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It is our great pleasure to present Volume 5, Number 1 of the International Journal of Science Education and Teaching (IJSET). Published by the Science Education Association (Thailand) (SEAT), IJSET is an open-access, peer-reviewed journal committed to disseminating high-quality research and scholarly works in science education.

IJSET welcomes original research articles, academic articles, and review articles covering a broad spectrum of topics, including physics, chemistry, biology, technology education, STEM education, science teacher education, early childhood science education, science curriculum and instruction, and other related fields of science education. As an open-access journal, IJSET does not charge article processing charges (APCs) or publication fees, ensuring that quality research remains freely accessible to both authors and readers.

To maintain the highest standards of scholarly publishing, all submitted manuscripts undergo a rigorous double-blind peer-review process conducted by qualified reviewers. Authors are expected to uphold the principles of research integrity by providing accurate citations, complying with applicable research ethics requirements, and transparently disclosing the use of artificial intelligence (AI) tools in conducting research or preparing manuscripts. We also encourage authors to cite only relevant and reliable scholarly sources and to carefully verify all references.

On behalf of the Editorial Board, I would like to express our sincere appreciation to our authors, reviewers, and editors for their valuable contributions and dedication. We hope that the articles published in this issue will stimulate further research, encourage international collaboration, and contribute to the continued advancement of science education and teaching.



Associate Professor Dr. Saksri Supasorn

Editor-in-Chief

International Journal of Science Education and Teaching (IJSET)

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Catch That Element: Development of a Web-based Educational Game on the Periodic Table of Elements for Grade 8 Learners

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Abstract. The Periodic Table of Elements in Grade 8 Science is often perceived by learners as abstract, content-heavy, and difficult to master using traditional instructional approaches. To address these challenges, this study aimed to develop a web-based educational game titled Catch That Element. Moreover, this study also determines the teacher evaluation, students' achievement, and students' perceptions towards the developed material. The study employed a developmental and quasi-experimental research design. The game was developed using the ADDIE model and incorporated interactive challenges, immediate feedback, scoring mechanisms, and increasing levels of difficulty to reinforce students' knowledge of element names, symbols, atomic numbers, and mass. The participants included 50 Grade 8 students for the implementation of the game, and eight Junior High School Science teachers for the evaluation of the developed game. Statistical analysis also revealed a significant difference between the pretest and posttest scores (normalized gain = 0.89) providing that the instructional material enhances students' understanding. Moreover, the game gained a rating of "very satisfactory" (mean = 3.72) in the teacher evaluation of content, instructional, and technical quality, indicating that the game meets curriculum standards and supports effective learning. Lastly, the students' perception of the developed game was "very high" (mean = 3.56) in interest/enjoyment, value/usefulness, and perceived choice. These results show that the game is engaging, relevant, promotes autonomous learning, and fosters positive affective and motivational outcomes. Overall, the results highlight the potential of the material in enhancing both cognitive and affective learning outcomes for teaching abstract and content-heavy concepts.

Keywords: Periodic Table of Elements; Student Achievement; Student Perceptions; Teacher Evaluation; Web-Based Educational Game

INTRODUCTION

Web-based educational games have been widely recognized as effective instructional tools that enhance student participation, motivation, and engagement, particularly in mastering complex and abstract subjects. Smiderle et al. (2020) emphasized that the integration of game elements into instructional activities increases learner engagement and sustains participation over time. Similarly, Wijaya et al. (2025) reported that students who learn through game-based approaches demonstrate higher levels of recall compared to those who rely on traditional memorization techniques. These findings suggest that embedding learning content within interactive digital games can significantly improve learning outcomes.

The Periodic Table of Elements (PTE) is a fundamental component of secondary chemistry education. It systematically organizes known elements according to atomic number, electron configuration, and recurring periodic properties, serving both as a reference tool and a conceptual framework for understanding chemical behavior. As a core component of the Science, Technology,

Engineering, and Mathematics (STEM) curriculum, the PTE enables learners to identify patterns, predict element properties, and establish connections across various scientific concepts. According to Vermehren et al. (2025), the STEM field includes abstraction such as reduction, pattern recognition, generalization, interiorization, encapsulation, and coordination, which are supported by the structured organization of the PTE. In the Revised K-10 Curriculum of the Department of Education, competencies related to the PTE start in Grade 8, including “the current structure of the atom includes subatomic particles, their symbol, mass, charge, and location” and “the periodic table is a useful tool to determine the chemical properties of elements” (DepEd, 2023).

Despite its importance, many students find the PTE difficult to learn, particularly in recalling element names, symbols, and properties. Yang and Choi (2023) noted that a substantial number of secondary students struggle with memorizing the periodic table and applying its patterns meaningfully. Traditional instruction of the PTE often relies heavily on textbooks and rote memorization, which may not adequately address diverse learning styles. Visual and kinesthetic learners, in particular, benefit from interactive and hands-on learning experiences. Chowdhury (2022) observed that misconceptions regarding element arrangement and properties frequently arise when students are not provided with sufficient opportunities for active engagement.

In response to these instructional challenges, web-based educational games have emerged as an effective pedagogical approach. Digital or web-based educational games are digital learning tools that integrate instructional content with game mechanics and are accessed through internet-enabled devices without the need for specialized software installation (Gui et al, 2023). These games offer several advantages, including ease of access, platform independence, immediate feedback, and the ability to support self-paced and exploratory learning (Bakhsh et al., 2022). More importantly, these features directly address the challenges of memorization and recall in learning the PTE. For instance, immediate feedback helps students correct errors in identifying element names and symbols in real time, while repetitive gameplay mechanics provide continuous exposure to key information, reinforcing memory retention. The use of timed challenges, scoring systems, and progressive levels further encourages active recall, which is essential for mastering symbol and name relationships and other fundamental periodic concepts. Moreover, these instructional materials also enhance student motivation, engagement, and enjoyment (Saleem et al., 2021).

Web-based educational games are grounded in a blend of behaviorist (rewards/feedback), cognitive (scaffolding/feedback), constructivist (active problem-solving), social cognitive (self-efficacy/social modeling), and motivational frameworks (Khaldi et al., 2023; Li et al., 2024; Nadi-Ravandi & Batooli, 2022; Sailer & Homner, 2019). These theoretical perspectives collectively explain how game-based environments facilitate learning by reinforcing correct responses through immediate feedback, structuring information into manageable and progressively challenging tasks, and engaging learners in meaningful interactions that promote knowledge construction. Moreover, these games support the development of self-efficacy as learners experience repeated success and observe modeled responses within the game environment, which can enhance confidence in performing academic tasks. Game elements such as goals, rewards, autonomy, and progression foster intrinsic motivation and sustained engagement, which promote active participation, persistence, and positive learning behaviors, making them effective tools for teaching complex and abstract concepts.

Web-based and digital chemistry games are increasingly used to make concepts more engaging, support remote teaching, and improve motivation and learning. Research consistently demonstrates that web-based educational games can enhance student motivation, engagement, and conceptual understanding across various chemistry topics and educational levels (Da Silva Júnior et al., 2022; De Boni et al., 2024; Irmita et al., 2025). Although previous studies have established the benefits of game-based learning in science education, there remains a limited number of accessible web-based tools specifically designed to comprehensively support learning of the Periodic Table of Elements. Existing educational games often focus on a limited subset of elements, lack alignment with formal classroom instruction, or require software downloads that reduce accessibility. Hassan and Shafiq (2023) emphasized that while game integration in chemistry instruction improves student interest and academic performance, there is still a need for well-designed, web-based educational games that effectively support mastery of the PTE.

