. Here is the position-time graph of the motion of the object. Which of the following indicates that the object is not moving at all?
(A) BC and DE, (B) AB and EF, (C) CD and FG,
(D) BC and CD, (E) EF and FG

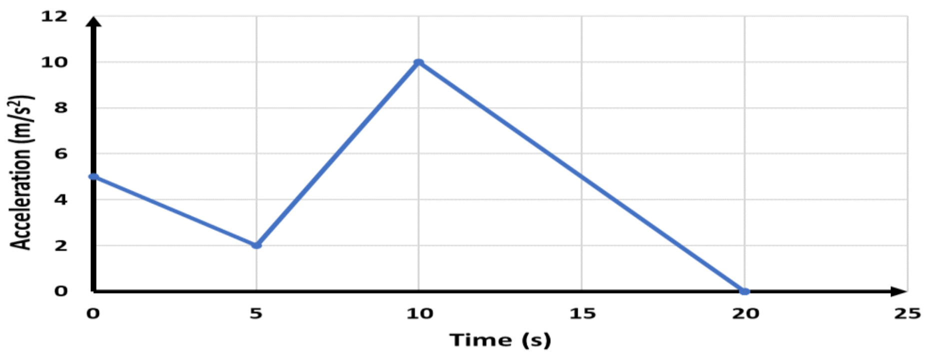
4. The displacement versus time graph for five objects is given below. Which object is moving slowly in the backwards direction with constant velocity?
(A) I, (B) II, (C) IV, (D) III, (E) V



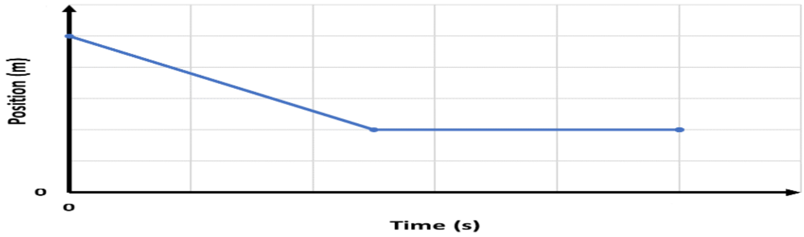
5. Given five velocity-time graphs below. Which graph represents an object's motion at constant velocity?
(A) IV, (B) V, (C) II, (D) III, (E) I



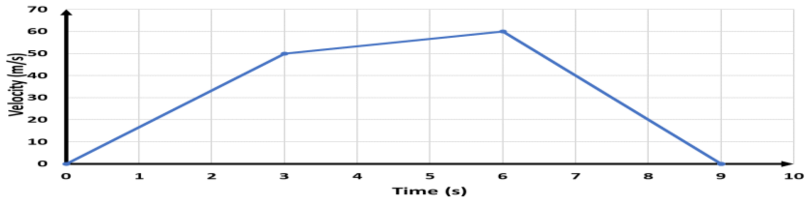
6. An acceleration-time graph is shown in the figure below. What does the area under the graph represent?
(A) Change in velocity (B) Total distance travelled (C) Retardation
(D) Total velocity (E) Total time spent



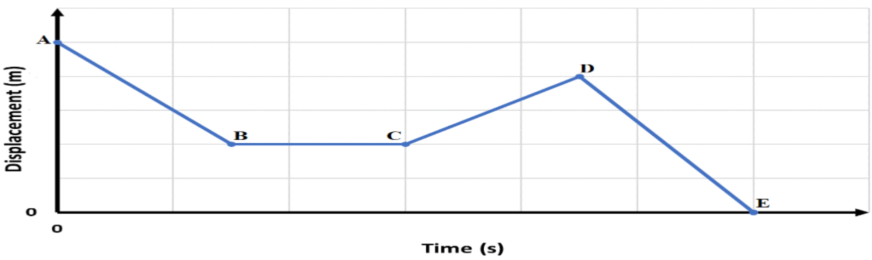
7. Two states of an object are shown in a position versus time graph below. How can you describe the states of an object?
(A) An object is moving backwards and then forward,
(B) An object is moving forward and then stopped
(C) An object is moving backwards and then stopped,
(D) An object is stopped and then moves forward
(E) An object is topped and then moves backwards



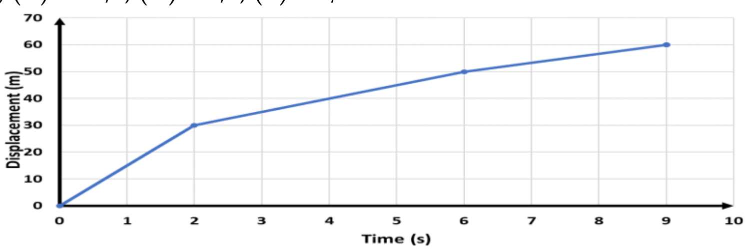
8. You are provided with a velocity-time graph below. The acceleration of an object between time (t)=6 seconds to time (t)=9 seconds is
(A) $20 m/s^2$ (B) $10 m/s^2$ (C) $50 m/s^2$ (D) $-20 m/s^2$ (E) $-10 m/s^2$



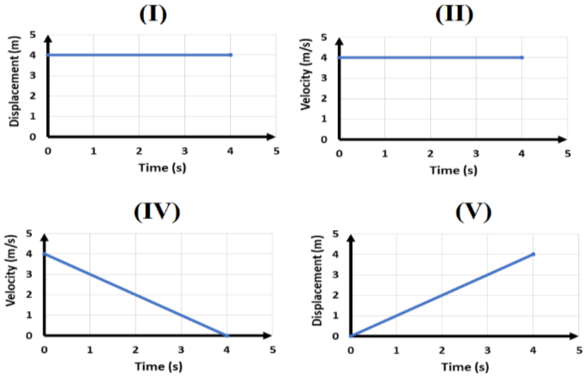
9. Different states of an object are shown in a displacement versus time graph below. How can you describe an object's motion from point A to point D?
(A) Forward, backward, and stationary,
(B) Backward, stationary, and then forward
(C) Stationary, backward and then forward
(D) Stationary, forward and then backwards
(E) Forward, stationary, and then backwards



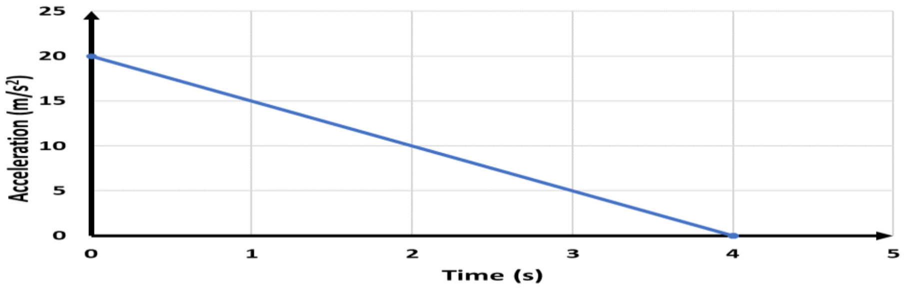
10. An object was moving as shown in the figure below. What is the velocity of an object at a time (t) = 4 seconds?
(A) 2m/s, (B) 4m/s, (C) 10m/s, (D) 6m/s, (E) 5m/s



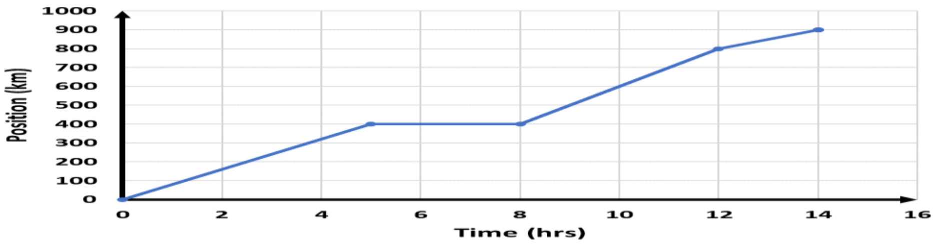
11. Given graphs below. Identify two graphs representing objects' motion at constant velocity
    (A) II and III, (B) I and II, (C) II and V, (D) III and IV, (E) IV and V



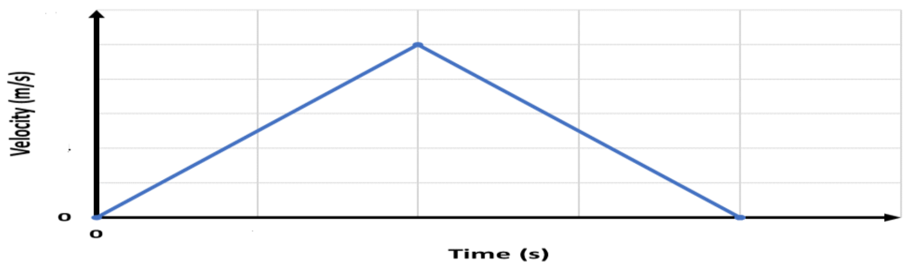
12. The figure below represents the acceleration-time graph. The change in velocity is?
    (A) 10m/s, (B) 40m, (C) 40m/s, (D) 80m/s, (E) 20m/s



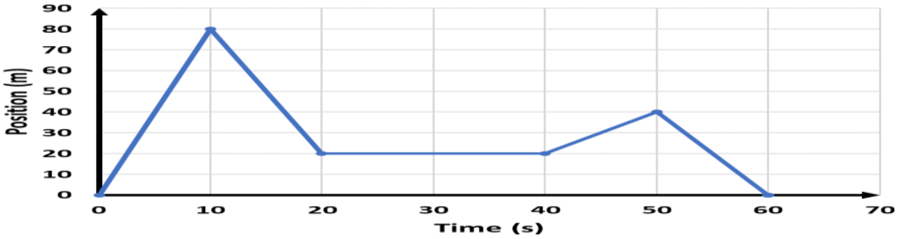
13. A car was travelling as shown in the figure below. How long does it travel from time(t) = 5 hours to time(t) = 12 hours?
    (A) 400km (B)200km (C)600km (D)1000km (E) 800km



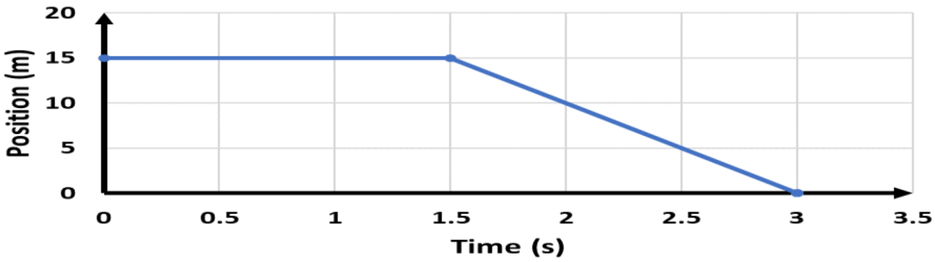
14. Given the velocity-time graph below. Which sentence is the best interpretation of the object's motion?
    (A) Deceleration then acceleration.
    (B) Acceleration then deceleration
    (C) Retardation then acceleration
    (D) Deceleration then retardation
    (E) The object does not move.



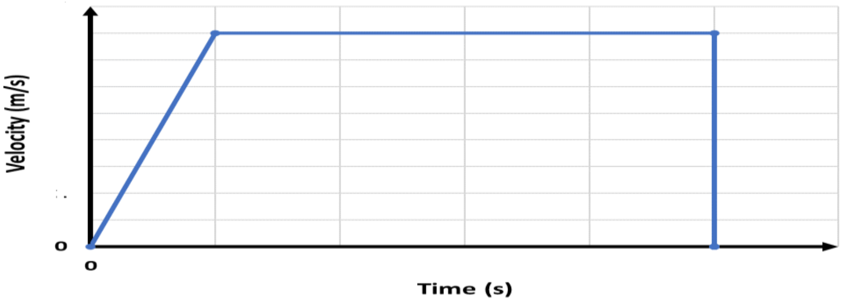
15. An object path is indicated in the displacement time graph below. How long does it journey from time (t) =10 seconds to time (t) =50 seconds?
(A) 20m, (B) 40m, (C) 60m, (D) 80m, (E)100m



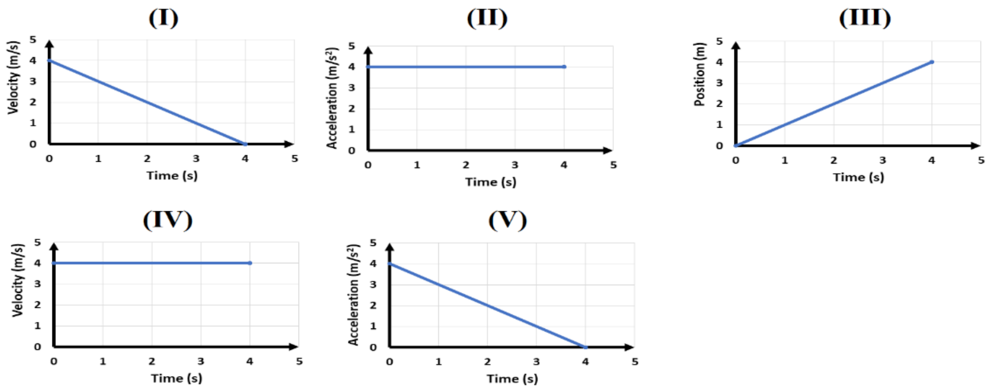
16. Displacement-time graph for an object is shown below. The velocity at the time (t) = 2 seconds is about?
(A) 5m/s, (B) 15m/s, (C) 10 m/s, (D) 2m/s, (E) 3m/s