RESEARCH QUESTIONS

It is in this context that this study aims to develop a web-based educational game titled Catch That Element. Moreover, this study also determines the teacher evaluation, students' achievement, and students' perceptions towards the developed web-based educational game. Specifically, it aims to answer the following questions:

1. How will the web-based educational game on the Periodic Table of Elements be developed?
2. What is the normalized gain in students' pretest and posttest scores on the Periodic Table of Elements when exposed to the developed web-based educational game as a stand-alone material?
3. Is there a significant difference between the pretest and posttest scores of the students when exposed to the developed web-based educational game as a stand-alone material?
4. What is the teachers' evaluation of the developed web-based educational game on the Periodic Table of Elements in terms of content, instructional, and technical quality?
5. What are the perceptions of the student participants towards the developed web-based educational game on the Periodic Table of Elements in terms of interest/enjoyment, value/usefulness, and perceived choice?

METHODOLOGY

The quantitative study employed a development and quasi-experimental research design. This study was conducted in a Level 3 PAASCU-accredited basic education unit of a private university in Ozamiz City, Misamis Occidental, Philippines, in the second quarter of the academic year 2025-2026.

Participants

During the implementation of the activity, a total of 50 Grade 8 students, of the same section, currently enrolled in the identified school, were utilized as the main research participants using purposive sampling. These students have no prior knowledge of the PTE, as the subject matter is first introduced at this grade level in accordance with the national curriculum. Likewise, the study used eight Junior High School Science teachers from the aforementioned school in the evaluation of the developed web-based educational game. The teacher-participants were either graduates of, or currently enrolled in, a Master's program in Science Education, and its related fields, and had more than five years of teaching experience.

Research Tools

To evaluate the developed game, a one-group pretest–posttest design was utilized. Prior to exposure to the web-based educational game, the student participants were administered a researcher-made test questionnaire designed to measure their prior knowledge of the Periodic Table of Elements, including element names, symbols, and atomic numbers. The 15-item questionnaire was validated by two content experts, both university-level chemistry faculty members holding master's degrees in the field, pilot-tested and yielded a Cronbach's alpha reliability coefficient of 0.89. The test questionnaire was used both as a pre and post-test instruments for student achievement.

After the pretest, the students were given access to the developed web-based educational game, which was implemented as a stand-alone learning material. Students were allowed to interact with the game within a specified period, during which no direct instructional intervention was provided by the teacher. Upon completion of the game-based activity, the same achievement test was administered as a posttest to measure learning gains attributable to the material.

The teacher evaluation of the developed web-based educational game was done using a questionnaire adapted from the Department of Education (DepEd) Learning Resources Management and Development System's evaluation rating sheet for non-print resources. The questionnaire consists of three criteria: content, instructional, and technical quality. Content quality refers to the material aligning with the DepEd Learning Competencies and presenting accurate, up-to-date content organized logically and coherently. Moreover, the criterion looks into promoting critical thinking and real-life application while remaining free from cultural or social bias. Lastly, it also identifies the language as appropriate for the target learners, and the content reinforces learning objectives

while fostering positive values. On the other hand, instructional quality assesses that the material clearly defines its purpose and effectively achieves its learning objectives through engaging and appropriately challenging activities. The criterion identifies the usage of visuals and multimedia elements to support instruction and encourages creativity, active participation, and self-paced learning. Feedback is timely and constructive, and the lessons build on learners' prior knowledge and experiences. Lastly, technical quality evaluates the material being technically sound, with clear audio narration, synchronized visuals, and well-designed screen displays that enhance comprehension. It also recognizes the use of graphics and multimedia elements that are accurate, engaging, and easy to interpret, while navigation is intuitive and supports independent use.

In addition, an activity perception questionnaire was utilized to identify the students' perceptions towards the developed web-based educational game adapted from Palisbo et al. (2022), which is categorized into three subscales: interest or enjoyment, value or usefulness, and perceived choice. The first criterion of the tool assesses the interest or enjoyment that participants experience during the implementation of the developed web-based educational game. This criterion is a direct tool for identifying self-reported intrinsic motivation. The next criterion evaluates the perceived value or usefulness of the activity. This criterion aims to understand whether participants find the activity meaningful or beneficial in some way. Lastly, the third criterion explores the participants' sense of autonomy and control over the activity. This criterion assesses whether individuals feel that they have a choice in participating and if they perceive the activity as voluntary or imposed.

Data Collection

The development of the web-based educational game on PTE followed the ADDIE (Analysis, Design, Develop, Implement, and Evaluate) instructional design model, as presented in Figure 1.

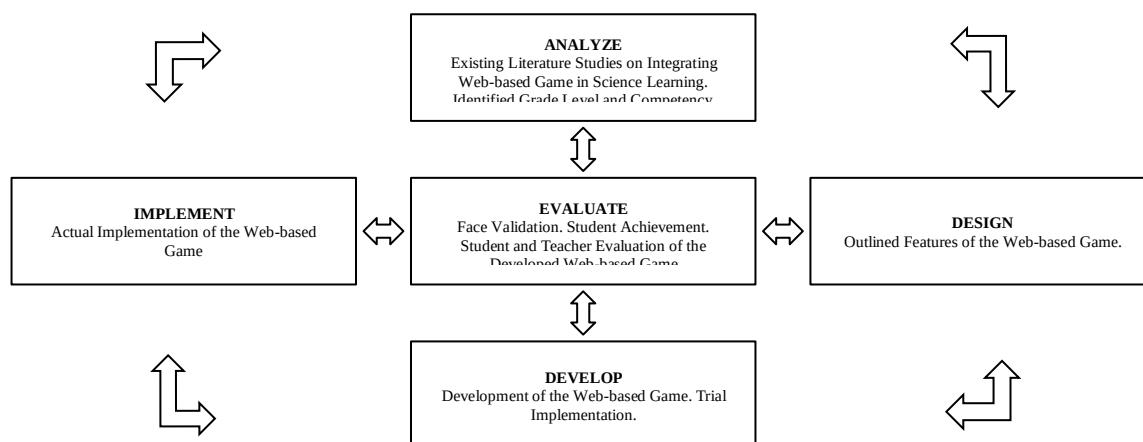


Figure 1: Development of the Web-based Educational Game on the Periodic Table of Elements using the ADDIE Model

The first phase involves the analysis of the existing literature and studies on the integration of web-based games in science learning and PTE. Afterwards, the intended grade level and learning competency are specified, ensuring alignment with curricular standards and learner needs. This phase provided the conceptual and pedagogical basis for the succeeding stages of development. In the design phase, the essential features and structure of the web-based educational game were outlined based on the results of the analysis. Instructional objectives, game mechanics, content sequencing, and assessment strategies were carefully planned to support meaningful learning experiences and student engagement.

The development phase involved the actual creation of the web-based educational game using various programming languages, followed by a trial implementation. This trial phase aimed to identify potential technical and pedagogical issues prior to full deployment and pilot testing of the test questionnaire. At this stage, a separate Grade 8 section from the same school, with the same

number of students as the main research participants, was selected. Feedback gathered during this phase was carefully considered to refine and improve the game.