17. You are given a graph as shown in the figure below. What does the area represent?
(A) Acceleration (B) Speed (C) Retardation
(D) Total distance travelled (E) Velocity

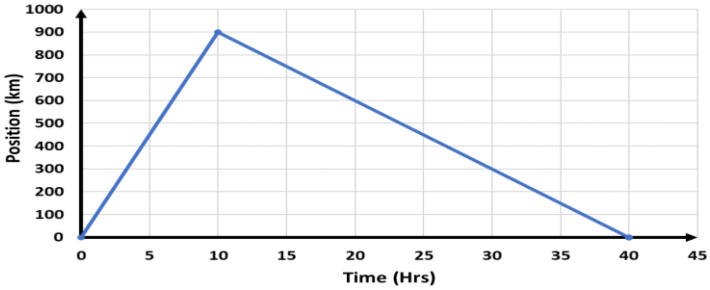


18. Consider the following graphs, noting the different axes

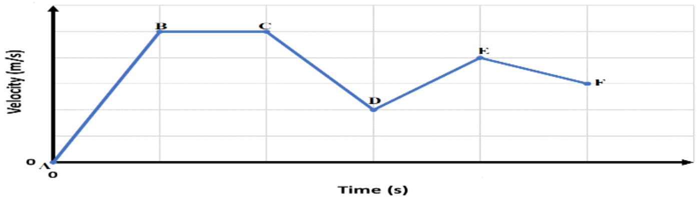


Identify graphs which indicate motion with zero acceleration
(A) I, II and IV (B) III and IV (C) II and V (D) IV only (E) V only

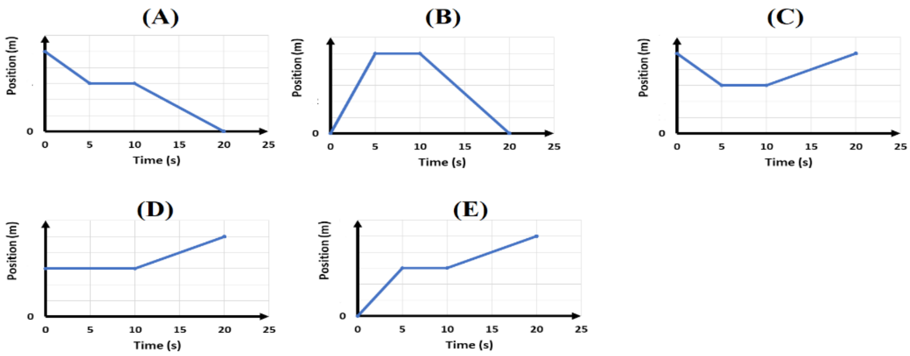
19. The following graph is a position-time graph. The distance of the object from time (t) =0 hours to time (t) = 20 hours is
    (A) 900Km, (B) 600Km, (C) 1200Km, (D) 1000Km, (E) 1500Km



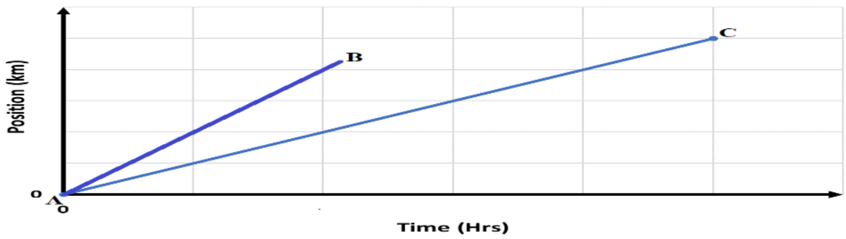
20. An object starts from rest and then moves as shown in the velocity versus time graph below. At which state an object is said to be decelerating?
    (A) AB and DE, (B) AB and EF, (C) DE and EF,
    (D) BC and DE, (E) CD and EF



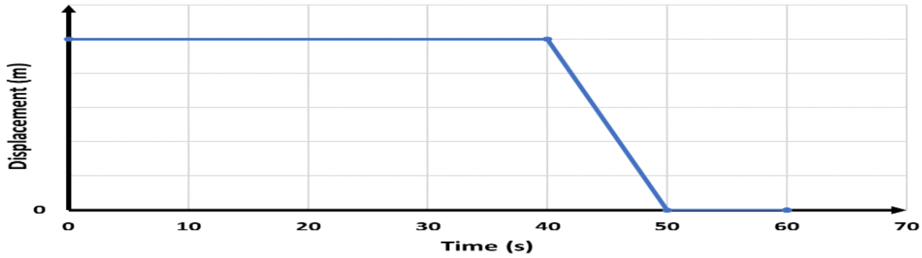
21. An object starts from rest and moves forward with constant velocity for five seconds. It then stops for five seconds and continues forward with constant velocity for 10 seconds. Which of the following graph correctly describes this situation?



22. By referring to the slope of the distance-time graph below. Which one of the sentences best describes the motion of object AC?
    (A) AC is moving slower than AB
    (B) AC and AB have the same velocity
    (C) AC is moving faster than AB
    (D) AC is moving forward and AB backwards
    (E) AC is moving backwards and AB forward

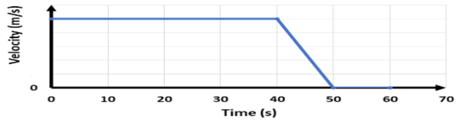


23. The displacement-time graph below represents an object moving motion during a 60s-time interval.

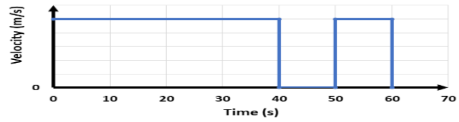


Which one of the following graphs of velocity versus time would best represent the object's motion during the same time interval?

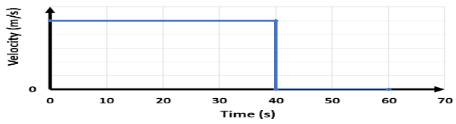
(A)



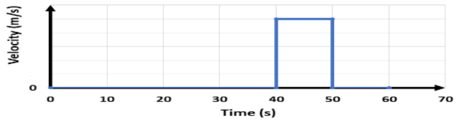
(B)



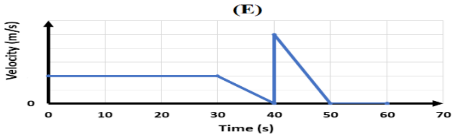
(C)



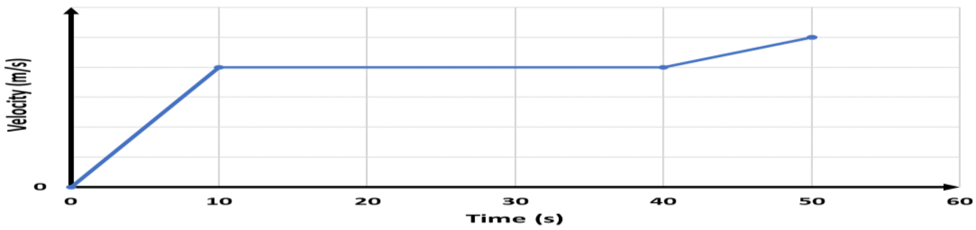
(D)



(E)

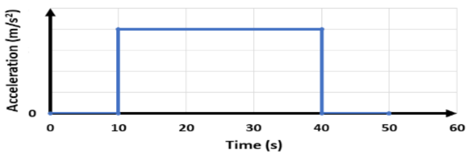


24. The velocity-time graph below represents an object's motion during a 50s-time interval

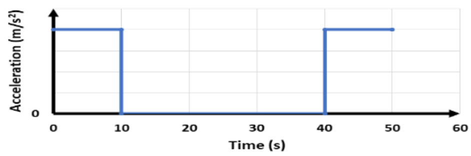


Which of the following graphs of acceleration versus time would best represent the object's motion during the same time interval?

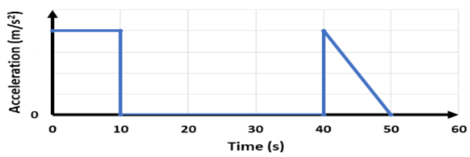
(A)



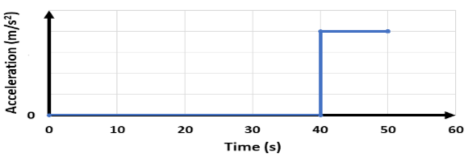
(B)



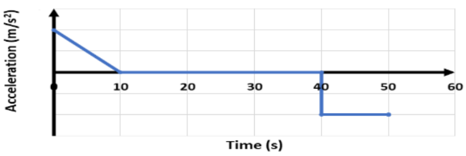
(C)



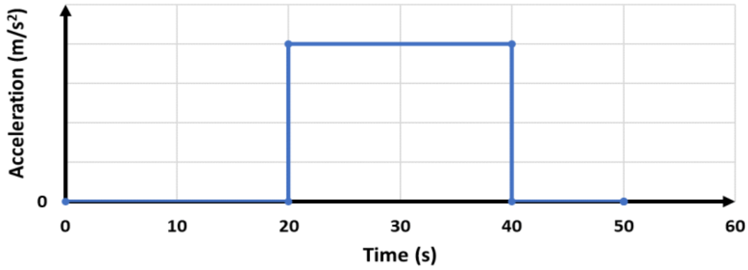
(D)



(E)

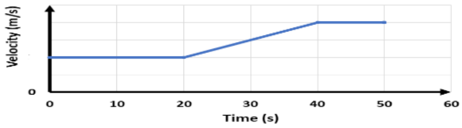


25. An acceleration graph for an object during a 50s-time interval is represented below

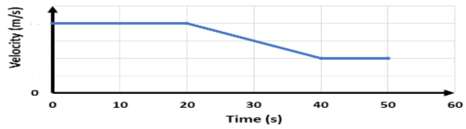


Which of the following velocity versus time represents the object's motion during the same time interval?

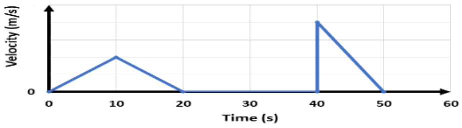
(A)



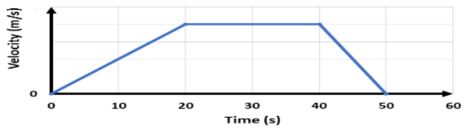
(B)



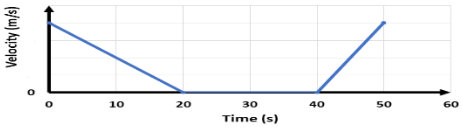
(C)



(D)



(E)



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The strategic role of conservation education in efforts to improve biodiversity literacy: a systematic review

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ABSTRACT

Biodiversity literacy is becoming increasingly important in the era of globalisation to understand and conserve various forms of life on Earth. Education plays a crucial role in improving biodiversity literacy, but this aspect is often underemphasized in formal and non-formal education. This study aims to analyse the strategic role of conservation education in improving biodiversity literacy through a systematic review of 25 relevant articles, selected using the PRISMA framework. These articles were sourced from reputable international journals indexed in Scopus and Google Scholar. The findings indicate that biodiversity literacy can be enhanced through various innovative learning models that integrate technology, such as virtual reality and mobile applications, to improve learning experiences, motivation, and student engagement. However, the study lacks direct empirical measurements of this improvement, highlighting the need for further research to quantify its impact. Additionally, direct learning approaches that incorporate nature-based experiences have been effective in fostering environmental awareness, though this finding is primarily drawn from the literature review rather than new empirical evidence. Integrating biodiversity literacy into curricula through multidisciplinary approaches and local knowledge is also beneficial for promoting students' understanding and conservation behavior. However, challenges such as the lack of appropriate teaching methods and the need for curriculum adjustments persist. To address these issues, a holistic and integrated educational approach is recommended, incorporating technology, hands-on experiences, and local knowledge. By implementing these strategies, conservation education can not only enhance biodiversity literacy but also cultivate a generation that is more environmentally conscious and committed to conservation efforts.

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Introduction

In the modern era of globalization, fostering biodiversity literacy is essential for comprehending and safeguarding Earth's diverse ecosystems. Education serves as a key driver in enhancing awareness of biodiversity conservation. However, its significance is frequently overlooked in both formal and informal learning settings. This neglect results in limited public engagement and insufficient conservation efforts. To bridge this gap, education must incorporate interdisciplinary approaches, hands-on experiences, and technological innovations to cultivate deeper ecological awareness. Strengthening biodiversity literacy will empower individuals to take informed actions, ensuring the sustainability of natural resources and promoting a more environmentally conscious society for future generations. Biodiversity literacy is not just a basic understanding of biodiversity, but more broadly includes the ability to use this knowledge to solve environmental problems and form a sensitive and responsive attitude to environmental issues (Utari et al., 2021). This knowledge is an important foundation in shaping effective conservation policies and practices, showing the link between scientific understanding and practical applications in daily life.

Knowledge and awareness about biodiversity gained through education are needed to shape pro-environmental behaviour and strengthen community involvement in nature conservation. Schneiderhan-Opel & Bogner (2020) emphasize that biodiversity education is an essential tool for sustainable development, providing a basis for individuals to make environmentally responsible decisions. According to Durmuş & Kinaci (2021), effective environmental education can improve environmental literacy and result in behaviour changes that support long-term sustainability. Nevertheless, challenges persist in implementing biodiversity education effectively, including inadequate integration into curricula, limited teaching resources, and a lack of innovative approaches.