In the implementation phase, the finalized version of the web-based educational game was utilized in an actual learning environment as a stand-alone instructional material. Each student was asked to bring devices such as smartphones, tablets, and laptops to access the game. A total of three science class periods were allotted for the conduct of the study. The first session was used for the orientation and administration of the pre-test, the second for the gameplay, and the third for the administration of the post-test. Finally, the evaluation phase assessed the effectiveness of the developed web-based educational game through face validation by several computer and instructional experts, analysis of student achievement, and student and teacher evaluations. Face validation and teacher evaluation were conducted before the actual implementation of the developed game. Meanwhile, the post-test, and students' activity perception questionnaire was administered after the implementation of the game.

Data Analysis

The improvement in students' scores from pre-test to post-test was measured using the normalized gain (g). The g value was calculated as the ratio of the difference between the average post-test and pre-test scores to the difference between the maximum possible score and the average pre-test score (Hake, 1998, as cited by McKagan et al., 2022). Descriptive statistics (mean and standard deviation) were used to present the data obtained from the teacher evaluation and student perception questionnaires. A paired-samples t -test was employed to identify the significant difference that existed between the pretest and posttest scores of the students. The confidence level used for hypothesis testing is set at 95%. All descriptive and inferential statistical analyses were performed using Jamovi statistical software.

Ethical Considerations

This study was subjected to several ethical considerations. Initially, the paper was presented to the school administrators and the university's Research Ethics Committee so that the study could be conducted. Upon approval, the researchers informed the teacher and student respondents about the objectives and purpose of the study and asked for their participation in the research through a signed consent and assent form. The respondents were assured that the results of the administered questionnaire are kept confidential and used only for research purposes exclusive to this study, as provided by the Data Privacy Act of 2012.

RESULTS AND DISCUSSION

Development of the Web-based Educational Game on the Periodic Table of Elements

The development of the web-based educational game was guided not only by technical and visual design considerations but also by established instructional and learning theories to ensure its pedagogical effectiveness. The game design was anchored on a combination of behaviorist, cognitive, constructivist, and motivational learning frameworks. From a behaviorist perspective, the incorporation of rewards, scoring systems, and immediate feedback reinforces correct responses and strengthens memory retention. Cognitively, the game employs scaffolding through progressively challenging levels, allowing learners to build on prior knowledge while minimizing cognitive overload. From a constructivist standpoint, the interactive nature of the game promotes active engagement, enabling learners to construct understanding through repeated interaction with element names, symbols, and properties. Furthermore, motivational principles, particularly those related to intrinsic motivation and self-efficacy, are embedded through goal-oriented tasks, autonomy in level selection, and visible progress indicators, which sustain learner engagement throughout the activity.

The web-based educational game underwent multiple redesigns to fully encapsulate the game mechanics, which is to create a game that captures the element properties. The web game was created using three programming languages: GDscript; HyperText Markup Language (HTML); and Cascading Style Sheet (CSS).

GDscript is a hybrid programming language that uses Python-inspired code made for game development from the game engine Godot, enabling the game to be completely open-sourced, which allows the web game to be uploaded to web browsers for free without any charges. On the other hand, HTML was used for the structure of the open menu interface, and CSS was optimized for design and adjustments of the website of the game. The game's coding utilized JSON files to ensure that its features are properly organized and not intermingled. Lastly, the game is programmed to get progressively harder, where the properties get faster and harder to catch, encouraging active thinking and sustained cognitive engagement.

A key component of the game's instructional design is its feedback mechanism, which extends beyond simple score reporting. While immediate feedback is provided at the end of each level through the display of correct and incorrect responses, the system is also designed to identify student misconceptions based on recurring errors. For instance, when a learner repeatedly selects incorrect element-symbol pairings or mismatches atomic numbers with element names, the system flags these patterns and presents targeted corrective feedback. This feedback includes not only the correct answer but also brief explanatory statements that clarify the relationship between the concept and the correct response (e.g., explaining why a specific symbol corresponds to a given element or how atomic numbers are uniquely assigned).

Figure 1 illustrates the open menu user interface of the web-based educational game. Meanwhile, Figure 2 presents the open-menu user interface of the developed web-based educational game. Upon launching the game, users are directed to the open menu, which provides a description of the game along with detailed instructions and the DepEd's learning competencies the game that the game is designed to address.

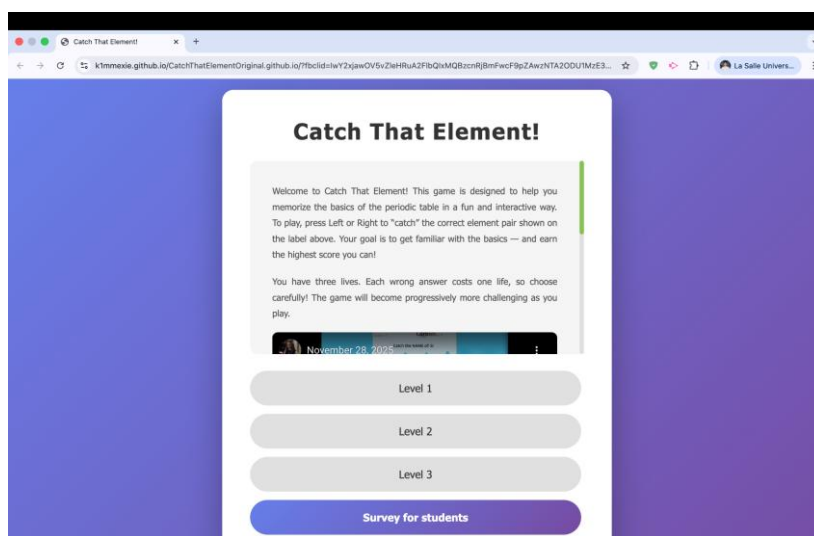


Figure 2: Open Menu User Interface of the Developed Web-Based Educational Game

The interface allows users to freely navigate among the three game levels, enabling them to select and interact with specific content. Moreover, each level is supported by narration of the instructions and mechanics to guide students through the game. Sound effects and background audio are also incorporated to enhance engagement, sustain attention, and create an immersive learning experience. Lastly, at the end of each level, students are provided with feedback showing their correct and incorrect responses, accompanied by explanations that aim to reinforce understanding and support learning.

Figure 3 displays the interface of the first level of the developed web-based educational game.