The integration of biodiversity literacy into the educational curriculum is a strategic step to strengthen understanding and appreciation of biodiversity. Through a well-designed curriculum, school learners are taught not only about species and ecosystems but also about the impact of human intervention on the environment and ways to reduce the ecological footprint of humans. Masemene & Msezane (2021) describe how science education and curriculum-based activities can promote sustainable behaviour and deeper ecological awareness.

There are several learning models or strategies that have been applied in biodiversity learning, including the use of environmental literacy instruments which has proven to be effective in increasing public awareness and knowledge about the environment(Miterianifa, 2024). The integration of local wisdom in biodiversity learning not only enriches learning materials but also contributes to the development of pupils' character, such as reading and writing literacy (Joyo, 2018). The application of technologies such as augmented reality (AR) and digital learning platforms has revolutionised the way we teach and learn about biodiversity. According to Merino et al., (2022), the use of AR in education helps learners visualise and understand the concept of biodiversity more deeply, which allows for richer interactions with the subject matter. This approach not only increases their engagement but also strengthens their understanding of complex environmental issues.

Recent research shows the importance of innovative approaches in education to increase understanding and engagement in biodiversity issues. (Wolff, 2023) emphasises the role of biodiversity education in fostering concern and concern for the environment. Education about organisms in the surrounding environment is important to instil a sense of responsibility for biodiversity (Lindemann-Matthies & Bose, 2008). Adolescents' perception of biodiversity has a significant effect on their attitudes and behaviours towards environmental conservation (Schneiderhan-Opel & Bogner, 2019). There has been a surge in global interest in biodiversity and conservation efforts, with research assessing the level of awareness of various groups, both professional and non-professional, regarding the concept of biodiversity (Akindele et al., 2021; Caetano et al., 2023). Promoting reflectivity and encouraging involvement in biodiversity protection is crucial to addressing knowledge gaps and encouraging proactive conservation behaviours (Quarshie et al., 2019). Local land-use planning is recognised as a key strategy for biodiversity conservation, emphasizing the importance of education programs in raising awareness and supporting conservation efforts (Stokes et al., 2010).

This review utilizes the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to conduct a structured and systematic analysis of biodiversity education's role in enhancing biodiversity literacy. While the study primarily synthesizes findings from existing literature, it also critically evaluates the effectiveness of various educational approaches. A true systematic review requires rigorous methodological criteria, including data extraction, quality assessment, and synthesis of empirical evidence. Therefore, this study aims not only to provide an overview but also to highlight gaps in current research, offering insights into how biodiversity education can be more effectively integrated into learning environments.Articles included in the review were selected based on explicit inclusion and exclusion criteria: (1) studies published in the last 10 years, (2) articles indexed in reputable databases such as Scopus and Google Scholar, (3) studies focusing on biodiversity literacy, conservation education, and innovative learning models.

To guide this systematic review, the following research question is posed: "What are the effective educational strategies and curriculum integration approaches that enhance biodiversity literacy and conservation behaviour among learners?"

By systematically examining the existing literature, this review aims to the growing body of knowledge on biodiversity education by exploring innovative methods and their integration into formal and non-formal educational systems. the study is to analyse and discuss the strategic role of biodiversity education in improving biodiversity literacy.

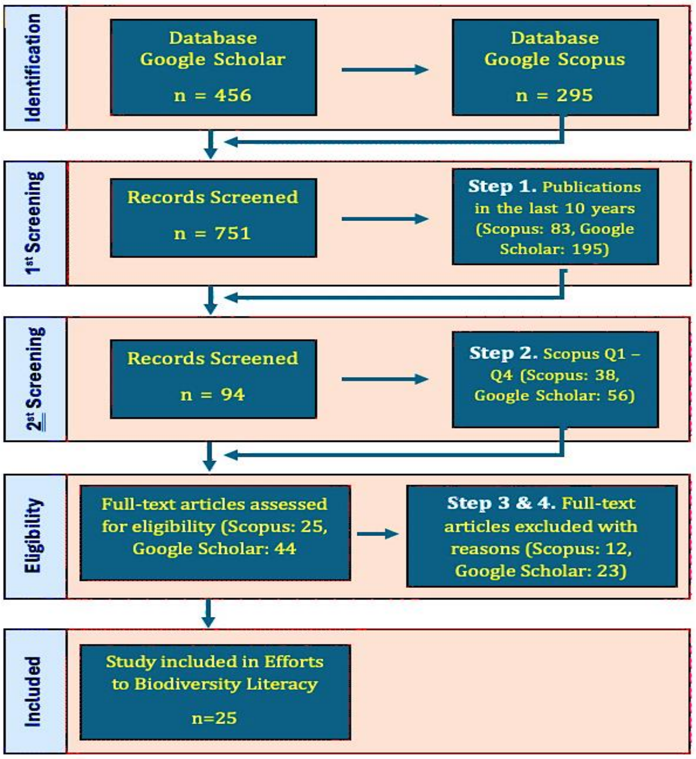
Methods

This study uses the PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses) framework to conduct a systematic review and meta-analysis (Zarate et al., 2022) of articles related to biodiversity literacy, conservation education and biodiversity learning from reputable international journals and proceeding indexed in Scopus. The PRISMA framework is a widely known tool for evaluating systematic reviews and meta-analyses consisting of 4 steps (Liberati et al., 2009; Moher et al., 2009): 1) Identification of journals to be included in the meta-analysis; 2) Screening, screening or selection of data; 3) Eligibility, determining the article to be used as material for literature assessment; and 4) Inclusion, combining and reporting results. The selection of articles uses the *Publish or Perish* application using databases from Scopus and Google Scholar.

The following is an illustration of the analysis from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) based on articles relevant to the research study can be seen in Figure 1 below. Based on Figure 1, The PRISMA diagram shown illustrates the systematic selection process for biodiversity literature studies. The process began with an identification stage, where an initial search was conducted using two databases, Google Scholar and Scopus, yielding a total of 751 publications (456 from Google Scholar and 295 from Scopus). The first screening stage restricted publications to those published in the last 10 years, reducing the number of publications to 278 (195 from Google Scholar and 83 from Scopus). The second screening further refined publications based on journal quality, with only journals indexed in the Q1 to Q4 quartiles of Scopus being considered. From this process, 94 publications remained for consideration (56 from Google Scholar and 38 from Scopus).

Figure 1

Mapping the selection of relevant articles for systematic review



Note. Adoption from (Zarate et al., 2022)

In the eligibility stage, 69 articles were evaluated based on their full text to determine their suitability to the study criteria. Of these, 25 articles from Scopus and 44 from Google Scholar were further assessed. However, some articles were excluded for specific reasons, such as relevance, methodology, or quality, resulting in the exclusion of 35 articles (12 from Scopus and 23 from Google Scholar). After the selection and exclusion process, 25 articles that met all the selection criteria were finally included in this study.

This process demonstrates a systematic and rigorous approach to ensure that only quality and relevant studies are included, increasing the validity and reliability of findings related to biodiversity literacy. In this way, research can produce more accurate and reliable insights in efforts to improve understanding and awareness of biodiversity. The following are the results of the analysis from PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) in Table 1 below.

Table 1

Article selection results

No	Author	Journal	Index-Journal
1	De Oliveira et al., 2020	Journal of Ethnobiology and Ethnomedicine	Scopus Q1
2	Hooykaas et al., 2019	Biological Conservation	Scopus Q1
3	Paradise & Bartkovich, 2021	Citizen Science: Theory and Practice	Scopus Q1
4	Grúňová et al., 2017	Applied Environmental Education and Communication	Scopus Q2
5	Ardoin et al., 2020	Biological Conservation	Scopus Q1

No	Author	Journal	Index-Journal
6	Thomas et al., 2019	Environmental Education Research	Scopus Q1
7	Lo & Tsai, 2022	Sensors	Scopus Q1
8	Kamaludin et al., 2022	Applied Environmental Education and Communication	Scopus Q2
9	Babou, 2023	International Journal of Educational Methodology	Scopus Q3
10	Zedda, 2023	Lichenologist	Scopus Q2
11	Akwetey, 2023	Limnology and Oceanography Bulletin	Scopus Q3
12	Børresen et al., 2023	Environmental Education Research	Scopus Q1
13	Audrin & Audrin, 2022	Environmental Education Research	Scopus Q1
14	Yli-Panula, 2018	Sustainability	Scopus Q1
15	Leksono et al., 2015	Educational Horizons	Scopus Q3
16	Coşkunserçe, 2024	Ecology and Evolution	Scopus Q1
17	Soddu Pirellas et al., 2024	Environments - MDPI	Scopus Q1
18	Babou et al., 2023	Education Sciences	Scopus Q2
19	Moss et al., 2014	Nature	Scopus Q1
20	Picanço et al., 2021	Environmental Conservation	Scopus Q1
21	Zukmadini et al., 2024	Indonesian Journal of Science and Technology	Scopus Q1
22	Janžekovič, 2022	The American Biology Teacher	Scopus Q3
23	Bermudez et al., 2022	International Journal of Education in Mathematics, Science and Technology	Scopus Q4
24	Aznar-Díaz et al., 2019	International Journal of Environmental Research and Public Health	Scopus Q2
25	Skupien et al., 2016	Human Dimensions of Wildlife	Scopus Q1

Findings

Biodiversity Learning Model

In this study, researchers identified and compared various learning models that are effective in increasing biodiversity literacy. Therefore, from the 25 articles reviewed, 7 articles were obtained that mentioned a learning model that was able to increase learners' biodiversity literacy. Details can be described in Table 2 below.

Table 2

Biodiversity learning model

No	Author	Learning Model	Synthesis
1	Lo & Tsai, 2022	3D virtual reality architecture in the metaverse (VRAM)	In the learning process of water resources education, it was stated that participants who were given learning and received instruction by involving VRAM had a significant increase in learning experience, learning motivation, learning interaction, self-efficacy, and attendance in learning the concept of environmental conservation.
2	Yli-Panula et al., 2018; Zedda, 2023	Hands-on learning, hands-on instruction, experiential learning, roleplay, and service learning	Effective direct learning must support hands-on experience in nature, interdisciplinary knowledge transfer, active participation, cooperation, the use of digital media in the learning process and increased environmental awareness. But unable to improve high-level thinking skills
3	Coşkunserçe, 2024	Mobile PlantNet	By implementing Mobile PlantNet, behaviour related to biodiversity conservation can be improved. Students can also identify more plant species in their environment than ever before. In particular, the number of plant species that students can recognise increases significantly after using the app. In addition, this research was able to overcome the problem of recognizing plant species that exist around them as "plant blindness". The use of these apps can also increase their interest and knowledge about biodiversity.
4	Aznar-Díaz et al., 2019	Environmental care attitude instrument	Through the implementation of environmental attitude test instruments, primary school teachers have highly positive environmental attitudes. This is important to teach the next generation.
5	Skupien et al., 2016	Classroom-based conservation education programmes and field trips.	The growing population of *Alligator mississippiensis* in a human-dominated landscape presents challenges for wildlife managers. Therefore, managers conducted an evaluation using two classroom-based conservation education programs and field trips. The results showed that respondents had more positive attitudes toward alligators and believed they could coexist.
6	Grúňová et al., 2017	Conservation education programmes	The results of the evaluation of the impact of environmental education programmes on children's short-term and long-term environmental knowledge in West Africa showed a significant increase in knowledge after the programme. Furthermore, the knowledge gained was proven to be long-lasting and contributed to increased awareness of the importance of conservation. However, increased knowledge alone is not enough to drive behavioral change. More targeted awareness campaigns are needed to encourage individuals to take real action in conserving the environment. With a more comprehensive approach, environmental education programs can have a more sustainable impact on conservation behavior.

Curriculum Integration

Ways to integrate biodiversity literacy can be carried out in the educational curriculum, both formal and non-formal education. Based on the 25 articles reviewed, 8 ways or strategies have been carried out in integrating biodiversity into the learning process. The strategy can be detailed in Table 3 of the synthesis results of How to Integrate Biodiversity in Learning below.

Table 3

How to integrate biodiversity in learning

No	Author	How to Integrate Biodiversity in Learning	Synthesis
1	Ardoin et al., 2020; Paradise & Bartkovich, 2021	Integrating local knowledge	Through a new approach to the learning process, it can enrich the learning experience, and actively involve them in seeking knowledge of biodiversity conservation in residents, as well as being able to increase their understanding and literacy of biodiversity
2	Kamaludin et al., 2022	Providing Mangrove Ecosystem Conservation Education	This study assessed the effectiveness of conservation education in improving students' understanding of the mangrove ecosystem in Setiu Wetlands. With 74 students participating in the survey and workshop, the results showed that the benefits of cultural services were less recognized, while regulatory, provision, and support services were considered important. Further analysis showed no significant difference in the improvement of understanding between male and female students, suggesting a need for a more comprehensive educational approach.
3	Babou et al., 2023	Providing Biodiversity Knowledge	The study involved 202 a grade level of 2nd year Baccalaureate. The results showed that only 2% of the students, were able to provide a complete definition of biodiversity that includes three dimensions: species, ecosystems, and genetic diversity. The study found that there was a low to moderate correlation between their representations and the knowledge they acquired related to the biodiversity concepts discussed in the school program.
4	Audrin, 2023; Zukmadini et al., 2024	Textbook	By integrating biodiversity education into compulsory textbooks in the French-speaking region of Switzerland in natural sciences, humanities and social sciences at all levels of education. The results show that it can improve biodiversity literacy, the ability to deal with environmental issues and manage natural resources.
5	Akwetey, 2023	Integrating water resources and biodiversity learning	The activity involved 50 student and 5 teachers. The results showed that participants gained a better understanding of aquatic life forms and their ecological functions as well as the impact of human activities on organisms living in lagoons. and fostering a sense of responsibility to maintain cleanliness and environmental sustainability.
6	Leksono et al., 2015	Conservation Based on Local Wisdom (BKBKL)	Lectures by integrating BKBKL can affect the improvement of biodiversity literacy. This is because BKBKL lectures involve learners' ability to investigate, develop biodiversity process skills and the ability to master concepts so that they can act to appreciate biodiversity.
7	Bermudez et al., 2022	Integrate knowledge about biodiversity education using a holistic approach	Learners have a diverse understanding of biodiversity, with a primary focus on species diversity. However, an understanding of the broader components and attributes of biodiversity is often neglected. The research also found that conceptions of biodiversity among students from ethnic and rural communities were stronger than among students from urban contexts, indicating a link between local knowledge and understanding of biodiversity.

No	Author	How to Integrate Biodiversity in Learning	Synthesis
8	De Oliveira et al., 2020	Integrating biodiversity knowledge	Exploring the biology education approach to teaching wildlife and conservation in urban and rural schools in a semi-arid region of Brazil. The study involved 990 students, with 528 urban and 462 rural students, who were interviewed using a questionnaire. The results showed that students had a high level of knowledge regarding the richness and diversity of birds and mammals among other fauna. Only about 70% said that their educational process discussed wildlife conservation, while almost 50% in both urban and rural contexts showed no conceptual understanding of nature conservation.

The Role of Biodiversity Literacy and Conservation Education

Biodiversity literacy and conservation education play an important role in promoting pro-environmental awareness and action among the public. Evaluation of conservation programs should be more rigorous and based on local cultural contexts for greater effectiveness, while active participation of local communities and integration into formal education curricula are also needed. The following articles can explain this in Table 4 below.

Table 4

The role of biodiversity literacy and conservation education

No	Author	Synthesis
1	Hooykaas et al., 2020	Biodiversity literacy is essential for conservation, yet a gap exists between experts and the public. Professionals have higher species literacy, emphasizing the need for broader education. Conservation education can bridge this gap by promoting inclusive learning and increasing species awareness. By integrating biodiversity literacy into education, society can develop a stronger connection to nature and actively participate in sustainable conservation efforts.
2	S. Thomas, 2016	Conservation Education (CE) approaches are essential in biodiversity conservation. However, challenges remain in evaluating the effectiveness of CE programs. More rigorous, longitudinal, and contextual evaluation methods that consider cognitive, behavioral, social, and ecological aspects are needed. Thus, through a collaborative and culturally integrated assessment approach can increase the effectiveness of CE, ensuring long-term engagement and impactful biodiversity conservation efforts.
3	Børresen, 2023	Education plays an important role in increasing awareness and knowledge of ecosystem services and biodiversity. Through education, students can demonstrate positive attitudes towards environmental conservation, understand the negative impacts of climate change, and the importance of ecosystem services. Education that incorporates conservation materials into school curricula, especially in areas near conservation areas, can increase participation and awareness of local communities.
4	Moss, 2017; Moss et al., 2014a	Visiting a zoo can increase visitors' understanding of biodiversity. While raising awareness, there is a need to ensure that zoos also encourage significant behavioural change to support conservation efforts.
5	Picanço et al., 2021	Teachers' perspectives in the Azores found that although teachers are aware of the importance of conservation, the use of the internet as a tool for teaching about biodiversity has not been maximized. Most teachers focus more on the species level than on the ecosystem or genetic level. This suggests the need for further training for teachers to integrate biodiversity knowledge into the curriculum in a more holistic way.
6	Janžekovič, 2022b	Biodiversity loss is a global challenge that can only be addressed through behaviour influenced by education. Biodiversity literacy must be promoted through educational approaches that reconnect people with nature, recognizing the importance of nature for children's well-being and cognitive development.

Discussion

Theories and Concepts of Conservation Education to Improve Biodiversity Literacy

Conservation education is essential for fostering awareness, knowledge, and behaviors that support biodiversity protection and natural resource sustainability (Leksono et al., 2023). By equipping individuals with the necessary skills and attitudes, these programs encourage active participation in conservation efforts. Research highlights that knowledge gained through conservation education significantly influences conservation beliefs and behaviors (Oražem et al., 2022; Thomas, 2016). Institutions such as zoos and aquariums play a key role in this process by integrating conservation education into their missions, providing hands-on experiences that promote ecological awareness (Mellish et al., 2018).

To ensure the effectiveness of conservation education, a structured evaluation framework is required to assess learning outcomes and behavioral changes (Thomas, 2016). Effective programs employ multidisciplinary approaches that incorporate iterative monitoring and participatory learning, enhancing long-term engagement in conservation efforts (Lukas et al., 2017). However, many programs rely on a top-down pedagogical approach delivered by biologists rather than trained educators, which may limit educational effectiveness (Fernanda Bernárdez-Rodríguez et al., 2021). Addressing this gap by integrating formal education strategies can enhance program impact.

Furthermore, conservation education plays a critical role in raising public awareness about the sustainable management of natural resources, such as water conservation (Valenzuela-Morales et al., 2022). Studies show that well-designed educational practices positively influence public perceptions and attitudes toward conservation (Mormul et al., 2017). To maximize impact, conservation education must incorporate evidence-based strategies that translate knowledge into actionable conservation behaviors, ensuring long-term environmental sustainability (Sakurai & Uehara, 2020).

To achieve sustainable conservation goals, conservation education must continue to be developed and implemented with a holistic and measurable approach. It involves collaboration between different disciplines and stakeholders to ensure that such educational programs not only increase knowledge but also encourage real action in conservation efforts. Through effective conservation education, future generations can be equipped with the knowledge and skills necessary to safeguard and preserve our environment. Conservation education plays a strategic role in addressing global challenges related to biodiversity conservation and environmental sustainability. In an era where pressure on natural resources and biodiversity is constantly increasing, it is important to develop a deep understanding of these issues among the wider community. One effective way to achieve this is through increasing biodiversity literacy, which not only increases knowledge but also fosters concern and responsibility for the environment (Kusumaningrum, 2017; Nugraha et al., 2021)

Biodiversity literacy plays a crucial role in understanding biodiversity concepts as well as promoting conservation efforts. As explained by (Aslan Efe & Efe, 2022), a deep understanding of biodiversity helps individuals and communities realize the importance of preserving biodiversity in their surrounding environment. To introduce biodiversity literacy in the classroom, several techniques have been developed by several previous researchers such as integrating biodiversity education in learning textbooks (Nuraeni et al., 2022) and learning models (Katili & Rahmat, 2020; Rijal et al., 2018). Through biodiversity learning, not only biodiversity literacy increases but also conservation behaviours both through direct and indirect actions. This starts from the surrounding environment first (Ardoin et al., 2020; R. E. W. Thomas et al., 2019)

Improving biodiversity literacy through conservation education is crucial, as has been highlighted in various literature. Stokes et al., (2010) emphasise the importance of educating the public about local conservation, increasing ecological literacy, and promoting collaboration for biodiversity conservation in local land use planning. (Jiménez (2015); and Jiménez et al., 2014) also emphasize the significance of conservation education and counseling programs in fostering public understanding vation. Birdsall & Kelly (2022) propose that effective conservation education occurs when students engage with local nature and take action to increase biodiversity in their communities. Thus, through targeted conservation education efforts, biodiversity literacy can be improved, which in turn will strengthen conservation behaviour in the community. This approach not only has an impact on local environmental conservation but also contributes to global conservation efforts.

In addition, Fischer et al., (2020) highlight the positive correlation between knowledge about biodiversity and attitudes towards biodiversity-friendly green space management, emphasizing the need to provide environmental information and education about the role of biodiversity in urban areas. Caetano et al., (2023) recommend increased extension and education efforts, especially in areas with economic disparities and weak education systems, to promote biodiversity conservation. Education is emerging as an important element in the success of biodiversity conservation, as noted by Daan et al., (2020), which emphasizes the need for educational initiatives. Faruhana et al., (2022) highlight the important role of educators and policymakers in instilling the positive traits of biodiversity conservation in children through hands-on experience. Coracero (2021) Suggests reviewing the college curriculum to ensure environmental education in all courses of study, with an emphasis on biodiversity conservation. Furthermore, Merino et al., (2022) rewords an interdisciplinary approach to improve students' knowledge and literacy about biodiversity and its conservation. Integrating citizen science, as proposed by Paradise & Bartkovich (2021), can equip students with the knowledge and motivation to contribute effectively to biodiversity conservation. Efe & Efe (2022) showed that biodiversity literacy is included in environmental literacy, emphasizing its importance in science education.

Based on the literature above, the steps that need to be taken to increase biodiversity literacy through conservation education can be concluded including:

1. Community and Student Education: Provide easily accessible and relevant information on the importance of biodiversity and ways to protect it, both through formal schools and community outreach programs.
2. Hands-on Experience: Facilitate hands-on experiences with nature for students, such as outdoor learning programs and local conservation projects, to enhance their engagement and understanding.
3. Collaboration and Public Participation: Encourage active community participation in conservation efforts through citizen science programs and community initiatives, which can increase conservation awareness and action.
4. Multidisciplinary Education: Integrating biodiversity conservation materials in various disciplines and courses in colleges and universities to ensure that all students have a basic understanding of the importance of biodiversity conservation.
5. Inclusive Approach: Addressing economic and educational disparities by providing additional resources and support to underprivileged areas, to ensure that all levels of society receive adequate conservation education.

By implementing these strategies, it is hoped that biodiversity literacy can be significantly improved, which will ultimately support more effective and sustainable biodiversity conservation efforts.

Biodiversity Learning Model

Based on Table 2, states that various innovative learning models have shown effectiveness in improving environmental conservation understanding, attitudes, and behaviour among students. For example, the use of 3D virtual reality architecture in the metaverse (VRAM) by Lo & Tsai (2022) has been shown to improve learning experiences, motivation, interaction, self-efficacy, and participant attendance in learning environmental conservation concepts. This model offers an immersive learning experience that can replace the limitations of direct experience in the real world. The application of various innovative learning models shows great potential in improving environmental and conservation education. The use of technologies, such as 3D virtual reality architecture in the metaverse (VRAM) and the Mobile PlantNet application, presents new opportunities to make learning more interactive, engaging, and relevant to today's digital generation. VRAM provides an immersive experience that allows students to deeply understand environmental concepts, while Mobile PlantNet helps overcome "plant blindness" and enrich students' knowledge of biodiversity. These technologies not only increase students' motivation and learning experience but also foster interest and caring attitudes towards the environment.

Zedda (2023) emphasizes the importance of direct, hands-on learning in nature, cross-disciplinary knowledge transfer, active participation, and digital media use to enhance students' environmental awareness. Breaking this down, hands-on learning models allow students to engage directly with natural processes, reinforcing conceptual understanding and fostering a deeper awareness of environmental issues. Additionally, these activities promote collaboration and active participation. These skills are particularly crucial in 21st-century learning, as they equip students with problem-solving abilities, critical thinking, and teamwork—competencies essential for addressing complex global challenges in an increasingly interconnected world (Dewi & Rahayu, 2024).

Coşkunserçe (2024) demonstrates that the Mobile PlantNet application effectively enhances biodiversity conservation behavior by addressing "plant blindness" and increasing students' engagement with biodiversity. This effectiveness is evidenced by measurable improvements in students' ability to identify plant species, increased participation in conservation activities, and higher self-reported interest in biodiversity topics. Similarly, Aznar-Díaz et al., (2019) found that teachers with positive environmental attitudes, as measured by standardized environmental attitude instruments, play a crucial role in fostering conservation values among students. Skupien et al., (2016) further reported that a classroom-based conservation education program, combined with field trips, led to a statistically significant increase in students' positive perceptions of species such as Alligator mississippiensis and their willingness to support conservation efforts. Overall, integrating technology, experiential learning, and attitude-focused approaches in conservation education proves to be highly effective in fostering long-term pro-environmental awareness and actions across different educational levels. The implementation of various innovative learning models has proven effective in improving environmental and conservation education. Technologies such as 3D virtual reality (VRAM) and mobile applications such as PlantNet provide more interactive and engaging learning experiences, which can increase students' knowledge, motivation, and engagement in environmental issues. In addition, direct or hands-on learning models that involve real-world experiences provide opportunities for students to be actively involved, which ultimately increases their understanding and awareness of conservation issues.

Instruments to measure environmental attitudes are also important in ensuring that conservation values are taught effectively, starting from teachers to students. The positive attitudes held by teachers towards the environment can have a direct impact on how they teach these values to the younger generation. In addition, conservation education programs that combine classroom-based learning with field experiences have shown success in changing students' perceptions and attitudes towards wildlife, emphasizing the importance of coexisting with other living things.

Overall, the combination of technology, direct experience, and attitude-based approaches in environmental education provides a strong foundation for creating a more environmentally aware and caring young generation. This approach not only increases environmental awareness but also equips students with the critical thinking, problem-solving, and collaboration skills needed to face future ecological challenges. Thus, the integration of this innovative learning method is an important step in supporting environmental sustainability and conservation in the future.