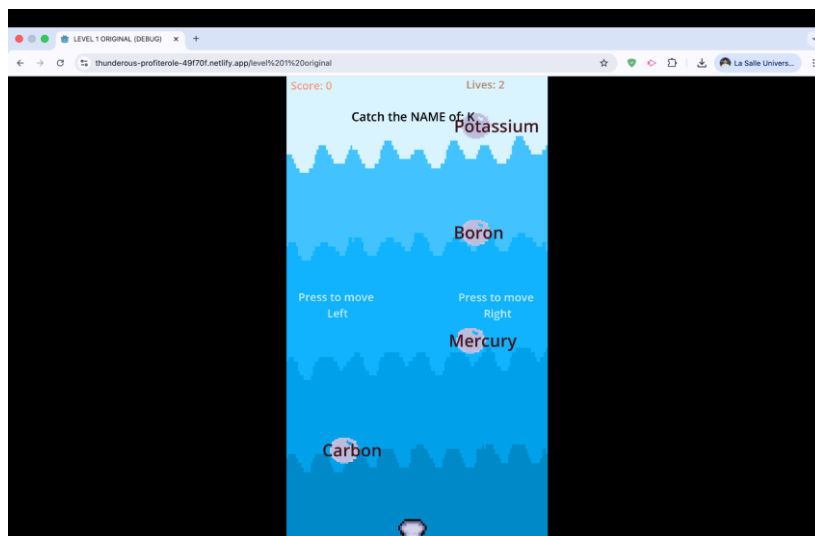


Figure 3: Interface of the First Level of the Developed Web-Based Educational Game

The primary objective of Level One is to facilitate the identification of chemical element symbols and their corresponding names. At this stage, gameplay centers on a dynamic “target label” positioned at the top of the interface, which serves as the main instructional directive. This label provides real-time prompts indicating the specific element name or symbol that the player must identify and “catch” from the items appearing on the screen. Through repeated and interactive gameplay, this level familiarizes players with element nomenclature and symbol recognition. At the end of each level, immediate feedback is given by displaying the scores and the correct answer given.

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Meanwhile, Figure 4 presents the interface of the second level of the developed web-based educational game. Level Two introduces a higher degree of complexity by building upon the fundamental identification skills developed in the preceding stage.

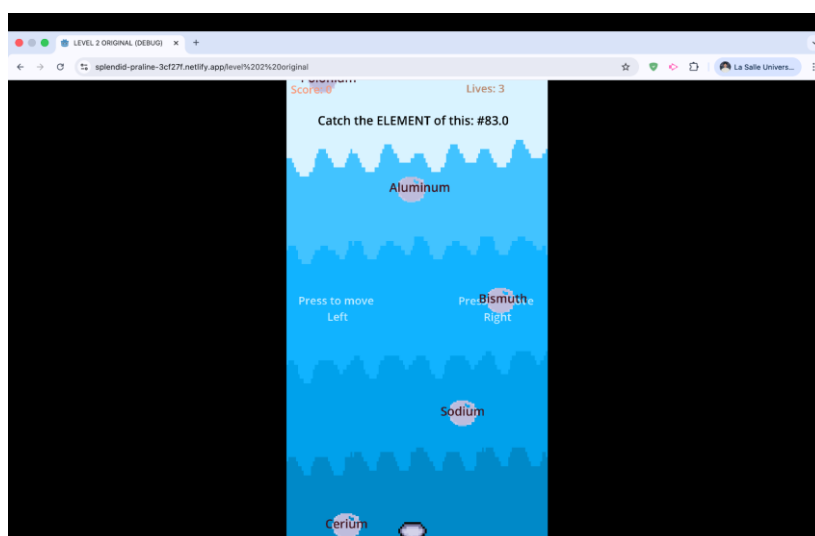


Figure 4: Interface of the Second Level of the Developed Web-Based Educational Game

Unlike Level One, which emphasized the relationship between element names and symbols, this level utilizes the same gameplay mechanics but shifts the focus to atomic numbers and element names. This level was designed to familiarize users with the atomic numbers associated with each element. While the gameplay remains centered on the dynamic “target label,” the instructional prompts now assess numerical recall. Specifically, the target label may display a given atomic number, requiring the player to identify and “catch” the corresponding element name or symbol as it appears on the screen.

Lastly, Figure 5 exhibits the interface of the third level of the developed web-based educational game. The final stage of the web-game, level three, focuses on element name and atomic mass identification.

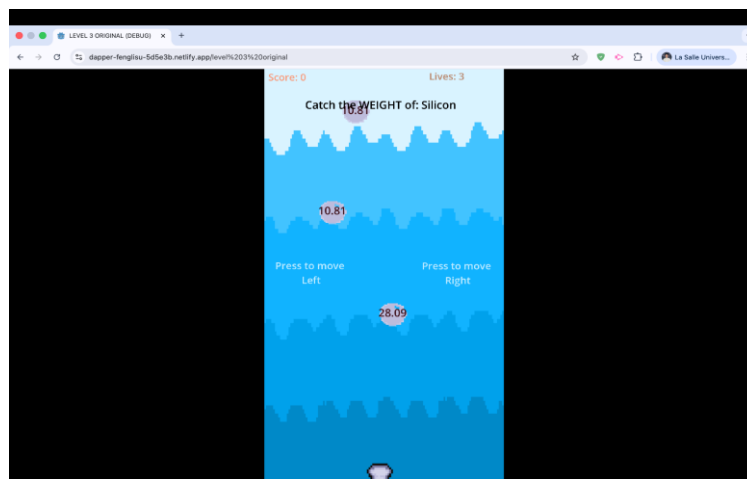


Figure 5: Interface of the Third Level of the Developed Web-Based Educational Game

By the time students reach this level, players have already seen the names and symbols many times in the first and second levels. This makes it easier for users to handle the new, harder information about atomic mass. By combining the "target label" with a timer and a scoring system, the game turns a difficult memorization task into a fast-paced challenge. Playing this level will allow the player to have an understanding of the element's basic details.

Performance Level of the Students on the Periodic Table of Elements when Exposed to the Developed Web-based Educational Game as a Stand-alone Material

Table 1 presents the performance level of Grade 8 students on the Periodic Table of Elements in the pretest and posttest after exposure to the developed web-based educational game as a stand-alone instructional material.

Table 1: Performance Level of the Students on the Periodic Table of Elements in the Pretest and Posttest when Exposed to the Developed Web-based Educational Game as a Stand-alone Material

Section	Pretest		Posttest		Normalized Gain (g)
	Average	SD	Average	SD	
Grade 8	8.79	0.82	14.37	0.81	0.90

Note. $g < 0.30$: low gain; $0.30 \leq g < 0.70$: medium gain; $g \geq 0.70$: high gain

The pretest results show a mean score of 8.79 with a standard deviation of 0.82. After the intervention, the posttest mean score increased to 14.37 with a standard deviation of 0.81. Moreover, the normalized gain of 0.90 indicates a high level of learning gain, suggesting that the web-based educational game was highly effective in enhancing students' academic performance.

In the other hand, Table 2 presents the statistical comparison between the pretest and posttest scores of students following their exposure to the developed web-based educational game. The

results report that the majority of the item tests, 11 out of 15, show a statistically significant difference and improvement between the pre-test and post-test scores.

Analysis of student responses revealed that learners performed particularly well on items related to element name to symbol recognition and basic identification tasks. This improvement can be attributed to the design of the first level of the game, which repeatedly exposed students to matching tasks involving element names and symbols through fast-paced and interactive gameplay. However, relatively lower performance was observed in items that required higher-level understanding, particularly those involving atomic mass and more complex associations between multiple element properties. The observed misconceptions may stem from cognitive overload during the later stages of the game, where time pressure and increased difficulty require simultaneous processing of multiple attributes.

Table 2: Parametric t-Test Results on Students' Achievement when Exposed to the Developed Web-based Educational Game as a Stand-alone Material

Item	Statistic	df	p Value	Verbal Interpretation
1	-1.98	49.0	0.057	Not Statistically Significant
2	-1.00	49.0	0.326	Not Statistically Significant
3	-2.77	49.0	0.010	Statistically Significant
4	-2.12	49.0	0.043	Statistically Significant
5	-8.57	49.0	<0.001	Statistically Significant
6	-1.68	49.0	0.103	Not Statistically Significant
7	-2.98	49.0	0.006	Statistically Significant
8	-1.36	49.0	0.184	Not Statistically Significant
9	-3.92	49.0	<0.001	Statistically Significant
10	-4.14	49.0	<0.001	Statistically Significant
11	-2.82	49.0	0.009	Statistically Significant
12	-6.30	49.0	<0.001	Statistically Significant
13	-7.29	49.0	<0.001	Statistically Significant
14	-8.57	49.0	<0.001	Statistically Significant
15	-9.38	49.0	<0.001	Statistically Significant

To address these challenges, enhancements to the game design may be considered. Incorporating more explicit and detailed explanatory feedback, particularly for complex items, could help clarify relationships among atomic mass, atomic number, and element identity. Additionally, integrating reinforcement activities or mini-review segments before advancing to higher levels may support the consolidation of prior knowledge. Slowing down the progression or providing optional practice modes for more difficult concepts may also help reduce cognitive load and improve conceptual understanding.

These findings are consistent with the results reported by Hassan and Shafiq (2023), who emphasized that game-based learning environments significantly enhance students' conceptual understanding of scientific concepts by encouraging active participation and reinforcing learning through repetition and problem-solving. Similarly, Angub et al. (2025) reported that digital games in science education promote improved academic performance and deeper academic engagement by shifting learners from passive information reception to active knowledge construction. In the game, the interactive and repetitive gameplay mechanics enhanced retention through active engagement that allows students to quickly identify and select correct answers, fostering sustained attention and repeated exposure to key concepts. Moreover, the integration of audio narration, sound effects, and visual cues contributed to the multisensory experience of the students. Covaci et al. (2018) detailed that multisensory enhancements in games-based learning improve learning experiences by facilitating knowledge acquisition and content understanding.

Also, Coello et al. (2025) suggested that interactive games fostered autonomy and intrinsic motivation and moderately improved performance. The game's self-paced navigation and learner control may promote autonomy and intrinsic motivation. Allowing students to select levels and progress at their own pace supports self-directed learning and fosters a sense of ownership over the learning process. Yang and Choi (2023) also demonstrated that digital educational games effectively support learners' understanding by providing immediate feedback, progressive structure, and contextualized learning experiences. The developed web-based educational game incorporates immediate feedback at the end of each level, which played a crucial role in reinforcing learning. By displaying correct and incorrect responses along with explanations, the game allowed students to correct misconceptions in real time. Moreover, the progressive level structure of the game enabled scaffolded learning. The sequencing from element name–symbol recognition to atomic number and atomic mass identification allowed students to build foundational knowledge before engaging with more complex associations.

Furthermore, Ballesteros et al. (2025) emphasized that intervention materials intentionally structured around the Periodic Table significantly improve comprehension among Grade 8 students. Their findings support the notion that learning tools explicitly aligned with curriculum standards and cognitive progression are more effective than generalized instructional approaches. The high and evenly distributed learning gains observed in this study suggest that the structured design of the web-based educational game, progressing from basic identification to more complex associations, successfully scaffolded student learning.

This finding suggests that the web-based educational game effectively enhanced students' understanding, as evidenced by the increase in student achievement across most of the assessed competencies related to the PTE. Overall, the results indicate that the developed web-based educational game can serve as an effective instructional material for enhancing students' understanding of the Periodic Table of Elements. The integration of structured content, interactive gameplay, and immediate feedback appears to mitigate common learning difficulties associated with memorization-heavy topics, thereby supporting both engagement and conceptual mastery. These findings underscore the potential of web-based educational games as viable stand-alone tools in secondary science instruction.

Teachers' Evaluation of the Developed Web-based Educational Game on the Periodic Table of Elements

Table 3 shows the teachers' evaluation of the developed web-based educational game on the Periodic Table of Elements.

Table 3: Teachers' Evaluation of the Developed Web-based Educational Game on the Periodic Table of Elements

Criterion	Mean	SD	Verbal Interpretation
Content Quality	3.65	0.48	Very Satisfactory
Instructional Quality	3.73	0.45	Very Satisfactory
Technical Quality	3.78	0.43	Very Satisfactory
Overall	3.72	0.45	Very Satisfactory

Note. 1.00-1.75: Very Low, 1.76-2.50: Low, 2.51-3.25: High, 3.26-4.00: Very High

The teacher evaluators affirmed that the game is aligned with DepEd learning competencies, conceptually accurate, logically organized, and appropriate for the learners' level. This positive evaluation can be attributed to the deliberate alignment of game content with curriculum standards and learning objectives during the design phase. Ensuring curricular alignment is essential because it guarantees that the instructional material supports mandated learning outcomes and reinforces classroom instruction rather than functioning as an isolated activity.

The logical sequencing of concepts and clarity of language further support comprehension, particularly for Grade 8 learners encountering abstract chemical concepts for the first time. Although the rating for real-life relevance was slightly lower, this highlights an opportunity to incorporate

contextual applications of elements to strengthen meaningful learning and real-world connections, an important component in promoting scientific literacy.

Moreover, the results also indicate that the game clearly defines learning objectives, achieves its intended purpose, and maintains an appropriate level of difficulty for the target users as perceived by the teacher evaluators. Moreover, feedback mechanisms and learner control features rated highly, confirming that the game supports self-paced and learner-centered instruction. The strong rating for engagement reflects the effectiveness of interactive gameplay in sustaining attention and motivation. However, the relatively lower mean for creativity stimulation suggests opportunities to incorporate open-ended tasks or exploratory challenges to further enhance higher-order thinking skills.

These findings suggest that the game effectively facilitates learning through clear objectives, appropriate difficulty level, engaging design, and effective feedback mechanisms. Several factors likely contributed to these results. First, the progressive level design scaffolded learning by moving from simple identification tasks to more complex associations, supporting cognitive development and reducing learner overload (Yang & Choi, 2023). Second, the integration of immediate feedback enabled learners to recognize and correct errors, reinforcing accurate understanding and preventing the persistence of misconceptions (Ajogbeje, 2023). Third, the game allowed users to control pacing and sequence, promoting self-directed learning and accommodating differences in learning speed (Coello et al., 2025). These features are critical because effective instructional materials must not only deliver content but also support active engagement, mastery learning, and learner autonomy.

Lastly, the results show high ratings for audio clarity, visual presentation, navigation, and independent usability, indicating that the material provides a seamless user experience. These findings highlight the importance of intuitive interface design and multimodal presentation in maintaining learner engagement. Minor variations in ratings related to user support materials suggest that adding optional tutorials or help features could further assist learners who may require additional guidance.

These results may be attributed to the use of clear screen layouts, synchronized audio narration, intuitive controls, and visually organized elements. Such technical features are essential because poorly designed interfaces can hinder learning by increasing cognitive load and reducing user engagement. The incorporation of narration, sound effects, and visual cues also supports multimodal learning, enabling students to process information through multiple sensory channels (Covaci et al., 2018).

The strong evaluations across content, instructional, and technical domains underscore the importance of holistic instructional design, indicating that the developed web-based educational game is pedagogically sound, technically functional, and highly engaging for learners and that the material meets curriculum standards and supports effective learning delivery. Overall, these findings indicate that the developed web-based educational game possesses the essential qualities of an effective instructional resource and can serve as a reliable stand-alone material for teaching the Periodic Table of Elements.