Curriculum Integration

Based on the synthesis results in Table 3, the integration of biodiversity in learning through specific approaches—such as utilizing local potential, applying a multidisciplinary approach, and incorporating hands-on experiences—has been shown to enhance students' knowledge, skills, and environmental conservation behaviors. These approaches improve learning outcomes by fostering direct engagement with ecosystems, encouraging critical thinking, and connecting theoretical knowledge with real-world applications. However, challenges remain in delivering conservation materials effectively. Studies by Kamaludin et al., (2022) and Babou (2023) highlight difficulties such as the lack of teacher training, limited educational resources, and insufficient curriculum alignment. Addressing these issues requires improved instructional strategies, better resource allocation, and curriculum reforms to ensure a more impactful biodiversity education.

The following is a summary of the results of the article review:

a) Integration of Local Knowledge in the Learning Process

Paradise & Bartkovich (2021) emphasize the importance of integrating local knowledge into the learning process to enhance students' learning experiences. They point out that this approach not only enriches students' knowledge about biodiversity conservation but also actively engages them in seeking this knowledge through direct interaction with the local community. For example, by inviting students to participate in conservation projects involving local communities, students can learn firsthand about traditional ways of preserving their environment. This not only improves their understanding and literacy of biodiversity but also forms a positive attitude towards environmental conservation. Additionally, Dewi et al., (2021) this approach, students can understand the importance of maintaining biodiversity in the context of their daily lives, which in turn can influence their behaviour to support environmental sustainability and make learning more relevant and engaging for students.

b) Mangrove Ecosystem Conservation Education

A study by Kamaludin et al. (2022) highlights the importance of mangrove ecosystem conservation education, which can provide important insights into this often-under-appreciated ecosystem. In this study, 74 students were involved in learning about mangrove ecosystem conservation. However, most respondents were not familiar with the learning material. These findings suggest the need for increased efforts to introduce the topic of mangrove ecosystem conservation to students, both through formal curricula and extracurricular activities. Education about mangroves is important because this ecosystem plays an important role in maintaining ecological balance, including as a habitat for various species, protecting the coast from erosion, and absorbing carbon. Through a comprehensive educational approach, students can better understand the importance of preserving mangrove ecosystems and their role in preserving nature.

c) Increasing Knowledge of Biodiversity

Babou et al. (2023) identified that students' understanding of biodiversity is still limited, with only 1.82% of students being able to provide a complete definition of biodiversity that includes three dimensions: species, ecosystems, and genetic diversity. This study showed a low to moderate correlation between students' representations and the knowledge they gained from the school curriculum regarding the concept of biodiversity. These results underscore the need for a more comprehensive approach to environmental education, which does not only focus on one aspect, such as species but also includes ecosystems and genetic diversity. This holistic approach will enable students to understand the interrelationships between ecosystem components and how various factors affect the survival of species and the balance of the ecosystem.

d) The Importance of Interdisciplinary Integration in Environmental Education

Audrina (2023) suggests that integrating multiple disciplines in environmental education, as is done in the environmental education curriculum in the French-speaking region of Switzerland, can provide a more comprehensive understanding of environmental issues. In compiling textbooks, it is important to combine perspectives from multiple disciplines such as biology, geography, economics, and social sciences. This not only helps students understand environmental issues from multiple perspectives but also enriches their ability to solve environmental problems. With this interdisciplinary approach, students can develop broader knowledge and better skills in responding to complex environmental challenges.

e) Water Resources and Biodiversity Education

A study by Akwetey (2023) highlighted the importance of integrating learning about water resources and biodiversity to improve students' understanding of aquatic ecosystems and their ecological functions. In an activity involving 50 students and 5 teachers, the results showed that participants gained a better understanding of aquatic life and its ecological functions as well as the impact of human activities on organisms living in the lagoon. In addition, this activity succeeded in fostering a sense of responsibility for maintaining environmental cleanliness and sustainability. This study shows that learning that focuses on aquatic ecosystems can be an effective means of educating students about the importance of maintaining ecosystem balance and their active role in conservation efforts.

f)Integration of Nature Conservation in the School Curriculum

Oai (2019) highlighted the importance of integrating conservation content into routine lessons such as biology and geography, as well as through activities such as field trips and environmental clubs. The results of this approach showed that students not only gained better knowledge and skills about nature and biodiversity conservation but also developed positive attitudes and behaviours towards the environment. By involving students in hands-on activities such as field trips, they can observe firsthand the impacts of human activities on the environment and the importance of conservation efforts. This approach can also increase students' active participation in environmental conservation efforts, both at school and in their communities.

g) Local Wisdom-Based Conservation

Leksono et al. (2015) discuss the benefits of using local wisdom-based conservation in lectures to improve students' biodiversity literacy. By integrating BKBKL in lectures, students can engage in investigative activities that allow them to develop process skills in biodiversity and the ability to master important concepts. This approach also encourages students to appreciate biodiversity and understand the importance of conservation from a local perspective, which is often more relevant and understandable to students than a more abstract global approach. The use of local wisdom as a learning resource can also increase students' awareness of the cultural and ecological values in their environment, which ultimately supports sustainable environmental conservation. The application of a learning model based on local wisdom through the reconstruction of original knowledge can significantly improve students' conservationist character and their investigative abilities (Khusniati et al., 2017; Parmin et al., 2016).

h) Holistic Approach to Biodiversity Education

Bermudez et al. (2022) emphasized the importance of a holistic approach in biodiversity education, which recognizes students' diverse understandings of biodiversity. This study found that understanding the concept of biodiversity often focuses on species diversity, while broader components and attributes are often overlooked. In addition, the concept of biodiversity among students from ethnic and rural communities was stronger than that of students from urban contexts, indicating a relationship between local knowledge and understanding of biodiversity. This suggests that integrating local knowledge and cultural perspectives in biodiversity education can provide students with deeper and more relevant understandings. With a holistic approach that considers local context and cultural diversity, biodiversity education can be more effective in fostering broad understanding and positive attitudes towards environmental conservation.

The integration of local knowledge, interdisciplinary approaches, and contextualized educational strategies are key to improving biodiversity literacy among students. The results of various studies indicate that by combining local knowledge and innovative educational approaches, students can develop a more comprehensive understanding of biodiversity and form attitudes and behaviours that support environmental conservation. Therefore, it is important for educators and educationpolicymakerss to adopt learning strategies that involve local knowledge, practical activities, and holistic approaches in environmental education curricula. Thus, biodiversity education not only enhances students' knowledge but also prepares them to become responsible and proactive citizens in environmental conservation efforts.

Conclusion

The following are the conclusions based on the three main topics of discussion:

1. Biodiversity Literacy Theory and Concept: Biodiversity literacy is the ability to understand and use knowledge about biodiversity to solve environmental problems. This literacy is more than just a basic understanding of species and ecosystems; it includes the ability to contribute to environmental conservation and the formation of responsive attitudes towards environmental issues. Through conservation education, individuals can develop a deeper understanding of the importance of biodiversity, which in turn can encourage pro-environmental behaviour.
2. Biodiversity Learning Models: Various learning models have been developed to improve biodiversity literacy. For example, the use of technology such as 3D virtual reality and mobile applications can increase student interaction and motivation to learn, as well as their understanding of environmental conservation concepts. In addition, direct and attitude-based learning approaches, such as conservation education programs combined with field trips, are effective in increasing students' positive attitudes towards species and environmental conservation.
3. Curriculum Integration of Biodiversity Literacy: Integration of biodiversity literacy into formal and non-formal education curricula can be done through various strategies, including the use of local knowledge, multidisciplinary approaches, and direct experiences. This integration not only improves students' knowledge and skills about environmental conservation but also forms attitudes and behaviours that support environmental sustainability. Challenges in this implementation include the need for more effective teaching methods and curriculum adjustments to achieve better results.

Recommendations

To strengthen biodiversity literacy, this research suggests specific actionable recommendations for educators and policymakers:

1. Educators: Incorporate hands-on, technology-enabled learning activities in the classroom to engage students actively and enhance their understanding of biodiversity.
2. Policymakers: Develop and implement policies that prioritize the integration of biodiversity education within national curricula and support professional development for educators in this area.
3. Community Engagement: Encourage collaboration between schools and local communities to promote knowledge sharing and participation in biodiversity conservation efforts.

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Improving students' achievement in organic chemistry: A systematic review of experimental studies

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ABSTRACT
Organic chemistry is a cognitively demanding subject with persistently low student achievement. This review aimed to identify instructional strategies and educational technologies used to improve learning outcomes in organic chemistry across educational levels and learning environments. A systematic review of 40 experimental studies (2014–2023) was conducted using PRISMA guidelines. The analysis revealed that group-based learning, such as cooperative and problem-based learning, is the most frequently used instructional approach to enhance academic performance and retention. Task-based and individual learning strategies were also reported but less common. E-learning technologies were most widely used in high school and classroom settings, while multimedia tools were more prevalent in higher education and laboratory contexts. Representational competence was primarily supported through the use of models. The findings suggest that instructional methods and technologies should be aligned with students' learning needs, content complexity, and context. These results offer practical guidance for improving cognitive outcomes in organic chemistry education.

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Introduction

Organic chemistry is a challenging subject with notable attrition, failure rates and low performance (Childs & Sheehan, 2009; Eastwood, 2013; Flynn, 2015; Johnstone, 2006; O'Dwyer & Childs, 2017; Ratcliffe M, 2002; Teixeira & Holman, 2008). Organic chemistry is a discipline that necessitates substantial cognitive effort and demands during the learning process (Akaygun & Jones, 2013; Ahmad & Samara, 2016; McCollum et al., 2014; Seery & McDonnell, 2013). To facilitate this, instructors may employ active learning methods or approaches (Crouch & Mazur, 2001; Prince, 2004; Lasry et al., 2008). Various studies reveal that chemistry learning is best conducted by applying models or approaches that can facilitate student to think at a high level (Fensham & Bellocchi, 2013). Hermanns and Schmidt (2019) revealed that the integration of various methods or approaches can increase student participation as well as be one of the solutions to address heterogeneous class problems. Research examining the implementation of methods or approaches in organic chemistry and learning has yielded beneficial outcomes. These including an application of active learning methods through multiple strategies (e.g., cooperative, class discussion, conceptual maps, and lectures) which improve student participation (Houseknecht et al., 2019) and academic achievement; (Christiansen et al., 2017; Dai et al., 2021; Iyamuremye et al., 2023; Shattuck, 2016a; Wenzel & Pichler, 2005; Wilson & Varma-Nelson, 2019). Instructors play a key role in applying active learning strategies effectively, especially when they are aware of appropriate teaching methods and set clear learning objectives. (Hermanns & Schmidt, 2019). Therefore, it is necessary to advise teachers on choosing the appropriate learning method or approach. A review of previous researchers' work on the application of instructional approaches can serve as a guide for educators in selecting the appropriate instructional approaches.

The incorporation of technology into education is a type of educational advancement. Empirical research examining the incorporation of technology into organic chemistry instruction has demonstrated beneficial effects. These investigations have found that digital technology (e.g. virtual simulations, animations, multimedia tutorials, and online platforms) can help student visualize complex organic structures and reactions, predict the properties of organic compounds (Hoover et al., 2021; McCollum et al., 2014; Seery & McDonnell, 2013; Soong et al., 2020), improve conceptual understanding, motivation and involvement (Akpokiere et al., 2020; Chekour et al., 2022; Miller et al., 2021; Nadelson et al., 2015; Shoesmith et al., 2020), support independent and stress-free learning (Mistry & Shahid, 2021), and correct misconceptions (Srisawasdi & Panjaburee, 2019). These outcomes ultimately contribute to improved performance in learning chemistry (Ryoo et al., 2018). Despite these advantages, Barak (2007 noted that many chemistry teachers remain hesitant to integrate technology due to insufficient knowledge about how to effectively use appropriate tools in classroom instruction. This cause can be attributed to their failure to find technology that can have a positive impact on their teaching and learning (Rutten et al., 2012). Hence, it is crucial to provide guidance to educators in selecting appropriate and efficient technology. Researchers have demonstrated that employing effective technology-based learning methods can inspire instructors to enhance their research and teaching. (Halverson et al., 2014). A review is needed to encourage educators to implement appropriate learning innovations to enhance quality of education and achieve the desired goals (Zhang et al., 2012). Examining and elucidating technologies and instructional methods that can improve the effectiveness of teaching and learning can aid educators and researchers in creating successful learning activities, as suggested by certain researchers (Agwuudu & Udu, 2017; Alegre et al., 2020; Campbell & Mayer, 2009; Chung et al., 2019; Febliza et al., 2023; Valcazar et al., 2023).

Four review papers have explored organic chemistry learning, each with specific but limited scopes. First, Dood & Watts (2022) conducted a scoping review focused on how students describe and explain reaction mechanisms. However, the study did not address instructional methods or evaluate their effects on learning outcomes. Second, Dood & Watts (2023) expanded their review on the mechanisms of organic reactions at the college level. While conceptually rich, this paper lacks attention to how these topics are taught or supported through teaching strategies or technologies. Third, (Sukmawati, 2020) reviewed instructional techniques for undergraduate organic chemistry but did not specify the types of research designs employed, nor did it assess the impact of these techniques on student achievement. Fourth, (Sibomana et al., 2020) reviewed learning strategies from a Rwandan educational context but omitted crucial methodological details such as article inclusion criteria, participant types, or measurable learning indicators. These four reviews, although informative, do not systematically analyze how instructional approaches and technologies affect measurable learning outcomes—particularly in terms of academic achievement, retention, and problem-solving ability.