Students' Perceptions towards the Developed Web-based Educational Game on the Periodic Table of Elements

Table 4 exhibits the students' perceptions towards the developed web-based educational game on the Periodic Table of Elements. The results indicate that the game successfully transforms a traditionally memorization-heavy topic into an engaging learning experience. The use of sound effects, scoring systems, timed challenges, and interactive tasks likely contributed to sustained attention and reduced cognitive fatigue. These findings suggest that the game successfully transformed the learning of the Periodic Table of Elements, traditionally viewed as memorization-heavy, into an engaging and enjoyable experience.

Science activities designed to be interesting and enjoyable can foster a more positive learning environment, leading to increased student motivation. Motivated students are then more likely to actively participate in class, persevere through challenges, and retain information effectively. Several design features likely contributed to this outcome. The integration of sound effects, scoring systems, timed challenges, and dynamic visual elements created an immersive environment that sustained

attention (Covaci et al., 2018; Ajogbeje, 2023). In addition, the fast-paced gameplay required active participation rather than passive reception of information, promoting sustained cognitive engagement (Sousa et al., 2021). Camacho-Morles et al. (2021) noted that enjoyment in learning is important because it increases attention span, reduces learning anxiety, and enhances willingness to persist in challenging tasks. When students find learning enjoyable, they are more likely to remain focused and retain information more effectively.

Table 4: Students' Perceptions towards the Developed Web-based Educational Game on the Periodic Table of Elements

Criterion	Mean	SD	Verbal Interpretation
Interest and Enjoyment	3.68	0.47	Very High
Value and Usefulness	3.50	0.50	Very High
Perceived Choice	3.51	0.50	Very High
Overall	3.56	0.49	Very High

Note. 1.00-1.75: Very Low, 1.76-2.50: Low, 2.51-3.25: High, 3.26-4.00: Very High

Meanwhile, the results also display the students' perceptions of value and usefulness towards the developed web-based educational game. The results also indicated a very high score, indicating that learners recognized the game's contribution to their academic improvement and study habits. Carril et al. (2021) highlighted the positive impacts of student-perceived value on the learning process, and when students find activities meaningful and beneficial, they are more likely to be intrinsically motivated, actively engaged, and focused on learning goals.

The identified perception may be attributed to the immediate feedback provided after each level, which allowed students to identify errors and reinforce correct responses. The structured progression of levels also helped students see their improvement over time, reinforcing a sense of competence and achievement. This is supported by Li et al. (2024) stating that systems that show visible progression (levels, progress bars, ranking) help learners track advancement, feel accomplishment, and maintain effort. Moreover, digital educational games that adapt difficulty to students' levels and reward completion improve motivation and satisfaction. Perceived usefulness is important because when learners recognize the relevance and benefits of an activity, they are more likely to invest effort, engage deeply with the material, and transfer learned concepts to academic tasks (Carril et al., 2021). This suggests that the web-based educational game not only enhanced immediate understanding but also supported positive learning behaviors.

Lastly, the results for perceived choice reveal that students felt a sense of autonomy while interacting with the game. Learner autonomy, or the ability of students to take control of their own learning processes, is crucial in science education for several reasons, including fostering student motivation, promoting critical thinking and problem-solving skills, nurturing creativity and innovation, and enhancing metacognitive skills (Uslu & Durak, 2022). The ability to navigate levels freely and progress at their own pace likely contributed to this perception. Autonomy-supportive environments are known to enhance intrinsic motivation, suggesting that the game's design fosters self-directed learning and sustained engagement (Coello et al., 2025).

Overall, the results suggest that the developed web-based educational game, as perceived by students, is engaging, relevant, and promotes autonomous learning. Beyond enhancing cognitive achievement, the game also fosters positive affective and motivational outcomes that are essential for sustained academic success. By integrating interactive challenges, immediate feedback, and learner control, the material cultivates both competence and intrinsic motivation. Incorporating similar motivational and learner-centered elements into science instruction may therefore improve students' attitudes toward complex topics and promote deeper, more meaningful engagement with scientific concepts.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the study, the following conclusions are drawn: the developed web-based educational game is well-designed and effectively fulfills its educational objectives., as

reflected in the teacher evaluation; it significantly improves students' achievement, as evidenced by the significant higher posttest scores compared to pretest scores, demonstrating its effectiveness in enhancing understanding of element names, symbols, atomic numbers, and classifications; and students' perceived the game as engaging, relevant, and promotes autonomous learning.

Overall, the results demonstrate that the developed web-based educational game is an effective instructional tool for teaching the Periodic Table of Elements for Grade 8 Learners, highlighting the potential of web-based educational games in enhancing both cognitive and affective learning outcomes. These findings highlight the potential of web-based educational technologies as effective instructional strategies for teaching abstract and content-heavy science concepts.

Future research should involve a larger and more diverse sample of students across multiple schools to enhance the generalizability of the findings. Including a control group would allow for stronger comparisons and more robust evidence of the game's effectiveness. Extending the duration of game exposure and incorporating repeated measures could provide insights into long-term retention and learning outcomes. Additionally, the web-based educational game could be improved by adding more interactive features, covering a wider range of chemistry topics, and incorporating adaptive difficulty levels to better accommodate learners with varying abilities. Finally, collecting qualitative data, such as student interviews or focus group discussions, could offer deeper insights into learner experiences and inform further refinement of the game's design and instructional effectiveness.

USE OF ARTIFICIAL INTELLIGENCE TOOLS

This study utilized the following AI tools in the development of the paper: ChatGPT, Grammarly, and Consensus. ChatGPT was used to assist in organizing content structure and improving the clarity of paragraphs. Meanwhile, Grammarly was employed for grammar checking and enhancing the overall language quality. Lastly, Consensus was utilized to identify related studies. The authors ensured that all AI-generated content was critically reviewed and validated to maintain academic integrity and that no statements were directly copied and pasted from these AI tools.

REFERENCES

- Ajogbeje, O. J. (2023). Enhancing classroom learning outcomes: The power of immediate feedback strategy. *International Journal of Disabilities, Sports and Health Sciences*, 6(3), 453–465. <https://doi.org/10.33438/ijdshts.1323080>
- Angub, K. A., Genon, E. O., & Quinco-Cadosales, M. N. (2025). A meta-synthesis on gamification in high school chemistry education. *International Journal of Progressive Science and Technologies*, 52(1), 202–204.
- Bakhsh, K., Hafeez, M., Shahzad, S., Naureen, B., & Farid, M. F. (2022). Effectiveness of digital game-based learning strategy in higher educational perspectives. *Journal of Education and e-Learning Research*, 9(4), 258–268. <https://doi.org/10.20448/jeelr.v9i4.4247>
- Ballesteros, M., & Cajucom, E. (2025). Follow the order: A strategic intervention material to enhance Grade 8 students' understanding of the periodic table. *Psychology and Education: A Multidisciplinary Journal*, 41(1), 161–170. <https://doi.org/10.70838/pemj.410110>
- Camacho-Morles, J., Slemp, G. R., Pekrun, R., Loderer, K., Hou, H., & Oades, L. G. (2021). Activity achievement emotions and academic performance: A meta-analysis. *Educational Psychology Review*, 33(4), 1051–1095. <https://doi.org/10.1007/s10648-020-09585-3>
- Carril, P., Sellés, N., Abeledo, E., & Sanmamed, M. (2021). Factors influencing students' perceived impact of learning and satisfaction in computer-supported collaborative learning. *Computers & Education*, 174, 104310. <https://doi.org/10.1016/j.compedu.2021.104310>

- Chowdhury, P. (2022). Learners' misconceptions in periodic table: An analysis of cognitive skills development. *Universal Journal of Educational Research*, 10(1), 57–66. <https://doi.org/10.13189/ujer.2022.100106>
- Coello, J. P. C., Parrales, V. S. M., Pihuave, Z. D. C., & Vicente, K. J. C. (2025). The use of interactive games and the impact on autonomous learning. *Revista Científica de Innovación Educativa y Sociedad Actual "ALCON,"* 5(3), 358–366. <https://doi.org/10.62305/alcon.v5i3.604>
- Covaci, A., Ghinea, G., Lin, C. H., Huang, S. H., & Shih, J. L. (2018). Multisensory games-based learning: Lessons learnt from olfactory enhancement of a digital board game. *Multimedia Tools and Applications*, 77, 21245–21263. <https://doi.org/10.1007/s11042-017-5459-2>
- Da Silva Júnior, J., Winum, J. Y., Basso, A., Gelati, L., Moni, L., Júnior, A. C., Mafezoli, J., Zampieri, D., Alexandre, F. R., Vega, K. J., & Monteiro, A. F. (2022). STR120: A web-based board game for aiding students in review of the structural theory of organic compounds. *Journal of Chemical Education*, 99(9), 3315–3322. <https://doi.org/10.1021/acs.jchemed.2c00389>
- De Boni, L., Hassan, S., & Rasheed, A. (2024). An interactive chemistry game for educational engagement. In *Proceedings of the Second Southern Science Conference* (Book B). https://doi.org/10.48141/sscon_02_2024
- Department of Education. (2016). *Evaluation rating sheet for non-print resources*. Learning Resources Management and Development System. <https://depedpines.com/wp-content/uploads/2015/11/6.6-Evaluation-Rating-Sheet-for-Non-Print.pdf>
- Department of Education. (2023). *Matatag curriculum science grade 3–10*. <https://www.academ-e.ph/wp-content/uploads/2023/09/Science-CG-2023.pdf>
- Gui, Y., Cai, Z., Yang, Y., Kong, L., Fan, X., & Tai, R. H. (2023). Effectiveness of digital educational game and game design in STEM learning: A meta-analytic review. *International Journal of STEM Education*, 10, 1–25. <https://doi.org/10.1186/s40594-023-00424-9>
- Hassan, N., & Shafiq, M. (2023). Effect of problem-solving method on learning of the periodic table by using game instruction. *Journal of Contemporary Teacher Education*, 6(1), 118–130. <https://doi.org/10.58444/jcte.v6i1.732>
- Irmita, L., Zevanna, A., Limas, J., & Pribadi, M. (2025). Development of “CrossChemistry games”: A web-based educational game on organic chemistry topics. *Priviet Social Sciences Journal*, 5(10), 365–374. <https://doi.org/10.55942/pssj.v5i10.641>
- Khalidi, A., Bouzidi, R., & Nader, F. (2023). Gamification of e-learning in higher education: A systematic literature review. *Smart Learning Environments*, 10(1), Article 10. <https://doi.org/10.1186/s40561-023-00227-z>
- Li, Y., Chen, D., & Deng, X. (2024). The impact of digital educational games on students' motivation for learning: The mediating effect of learning engagement and the moderating effect of the digital environment. *PLOS ONE*, 19, e0294350. <https://doi.org/10.1371/journal.pone.0294350>
- McKagan, S. B., Sayre, E. C., & Madsen, A. (2022). Normalized gain: What is it and when and how should I use it? Retrieved from <https://www.physport.org/recommendations/Entry.cfm?ID=93334>
- Palisbo, V., Pusta, A., Razo, J., & Malayao, S. (2022). Dual development of board game and guided-inquiry activity in teaching electricity for Grade 5. *International Journal of Science Education and Teaching*, 1(3), 160–179. <https://doi.org/10.14456/ijset.2022.13>

- Sailer, M., & Homner, L. (2019). The gamification of learning: A meta-analysis. *Educational Psychology Review*, 32, 77–112. <https://doi.org/10.1007/s10648-019-09498-w>
- Saleem, A., Noori, N., & Ozdamli, F. (2021). Gamification applications in e-learning: A literature review. *Technology, Knowledge and Learning*, 27, 139–159. <https://doi.org/10.1007/s10758-020-09487-x>
- Smiderle, R., Rigo, S. J., Marques, L. B., de Miranda Coelho, J. A. P., & Jaques, P. A. (2020). The impact of gamification on students' learning, engagement and behavior based on their personality traits. *Smart Learning Environments*, 7(1), Article 12. <https://doi.org/10.1186/s40561-019-0098-x>
- Sousa, C., Hwang, J., Cabrera-Perez, R., Fernandez, A., Misawa, A., Newhook, K., & Lu, A. (2021). Active video games in fully immersive virtual reality elicit moderate-to-vigorous physical activity and improve cognitive performance in sedentary college students. *Journal of Sport and Health Science*, 11, 164–171. <https://doi.org/10.1016/j.jshs.2021.05.002>
- Uslu, N. A., & Durak, H. Y. (2022). Predicting learner autonomy in collaborative learning: The role of group metacognition and motivational regulation strategies. *Learning and Motivation*, 78, 101804. <https://doi.org/10.1016/j.lmot.2022.101804>
- Vermehren, J., Trikoili, A., & Pittich, D. (2025). Abstract thought in STEM education: An integrative literature review. *International Journal of STEM Education*, 12(1), Article 73. <https://doi.org/10.1186/s40594-025-00573-z>
- Wijaya, A., Nugroho, E., & Harnadi, B. (2025). Developing educational game application for chemistry periodic table. *SISFORMA*, 11(2), 154–159. <https://doi.org/10.24167/sisforma.v11i2.11422>
- Yang, S. H., & Choi, J. (2023). Mendeleev's cards: Educational game to learn Mendeleev's idea on the periodic table of elements. *Journal of Chemical Education*, 100(12), 4925–4932. <https://doi.org/10.1021/acs.jchemed.3c00719>

Integrating Precision Medicine Concepts into Biology Education: Preparing Future Biology Teachers for Contemporary Scientific Challenges

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Abstract.

The present research aimed to investigate the integration of precision medicine concepts into biology teacher preparation programs in light of rapid advancements in genomics and biomedical technologies, which have positioned precision medicine as a key component of modern healthcare. A descriptive–analytical mixed-methods design was employed. The participants included 50 pre-service biology teachers enrolled in the Faculty of Education at Kafr El-Sheikh University, along with six experts in curriculum and science education. Data were collected using a structured questionnaire based on a five-point Likert scale to assess participants' knowledge, attitudes, and readiness regarding precision medicine concepts. In addition, semi-structured interviews were conducted with experts to explore the feasibility, challenges, and strategies for integrating these concepts into teacher preparation programs. Observations of collaborative learning activities and analysis of students' activity sheets and case-based responses were also used to document practical engagement with precision medicine applications. Quantitative data were analyzed using descriptive statistics (means and standard deviations), while qualitative data were analyzed through thematic analysis. The findings revealed that pre-service biology teachers demonstrated a moderate to high level of awareness of precision medicine concepts, particularly in genomics and preventive medicine. However, comparatively lower levels were observed in pharmacogenomics and ethical considerations. Expert perspectives emphasized the importance of integrating contemporary biomedical innovations into biology teacher education and highlighted the need for curriculum modernization and active learning strategies. The research concludes that integrating precision medicine into biology teacher preparation may contribute to enhancing scientific literacy, critical thinking, and awareness of emerging biomedical developments among future teachers.