Therefore, this present review offers novelty by synthesizing experimental studies that evaluate the effectiveness of instructional approaches and learning technologies in organic chemistry education. This approach provides empirical evidence useful for chemistry educators, curriculum developers, and decision-makers to implement evidence-based strategies that enhance student learning.

Thus, this study offers valuable contributions for curriculum developers, chemistry educators, and policy-makers by presenting evidence of the effectiveness of instructional interventions in organic chemistry through experimental research. Prior studies have demonstrated measurable links between specific teaching interventions and improvements in student learning outcomes, such as achievement, retention, and engagement (Lavi et al., 2019). Furthermore, experimental analysis serves as a powerful tool to identify and refine instructional strategies, providing educators with evidence-based insights for successful implementation in formal educational settings (Baye et al., 2019; Finlayson & Mccrudden, 2019).

The Purpose and Research Questions

The objective of this study is to analyse and evaluate published experimental research conducted between 2014 and 2023 that focuses specifically on the use of instructional approaches and technologies to improve student academic achievement in organic chemistry. The selection of this time frame reflects the increased integration of digital tools and student-centred pedagogies during the last decade, which are highly relevant to current educational practices.

This study aims to explore how various instructional methods and emerging technologies have been applied to enhance organic chemistry learning, particularly in addressing underperformance in cognitive achievement. The following research questions have been formulated to investigate instructional approaches and technologies within the context of organic chemistry:

1. What are the instructional approaches used to enhance student cognitive achievement on topics of organic chemistry learning?
2. What are the technologies used to improve cognitive achievement of students on the topics of organic chemistry learning?
3. What are the appropriate types of instructional approaches and technology used for formal and laboratory classes?
4. What are the types of instructional approaches and technology suitable for different levels of education?

Methods

In order to accomplish the goals of this study, the researchers identified and integrated relevant research related to interventions in instructional approaches and technologies toward student academic achievement in organic chemistry. The researchers conducted a methodical and structured analysis to see whether treatments involving free variables (e.g., cooperative learning) had a positive impact on bound variables (e.g., academic achievement in organic chemistry (Agwuudu & Udu, 2017). Papers with insignificant effects are also used as samples (e.g., performance course or grades of Peer-Led Team Learning (PLTL) and cyber Peer-Led Team Learning (cPLTL) students on the exam for Organic Chemistry in the First Semester of the American Chemical Society (ACS) (Wilson & Varma-Nelson, 2019) to provide a balanced view.

Selection Criteria

The research was conducted through a comprehensive and systematic search using relevant keywords across multiple reputable databases, including Taylor & Francis Online, Springer Link, ERIC, Wiley Online Library Full Collection, Scopus, Web of Science, IEEE Explore, Sage, Emerald, ProQuest Dissertations & Theses Global, Open Access Theses & Dissertations, and Google Scholar. The search was limited to publications from 2014 to 2023 to capture the most recent decade of experimental research, reflecting current trends in the use of instructional approaches and educational technologies in chemistry education. This 10-year time frame was selected to ensure the relevance and applicability of the findings to today's educational practices. The final search was completed on December 31, 2023. The latest search was conducted on December 31, 2023, to ensure that all relevant studies published before 2023 have been included. One of the purposes of systematic surveys is to diagnose academic production over a period of time. The decision to limit the review to a 10-year period is supported by several factors, including the scope of the manuscript, the depth of analysis applied to the selected publications, and the intention to highlight recent developments that reflect current trends in chemistry education (Bernardi & Pazinato, 2022). Additionally, the study did not apply indexing restrictions when selecting databases. Limiting the search to specific indexing services could have excluded relevant research and introduced selection bias. By broadening the scope, this review aims to include a more representative sample of recent literature.

The determination of coding and inclusion criteria was conducted by measuring the agreement level between two raters specializing in the field of organic chemistry education. The agreement between these two raters was calculated using Cohen's Kappa, where the result for both coding and inclusion criteria was $\kappa = 0.95$. This value indicates an interpretation of "almost perfect" agreement (McHugh, 2012).

The author use the following keyword patterns in each database and search engine mentioned above:

Pattern 1: organic chemistry, educational technology, model, experimental, science education, or chemical education

Pattern 2: organic chemistry, educational technology, model, treatment, science education, or chemical education

Pattern 3: organic chemistry, educational technology, model, intervention, science education, or chemical education

Pattern 4: organic chemistry, educational technology, teaching method, experimental science education, or chemical education

Pattern 5: organic chemistry, educational technology, teaching method, treatment, science education, or chemical education

Pattern 6: organic chemistry, educational technology, teaching method, intervention, science education, or chemical education

Pattern 7: organic chemistry, teaching aids, models, experiments, science education, or chemical education

Pattern 8: organic chemistry, teaching aids, models, treatments, science education, or chemical education

Pattern 9: organic chemistry, teaching aids, model, intervention, science education, or chemical education

Pattern 10: organic chemistry, teaching aids, teacher's method, experimental, science education, or chemical education

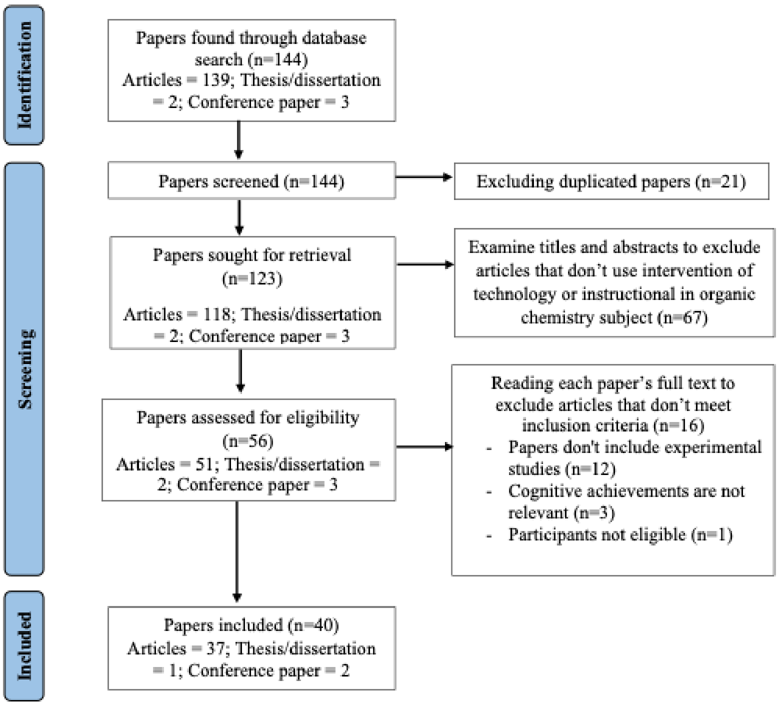
Pattern 11: organic chemistry, teaching aids, teacher's method, treatment, science education, or chemical education

Pattern 12: organic chemistry, teaching aids, teacher's method, intervention, science education, or chemical education

The authors identified 144 potential studies for analysis from the search results. All papers were in English. The subsequent phase involves scrutinising the paper to ensure its alignment with the study objectives. Refer to Figure 1 for the flow diagram illustrating the selecting procedure and screening process based on PRISMA flow diagram.

Figure 1

Flow chart of the selection process and screening process based on PRISMA flow diagram



From the initial search across multiple databases, a total of 144 papers were retrieved. To ensure the accuracy of the review, all entries were cross-checked for duplication, since many papers appeared in more than one database (e.g., the same study listed in both Scopus and ERIC). Each study was labelled consistently within the text to track its origin and avoid double-counting. As a result of this screening process, 21 duplicate papers were identified and excluded from the final dataset, leaving 123 studies for analysis.

A total of 67 articles that did not focus on instructional technology in organic chemistry were excluded. Authors assessed eligibility of the papers by reading the full text carefully and applying the inclusion criteria (experimental design: pre-, quasi-, and true-experiential designs; cognitive achievement: achieving, representational competence, and retention; and participant = students). As a result, 16 articles were excluded for not meeting these criteria. These exclusions included studies that employed only survey methods(e.g., Cha et al., 2021; Dixson et al., 2022; Popova & Jones, 2021), cross-sectional study (e.g., Austin et al., 2018), applied development research without experimental validation (e.g., Akpokiere et al., 2020), measured non-cognitive outcomes such as attitudes and perceptions (e.g. Collini et al., 2023; Gallardo-Williams, 2021; Knudtson, 2015), or participants: instructors (Leontyev et al., 2019). Articles employing mixed-methods designs were included only if they contained a clear experimental component, (e.g., (Iyamuremye et al., 2021). The inclusion assessment also involved verifying whether each intervention had an observable impact on cognitive achievement, based on reported quantitative data such as means, standard deviations, t-values, and p-values. To address potential publication bias, studies reporting statistically insignificant or negative results were also included in the review (e.g. De Gale, 2016; Wilson & Varma-Nelson, 2019). This ensured a more balanced and objective synthesis of evidence regarding the effectiveness of instructional approaches and technologies in organic chemistry learning.

Study Sample

The selection process yielded a total of 40 papers, all of which focused on evaluating the effectiveness of instructional technologies and teaching approaches in improving academic performance. The final sample consists of 37 research articles, two conference proceedings and a thesis/dissertation. Among the 37 research articles, 17 discuss the effectiveness of specific instructional approaches, while the remaining 20 evaluate the impact of technology on student learning outcomes.

Coding Procedure

Encoding is the method of extracting clear and study-appropriate data from the material gathered during research (Karadag, 2020). The primary goal of this technique is to create a specialized encoding system that encompasses both general and specific aspects, ensuring that no elements of any form of research are overlooked. In order to retrieve data from the manuscript, the author implemented an encoding technique utilising the subsequent parameters: research article reference, conference proceeding, thesis or dissertation, type of intervention (instructional approach and technology), cognitive achievement, level of education, and learning environment. The explanation of the parameter is as follows:

1. Research References

The references included in this review comprise experimental studies published as journal articles, conference proceedings, and dissertations. Each study examined the effectiveness of an instructional intervention, either in the form of a teaching approach or the use of technology, on students' cognitive achievement. The results were evaluated using quantitative data, including descriptive statistics such as mean scores and standard deviations, as well as inferential statistics such as t-values and p-values that indicate statistical significance (Çalik et al., 2024).

2. Type of Intervention

This review focuses on two categories of intervention: instructional approaches and instructional technologies. Instructional approaches refer to pedagogical frameworks or teaching methods, such as problem-based learning or peer-led team learning. Instructional technologies refer to the tools or platforms that support instruction, such as computer simulations, digital learning environments, or learning management systems. Although there may be some overlap between the two categories, the classification in this review is based on the stated emphasis of each study. A study was categorized as focusing on instructional approach if it emphasized the teaching method as the main factor. It was classified as technology-based if the primary intervention involved the use of a technological tool or platform to enhance learning.

3. Cognitive Achievement

This study categorizes cognitive achievement into three indicators: academic performance (e.g., scores from examinations and tests), representational competence, and retention. These indicators are consistently used across the selected studies to measure student learning outcomes. In one study that measured generic science skills, the data were classified under academic performance, as it involved assessment of conceptual understanding and application. Overall, cognitive achievement serves as a key parameter for determining the effectiveness of instructional interventions.

4. Education Level

The included studies involve participants from two levels of education: high school and higher education. High school refers to students in grades 9 through 12, which are also known as senior secondary levels (Iyamuremye et al., 2023). Higher education refers to students enrolled in university-level programs. If a paper identified participants as coming from senior secondary schools, they were classified under the high school category for consistency.

5. Learning Environment

Organic chemistry is studied in two distinct learning environments: classroom (theoretical learning) and laboratory (practical learning). Both environments are essential and often complementary. In this review, the learning environment is considered a contextual parameter for analysis, particularly in relation to how instructional technologies and approaches are applied. Studies that explicitly referenced either classroom-based or laboratory-based interventions were coded accordingly. In cases where both settings were involved, the study was marked as addressing dual learning environments.

Data Analysis

The mapping of each paper is determined by the following parameters: research article reference, conference proceeding, thesis or dissertation, type of intervention (instructional approach and technology), cognitive achievement, level of education, and learning environment. After the mapping, we perform a thematic analysis to formulate answers to each research question. If there is ambiguity or the author disagrees with whether an article contains findings on a particular topic, the entire author discusses (Dood & Watts, 2023) consensus (Dood & Watts, 2023).

Analysis Methods for RQ1

The initial phase of data extraction and analysis addressed Research Question 1 (RQ1). Data were categorized according to the following parameters: (1) instructional strategy, (2) category of instructional approach, (3) topic or theme related to organic chemistry, and (4) cognitive achievement. These categories were recorded systematically in a spreadsheet for subsequent analysis. To accurately identify and classify the instructional strategies described in each study, the research team extracted descriptive information directly from the articles. These descriptions were used to determine how instructional approaches were implemented. Across the reviewed studies, instructional approaches were grouped into several recurring types, including group-based learning, individual learning, and task-based instruction. At present, there is no universal agreement about how instructional approaches should be classified. Therefore, the research team established a grouping instructional approach by analyzing each description and applying the focus method to each paper. If researchers conduct learning activities with an emphasis on group learning (e.g., cooperative, collaborative, flipped classroom with peer-led team learning, problem-based learning with group work, etc.), then they categorize instructional approaches into group-based learning. If the paper does not mention the implementation of learning activities in groups (e.g., adaptive learning, analogy instructional strategy, etc.), then the instructional approach is classified as individual learning. If the paper the implementation of assignment, the instructional approach is classified as task-based instruction.

Analysis Methods for RQ2

The extraction and analysis of RQ2 were technology-oriented. The parameters used to categorize data are: (1) technology; (2) technology categories; (3) organic chemistry topics; and (4) cognitive achievement. The categorisation is documented in the spreadsheet for further analysis. Based on the analysis of the language used in the paper, the researchers conducted a technology categorization. The researchers found several terms: multimedia used for video; models used for molecular models, concrete models, physical models, animation, etc.; immersive learning for augmented reality, virtual reality, etc.; e-learning for online learning tools, web-based learning management systems, games hosted on a website, etc. Finally, we group technologies such as multimedia, models, immersive learning, and e-learning.

Analysis Methods for RQ3

The researchers grouped learning environments into formal learning classes that are coded classrooms and learning in laboratories that are code labs. The classroom is defined as the place where learning activities take place, whereas the laboratory is the environment in which students conduct scientific research and experiments (S. H. Wu et al., 2021). Further, the researchers mapped every type of instructional approach and technology to each learning environment, including topics of organic chemistry and cognitive achievement. Each article is analyzed to find out the characteristics of the instructional approach and the technology applied to each learning environment.

Analysis Methods for RQ4

We classify education levels into two categories: high school and higher education s. Then the researchers mapped the types of instructional approaches and technologies at each educational level, topics of organic chemistry, and cognitive achievement. Each article is analyzed to find out the characteristics of the instructional approach and the technology applied to each learning environment.

Data Distribution

Based on the 40 papers obtained, the distribution of data is based on the type of intervention given in each year, as shown in Figure 2.

Figure 2

Distribution of studies on instructional approaches and technology in organic chemistry (2014–2023)

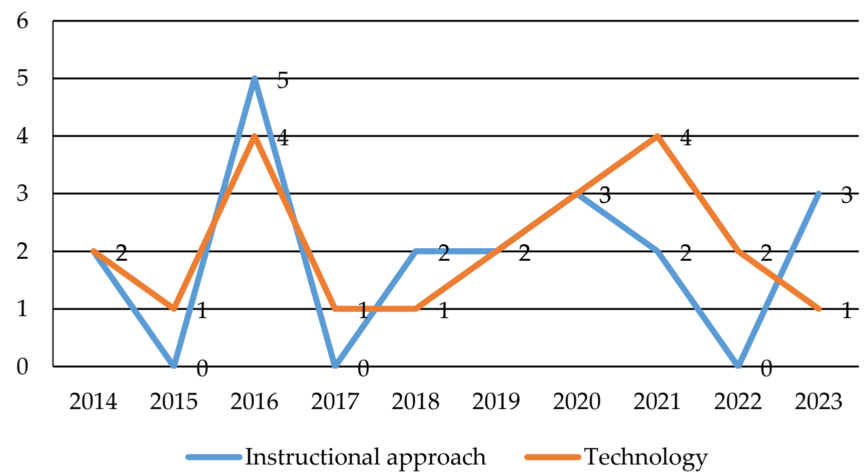


Figure 2 illustrates the annual number of studies focusing on instructional approaches and instructional technologies in the context of organic chemistry education between 2014 and 2023. The graph shows that publications related to technology use reached their highest points in 2016 and 2021, with four studies reported in each of those years. Studies on instructional approaches peaked in 2016 with five publications.While instructional technologies were used in 21 of the reviewed studies, instructional approaches were implemented in 19. These categories are not mutually exclusive, as several studies employed both instructional approaches and technological tools in combination. Overall, the frequency of technology-related studies increased between 2018 and 2021, reflecting growing interest in the integration of digital tools within chemistry instruction. The data do not show a consistent year-over-year increase, so no definitive prediction about future trends can be made based solely on this dataset. The distribution of data based on the country where the research was conducted can be seen in Figure 3.

Figure 3

Country distribution of studies on instructional approaches and technology in organic chemistry

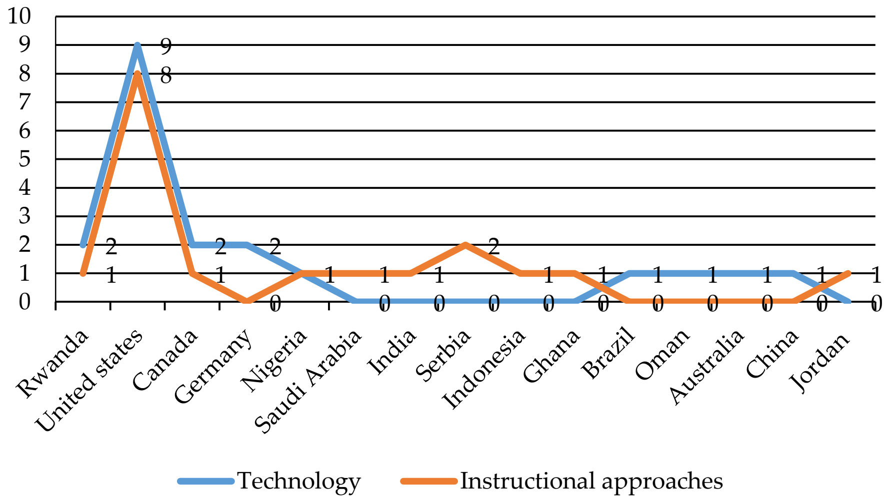


Figure 3 presents the distribution of reviewed studies based on the country in which the research was conducted. The United States appears most frequently in the dataset, indicating a higher volume of research originating from U.S.-based institutions. However, this observation should be interpreted with caution, as no statistical test was conducted to assess the significance of this distribution, and the presence of studies from a particular country does not necessarily imply a higher level of technological or instructional advancement. Both instructional technologies and teaching strategies were represented in studies from a range of countries. It is important to clearly define the distinction between "instructional approach" and "technology" throughout the analysis, as the two often overlap but are not conceptually identical.

Findings

The results of the data analysis were done to answer the research questions that have been set. There are four research questions in this study.

What Are the Instructional Approaches Used to Enhance Student Cognitive Achievement on Topics of Organic Chemistry Learning?

The first research question explores the types of instructional approaches applied to enhance students' cognitive achievement in organic chemistry learning. Table 1 presents a synthesis of the instructional approach categories, the specific methods employed, the related organic chemistry topics, and the cognitive outcomes reported. There are 17 papers on the application of instructional approaches to improving the cognitive achievement of students in organic chemistry learning. However, there are two articles that do not show significant results in improving student achievement. These two papers are the implementation of POGIL and Peer-Led Team Learning & Cyber Peer-Led Team Learning.

Table 1

Categorization of ınstructional approaches to enhance cognitive achievement in organic chemistry

Instructional approach category	Instructional approach	Reviewed studies	Topic	Cognitive achievement
Group-based learning	Cooperative learning, Flipped classroom, PLTL, Collaborative approaches, Problem based learning	(Angawi, 2014; Birundha, 2020; Pilcher et al., 2023; Dibyantini et al., 2018)	NMR spectroscopy, hydrocarbon, isomerism, Alkanes, alkenes, and alkynes; alkyl halides, Hybridisation, Functional group structures, resonance, organic chemistry reaction	Academic performance, Retention
Individual learning	Adaptive intervention, Analogy instructional strategy	(Dood et al., 2020; Samara, 2016)	Organic chemistry reactions, Functional group	Academic performance
Task-based instruction	Online homework, Writing-to-learn (WTL), Online categorization task, Systemic synthesis questions [SSynQs]	(Malik et al., 2014; Schmidt-Mccormack et al., 2019; Lapierre & Flynn, 2020; Hrin, Fahmy, et al., 2016; Hrin, Milenković, et al., 2016)	Organic chemistry reaction, Acid-base, Hydrocarbons	Academic performance

Based on Table 1, group-based learning was the most frequently implemented instructional category in the reviewed studies. This category includes cooperative learning, flipped classrooms, peer-led team learning, and problem-based instructional methods. These approaches were commonly used to improve students' academic performance and retention, particularly in topics such as spectroscopy, functional groups, and organic reaction mechanisms.

Two studies reported that the application of group-based strategies, specifically peer-led team learning (PLTL) and Process-Oriented Guided Inquiry Learning (POGIL), did not result in significant learning gains. This suggests that the effectiveness of instructional approaches may depend on how they are implemented and on contextual factors such as the learner's background. Previous research has shown that variables like prior academic achievement and student demographics can influence learning outcomes, as demonstrated by Alyahyan & Düşteaör (2020). Rather than attributing effectiveness solely to the instructional strategy, it is essential to consider how such strategies are implemented, and how learners interact with the materials and peers within each learning environment.

Task-based instruction appeared in several studies and typically involved structured activities such as online homework, writing-to-learn exercises, or categorization tasks. These strategies were designed to support conceptual understanding and improve academic performance (Ole & Gallos, 2023). Individual learning was the least represented category. It was implemented through approaches such as analogy-based instruction and adaptive interventions. These methods aim to enhance student understanding through personalized or independent learning experiences. Regarding content coverage, reaction mechanisms in organic chemistry, including electron pushing formalism (EPF), emerged as a recurrent topic across studies. Nonetheless, given the modest size of the dataset, no definitive claims about topic prevalence can be made. Notably, several studies have identified persistent challenges in students' interpretation of symbolic representations in reaction mechanisms (Bhattacharyya, 2013; Grove et al., 2012). This difficulty reflects a broader issue in science education: the cognitive demand of integrating macroscopic, sub-microscopic, and symbolic domains of understanding (Bhattacharyya & Bodner, 2005; Gilbert & Treagust, 2009; Johnstone, 1991).

What Are the Technologies Used to Improve Cognitive Achievement of Students on the Topics of Organic Chemistry Learning?

Numerous researchers have used technology to address the issue of learning organic chemistry. The distribution of the application of technology in improving student learning achievement in organic chemistry courses is presented in Table 2. 20 papers examine the effectiveness of the use of technology to improve student performance in organics courses.

Table 2

Types of technology to improve students' performance

Technology category	Technology	Reviewed studies	Topic	Cognitive achievement
Multimedia	Lightboard video, Tutorial video, Student-generated videos, Video-based demonstrations	(Schweiker et al., 2020) (Rodemer et al., 2021) (Box et al., 2017) (Nadelson et al., 2015) (Jordan et al., 2016) (Pölloth et al., 2020)	Organic reaction mechanisms, separation and purification, infrared spectroscopy (IR)	Academic performance
Models	Animation with concrete model, Computer model, Molecular model, Computer-based simulation	(Al-Balushi & Al-Hajri, 2014; Springer, 2014; Stull et al., 2016; Casselman et al., 2021; Stull & Hegarty, 2016; Nsabayezu et al., 2023)	Characteristics of organic molecules, stereochemistry, Molecular diagrams	Academic performance, Representational competence

Immersive learning	Augmanted Reality, Immersive virtual reality	(Ling et al., 2021; Miller et al., 2021)	Molecular structure	Academic performance
e-learning	Self-Directed Primer E-Book, e-module, Computer Game, Web-based discussion, Online-preparatory course	(Ali, 2019; Carle et al., 2020; Bodé et al., 2016; Da Silva Júnior et al., 2018; Iyamuremye et al., 2023; Iyamuremye et al., 2021; Fischer et al., 2019)	Nomenclature of organic compounds, functional group, resonance struvture	Academic performance

Table 2 presents the types of instructional technologies reported in the reviewed studies aimed at improving students' cognitive achievement in organic chemistry. These technologies are grouped into four main categories: multimedia, models, immersive learning, and e-learning platforms. Among these categories, e-learning was the most frequently reported. E-learning tools included digital modules, computer games, web-based discussions, and online preparatory materials. These were primarily applied to topics such as nomenclature, functional groups, and resonance structures. Multimedia tools, such as lightboard videos and video-based tutorials, were also widely implemented to enhance understanding of reaction mechanisms and spectroscopic methods.

Model-based technologies were often used to improve representational competence and conceptual understanding. These included animations, molecular models, and computer simulations, which were applied to topics such as molecular structures and stereochemistry. Although immersive learning technologies, such as augmented and virtual reality, appeared less frequently, they were used to improve spatial understanding of molecular concepts. Most of the studies in this review measured academic performance as the primary cognitive outcome. Only studies involving models explicitly assessed representational competence in addition to academic performance.

What Are the Appropriate Types of Instructional Approaches and Technology Used for Formal and Laboratory Classes?

As an inherently experimental discipline, organic chemistry is taught through both theoretical instruction and laboratory-based learning. This dual-context approach is reflected in several studies that investigate the application of instructional strategies and technologies across classroom and laboratory environmentsThe distribution of data-type instructional approaches and technologies applied in learning environments in classrooms and laboratories is presented in Table 3.

Table 3

Distribution of data types, instructional approaches, and technologies applied in classrooms and laboratories

Learning environment	Intervention	Intervention category	Reviewed studies	Cognitive achievement
Classroom	Instructional approach	Group-based learning	(Abukari et al., 2023; Agwuudu & Udu, 2017; Angawi, 2014; Birundha, 2020; Dibyantini et al., 2018; Mooring et al., 2016; Pilcher et al., 2023; Shattuck, 2016; Sibomana et al., 2021, 2023)	Academic performance and retention
		Individual learning	(Dood et al., 2020; Samara, 2016)	Academic performance
		Task-based instruction	(Hrin, Fahmy, et al., 2016; Hrin, Milenković, et al., 2016; Lapierre & Flynn, 2020; Malik et al., 2014; Schmidt-Mccormack et al., 2019)	Academic performance
	Technology	Multimedia	(Rodemer et al., 2021; Schweiker et al., 2020)	Academic performance
		Models	(Al-Balushi & Al-Hajri, 2014; Nsabayezu et al., 2023; Schweiker et al., 2020; Springer, 2014; Stull et al., 2016; Stull & Hegarty, 2016)	Academic performance and representational competence
		Immersive learning	(Ling et al., 2021; Miller et al., 2021)	Academic performance
		e-learning	(Ali, 2019; Bodé et al., 2016; Carle et al., 2020; Da Silva Júnior et al., 2018; Iyamuremye et al., 2021, 2023)	Academic performance
Laboratory	Instructional approach	-	-	-
	Technology	Multimedia	(Box et al., 2017; Jordan et al., 2016; Nadelson et al., 2015; Pölloth et al., 2020)	Academic performance
		e-learning	(Fischer et al., 2019)	

Table 3 summarizes the instructional approaches and technologies used in two learning environments: classroom and laboratory settings. The majority of the reviewed studies were conducted in classroom environments. Within these settings, group-based learning was the most frequently reported instructional approach, often aimed at improving academic performance and retention. Technology tools applied in the classroom included multimedia resources, models, immersive learning environments, and e-learning.

Studies in this category showed varied outcomes, with some reporting improvements in both academic performance and representational competence, particularly when models were used. Fewer studies were conducted in laboratory settings. Among those, multimedia and e-learning technologies were applied to support laboratory instruction. Instructional approaches in the laboratory were not specifically identified in the included studies. Although the number of laboratory-based studies was limited, the available data suggest that digital technologies were used to supplement hands-on experiences and to provide pre-laboratory instruction or virtual engagement.

What Are the Types of Instructional Approaches and Technology Suitable for Different Levels of Education?

Organic chemistry is studied at different levels of education: high school and higher education. The distribution of data on the application of instructional approaches and technologies at each educational level is presented in Table 4.

Table 4

Distribution of data types, instructional approaches, and technologies applied to each of the different levels of education

Levels of education	Intervention	Category	Reviewed studies	Cognitive achievement
High school	Instructional approach	Group-based learning	(Abukari et al., 2023; Birundha, 2020; Sibomana et al., 2021)	Academic performance and retention
		Task-based instruction	(Hrin, Fahmy, et al., 2016) (Hrin, Milenković, et al., 2016)	Academic performance
	Technology	Immersive learning	(Ling et al., 2021)	Academic performance
		e-learning	(Da Silva Júnior et al., 2018; Iyamuremye et al., 2021, 2023)	Academic performance
		Models	(Nsabayezu et al., 2023)	Academic performance
Higher education	Instructional approach	Group-based learning	(Agwuudu & Udu, 2017; Angawi, 2014; Dibyantini et al., 2018; Mooring et al., 2016; Pilcher et al., 2023; Shattuck, 2016; Sibomana et al., 2023)	Academic performance and retention
		Individual learning	(Dood et al., 2020; Samara, 2016)	Academic performance
		Task-based instruction	(Lapierre & Flynn, 2020; Malik et al., 2014; Schmidt-Mccormack et al., 2019)	Academic performance
	Technology	Multimedia	(Box et al., 2017; Jordan et al., 2016; Nadelson et al., 2015; Pölloth et al., 2020; Rodemer et al., 2021; Schweiker et al., 2020)	Academic performance
		Models	(Al-Balushi & Al-Hajri, 2014; Casselman et al., 2021; Springer, 2014; Stull et al., 2016; Stull & Hegarty, 2016)	Academic performance and representational competence
		Immersive learning	(Miller et al., 2021)	Academic performance
		e-learning	(Ali, 2019; Bodé et al., 2016; Carle et al., 2020; Fischer et al., 2019)	Academic performance

Table 4 presents the distribution of instructional approaches and technologies according to educational level, categorized into high school and higher education. Most of the reviewed studies were conducted at the higher education level, focusing primarily on university students. At the university level, group-based learning was the most frequently applied instructional approach. This method was associated with improvements in both academic performance and retention. Technologies commonly used in higher education included multimedia tools, e-learning platforms, and modeling technologies. These tools were employed across a range of topics, from reaction mechanisms to symbolic representations.

At the high school level, group-based learning was also used to improve academic achievement and retention. In addition, immersive learning and e-learning technologies were applied to support conceptual understanding. However, fewer studies were conducted at this level compared to higher education. Because of the limited number of studies reviewed in this synthesis, no definitive claims can be made about the broader prevalence of these interventions across educational systems. The findings reflect the distribution and content focus of the sampled research, rather than the full spectrum of instructional practices in organic chemistry education.

Discussion

What Are the Instructional Approaches Used to Enhance Student Cognitive Achievement on Topics of Organic Chemistry Learning?

Most papers apply learning with an emphasis on group-based learning. The conclusions of this analysis are consistent with previous research demonstrating that group learning enhances students' long-term retention of learned material (Akhtar et al., 2024; Morgan et al., 2000), which demonstrated that group learning enhances students' long-term retention of learnt material. Furthermore, research has demonstrated that group learning fosters the development of advanced skills to a greater extent than a conventional lecture-based learning setting (Sloffer et al., 1999). Through small groups, students maintain learning goals by helping each other in social settings (Pateşan et al., 2016). Group learning supports intellectual exploration and consensus-building through social interaction (Adu-Gyamfi & Asaki, 2022; Hanson, 2017; Sibomana et al., 2020). Students are not only preparing for examinations but also constructing a learning environment conducive to comprehensive academic development (Karacop, 2016; Tran, 2014; Yash & Singh, 2011). Group-based learning is based on the theory of learning that relates to the social arrangement of constructivism. Constructivism posits that the process of learning will primarily engage students by enhancing their capacity to conceptualise the knowledge being learned (Yassin et al., 2018). Effective learning is enhanced when students actively engage in social interactions. By utilising learning methods that encourage students to conceptualise their subjects and interact with both their peers and teachers, academic achievement can be improved. This is because students have the opportunity to learn from each other's unique perspectives and concepts, which may not be directly taught by educators.

However, two studies focus on Process-Oriented Guided Inquiry Learning (POGIL) and Peer-Led Team Learning (PLTL) did not report significant improvement in student learning outcomes. While both are rooted in social constructivist theory (Eberlein et al., 2008), the study by Wilson & Varma-Nelson (2019) found that students participating in PLTL often relied on memorizing reaction tables rather than conceptual understanding. The authors suggest that students' limited practice with drawing mechanisms such as electron-pushing formalism contributed to this outcome. This phenomenon aligns with Vygotsky's notion of verbalism, where learners mimic terminology without internalizing conceptual meaning (Vygotsky, 1986).

In the case of POGIL, the lack of improvement may be due to student unfamiliarity with the method. As Shadiev et al. (2023) suggest, cognitive processing is enhanced in familiar learning environments, whereas unfamiliar instructional designs may create additional cognitive burden. Familiarity reduces the cognitive resources needed for situational adjustment, allowing students to focus more effectively on content.

What Are the Technologies Used to Improve Cognitive Achievement of Students on the Topics of Organic Chemistry Learning?

E-learning is the predominant form of educational technology today (Elaine Allen et al., 2008; Kigozi Kahiigi et al., 2008; Lau et al., 2014; Kavitha & Lohani, 2019). This result is supported by Kavitha & Lohani (2019), who state that e-learning has provided benefits that vary in purpose and features that are generally suitable for people with any learning style. E-learning also offers many benefits, such as flexibility, accessibility and diversity (Barrot et al., 2021; Jantrasee, 2022). E-learning allows educators and teaching instructors to graphically present course content in a digital learning environment, enabling students to engage in an online setting (Chikileva et al., 2023). E-learning facilitates self-directed learning for students, allowing them to study at their own convenience and location. It also enables teaching activities to be conducted without the need for actual classrooms (Zedan, 2021;Masalimova et al., 2022).

Multimedia and models become the second choice of researchers to enhance student achievement in organic chemistry learning. Multimedia in the form of video is a good choice to enhance student achievement in organic chemistry learning. By utilizing features such as pausing, speeding up, slowing down, and replaying specific sections of the video, students have the capacity to learn at their own pace and can revisit the content as needed (Dangelo, 2014; Kraft et al., 2012; Richards-Babb et al., 2014). Models widely recognized that the study of conventions and the utilization of visual-spatial representations, such as different forms of molecular diagrams, are crucial for effective communication (Gilbert, 2008; Gilbert & Treagust, 2009). Teachers frequently promote the utilization of models as a means for students to enhance their learning (Stieff, 2011). The ability of students to perform actual actions rather than imagined ones when manipulating molecular models can help explain this finding (Maglio, 1994). These findings can be explained using cognitive load theory (Sweller, 2020). According to Sweller, the capacity of working memory is restricted, which means that only a few cognitive operations can be managed simultaneously.

What Are the Appropriate Types of Instructional Approaches and Technology Used for Formal and Laboratory Classes?

Based on the data analysis, it is seen that in the classroom, group-based learning and models become instructional approaches and technology that are mostly used to improve student achievement. These finding can be explained by constructivism theory and cognitive load theory. The process of building knowledge occurs in students themselves through social interaction with friends in the group (Vygotsky, 1986). Furthermore, models can help students to perform actual actions rather than imagined ones when manipulating molecular models (Maglio, 1994). Consequently, this decreases the requirement for working memory and minimizes the cognitive load on children (Chandler & Sweller, 1991). Reducing cognitive load allows students to allocate more cognitive effort towards understanding mapping conventions and translating diverse representations, leading to improved learning outcomes (H.-K. Wu & Shah, 2004).

Meanwhile, the data showed that the lab only applied technology as an alternative strategy for improving student cognitive achievement. Cognitive load theory explain that in intricate settings like organic chemistry lab courses, students mostly concentrate on practical inquiries pertaining to investigations (Agustian & Seery, 2017; Johnstone et al., 1994). This cognitive limitation reduces students' ability to reflect on theoretical and conceptual aspects of laboratory experiments. Therefore, improving the quality of learning in laboratory-based courses requires careful preparatory support. One effective strategy is the integration of pre-laboratory instructional materials, such as guided tutorials, simulation exercises, or digital modules, which help students develop familiarity with experimental procedures before entering the lab(Agustian & Seery, 2017; Rollnick et al., 2001). Such preparation enhances conceptual readiness and reduces the cognitive load during hands-on activities.

Additionally, the use of technology as a pre-class support tool can reduce the reliance on working memory and help alleviate students' cognitive burden (Chandler & Sweller, 1991). Digital materials provided in advance allow students to rehearse procedures and concepts, making them feel more confident and better prepared (Chaytor et al., 2017; D'Ambruoso et al., 2018) . This sense of preparedness also contributes to more positive attitudes toward laboratory work (Supasorn et al., 2008).

What Are the Types of Instructional Approaches and Technology Suitable for Different Levels of Education?

Based on the analysis of the available data, group-based learning appears to be the most commonly implemented instructional approach across various educational levels, particularly in high school and higher education. Although the number of reviewed studies is limited, this trend suggests that collaborative learning strategies are consistently used to support student achievement in organic chemistry education. Instructional activities such as small-group discussions, cooperative problem solving, and hands-on practical tasks have been identified as effective in promoting meaningful learning outcomes (Omwirhiren et al., 2016; Çimer, 2007). These approaches facilitate social interaction, which is a key factor in the construction of knowledge. When students engage actively with peers and instructors, they are more likely to develop a deeper understanding of subject matter through the exchange of perspectives (Sibomana et al., 2021). An effective chemistry teaching approach involves not only the delivery of content, but also the encouragement of conceptual application across different learning contexts. Teachers play a central role in promoting student engagement and helping learners to connect abstract concepts with real-world applications (Adu-Gyamfi & Asaki, 2023).

On the other hand, e-learning mostly used in high school and multimedia in higher education. Technology helps the learning process of teaching by improving its quality and value (Schindler et al., 2017). Technology can be used in a variety of ways that help teachers and students study their respective subjects in high school students. Students engage in technology-based courses that involve real activities, which aim to enhance their comprehension of the subject matter (Ghavifekr & Rosdy, 2015; Jantrasee, 2022). Besides, students in schools and colleges have high expectations of ICT integration in the classroom, as a new generation has been born and grown up with technology and can be defined as a native digital phenomenon (Chien et al., 2014).

Conclusion and Implications

Based on the findings of this review, group-based learning approaches such as cooperative learning, flipped classrooms, peer-led team learning, collaborative learning, and problem-based instruction are frequently implemented to support academic performance and student retention in organic chemistry. Although these methods are not new, the present synthesis provides updated insights into their application across different learning environments and educational levels.

With regard to technological interventions, e-learning tools including digital modules, self-directed e-books, web-based platforms, and educational games are commonly applied in classroom instruction. Multimedia resources, such as instructional videos and simulations, appear more frequently in laboratory-based learning. However, no reviewed study specifically reported the use of instructional approaches in laboratory settings, suggesting an area that requires further investigation.

At both high school and higher education levels, group-based learning remains a widely reported instructional strategy. E-learning is more often applied in high school settings, while multimedia tools are more commonly used in higher education contexts. These findings indicate that group-based learning and technology-enhanced instruction contribute positively to student learning outcomes in organic chemistry.

The findings suggest that instructional strategies and technology integration should be aligned with educational level, topic complexity, and cognitive demands to optimize learning outcomes in organic chemistry. These insights can guide educators, curriculum designers, and policymakers in selecting evidence-based interventions tailored to specific contexts and learners.

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