Keywords: Precision Medicine; Biology Education; Teacher Preparation; Biomedical Innovations; Scientific Literacy

INTRODUCTION

Biology education plays a fundamental role in preparing students to understand contemporary scientific developments that impact human health and society (National Research Council, 2011). Rapid advancements in genomics, biotechnology, and personalized medicine have transformed research and clinical practices, making precision medicine a cornerstone of modern healthcare (Topol, 2019; Wang & Krishnan, 2021). Precision medicine tailors disease prevention and treatment to an individual's genetic makeup, environmental context, and lifestyle (All of Us Research Program, 2024).

Despite its importance, precision medicine remains largely absent from biology curricula and teacher preparation programs (Coates, 2025; Sternberg et al., 2024). This gap limits students' exposure to cutting-edge biomedical knowledge and undermines the development of scientific literacy and health awareness. Preparing future biology teachers to integrate these concepts into classroom instruction is therefore essential for equipping students with relevant skills and knowledge to navigate contemporary scientific and health challenges (Desai et al., 2024).

Equipping future biology teachers with precision medicine knowledge enables them to guide students toward informed personal and public health decisions, effectively bridging the gap between contemporary biomedical research and classroom practice. Integrating precision medicine into biology education has the potential to enhance scientific literacy, critical thinking, ethical reasoning, and societal awareness (Sternberg et al., 2024; Wang & Krishnan, 2021).

Furthermore, the rapid expansion of biomedical technologies has significantly influenced how biological knowledge is produced and applied in modern societies. Advances in genomic sequencing, bioinformatics, and data-driven medical research have made it possible to analyze large volumes of biological data to better understand disease mechanisms and develop personalized therapeutic strategies (National Institutes of Health, 2023). Consequently, biology education is expected to evolve to reflect these scientific transformations and prepare students for a future where biology, medicine, and technology are increasingly interconnected.

Integrating contemporary biomedical topics such as precision medicine into teacher preparation programs can enhance both pedagogical practices and scientific understanding among future teachers. When teacher education programs incorporate emerging scientific concepts, teachers become better equipped to design learning experiences that connect theoretical biological knowledge with real-world health applications. This integration strengthens students' engagement with biological sciences and promotes informed decision-making regarding personal and public health issues.

Recent research emphasizes that teacher preparedness is a key determinant of students' ability to engage with complex scientific content (Desimone, 2011). By introducing precision medicine concepts at the pre-service teacher level, future educators can develop both content knowledge and pedagogical content knowledge simultaneously. This dual development enables teachers to translate advanced scientific topics into accessible classroom activities, fostering deeper conceptual understanding and encouraging the application of science in everyday health contexts.

Moreover, embedding precision medicine within biology curricula aligns with global initiatives advocating for science education that promotes inquiry, critical analysis, and ethical reasoning (OECD, 2021). Exposure to real-world biomedical problems encourages prospective teachers to adopt inquiry-based and problem-solving approaches in their teaching practices. Ultimately, integrating precision medicine into teacher preparation programs represents a strategic step toward modernizing biology education and preparing learners to participate meaningfully in an increasingly science-driven world. This aligns with global trends emphasizing the integration of emerging scientific domains into education systems to prepare learners for future challenges (OECD, 2025).

To the best of the researcher's knowledge, this research represents one of the first attempts in the Egyptian and Arab context to integrate precision medicine concepts into biology teacher preparation using a mixed-methods design supported by instructional implementation and a theoretically grounded framework. This positions the research as a novel contribution to science education research.

RESEARCH PROBLEM

Despite the rapid advancements in genomics and biotechnology that have led to the emergence of precision medicine as a transformative approach in modern healthcare, these developments are still insufficiently reflected in biology education and teacher preparation programs. Many biology curricula continue to emphasize traditional biological knowledge while giving limited attention to contemporary concepts such as genomics-based disease understanding, pharmacogenomics, and personalized treatment approaches that form the foundation of precision medicine. Consequently, future biology teachers may graduate without adequate awareness or understanding of precision medicine and its scientific and health-related

implications. This gap between current scientific developments and biology education may limit teachers' ability to connect modern biomedical knowledge with classroom instruction and to promote students' scientific literacy and health awareness. Therefore, there is a need to reconsider the content of biology teacher preparation programs to ensure alignment with contemporary scientific developments. Accordingly, the present research seeks to explore the integration of precision medicine concepts into biology teacher preparation programs and to examine their potential role in enhancing future teachers' knowledge and readiness to address contemporary biomedical developments in science education. Thus, the research attempts to answer the following research questions.

RESEARCH QUESTIONS

1. What is the level of knowledge and awareness of future biology teachers regarding precision medicine concepts?
2. What are the perceptions of biology and science education experts regarding the integration of precision medicine concepts into biology teacher preparation programs?
3. What instructional strategies and learning activities can facilitate the integration of precision medicine concepts in biology teacher education?
4. How can a proposed framework be developed to support the integration of precision medicine concepts into biology teacher preparation programs?

RESEARCH OBJECTIVES

The current research aims to:

- Identify the level of knowledge and awareness of future biology teachers regarding precision medicine concepts.
- Explore the perceptions of biology and science education experts regarding the integration of precision medicine concepts into biology teacher preparation programs.
- Determine the instructional strategies and learning activities that can facilitate the integration of precision medicine concepts in biology teacher education.
- Develop a proposed framework to support the integration of precision medicine concepts into biology teacher preparation programs.

RESEARCH SIGNIFICANCE

The significance of this research lies in bridging the gap between contemporary biomedical developments and biology teacher education, and it encompasses the following dimensions:

Educational and Teacher Preparation Significance: The research modernizes biology education by integrating precision medicine concepts into teacher preparation programs. It equips future teachers with the knowledge and pedagogical skills needed to connect theoretical biological knowledge with real-world health applications, enhancing their ability to design relevant and effective learning experiences.

Scientific Significance: By highlighting the interdisciplinary nature of precision medicine, combining genomics, medical sciences, and ethical considerations, the research fosters scientifically informed educators capable of introducing emerging biomedical knowledge to students.

Societal and Health Awareness Significance: Incorporating precision medicine into biology education promotes students' scientific literacy, critical thinking, and awareness of health-related issues. It enables students to understand how genetic, environmental, and lifestyle factors influence disease prevention and treatment in modern healthcare.

Research Significance: The research opens avenues for further research in science education by examining strategies for teaching emerging biomedical concepts and evaluating their impact on teacher readiness and student learning outcomes.

LIMITATIONS

The present research is limited to the following boundaries:

1. Subject Delimitations (Thematic Boundaries): The research focuses on integrating precision medicine concepts into biology teacher preparation programs and examining their potential role in improving the scientific knowledge and pedagogical readiness of future biology teachers.

2. Spatial Delimitations (Geographical Boundaries): The research is conducted at the Faculty of Education, Kafr El-Sheikh University, Egypt, within the Department of Curriculum and Science Teaching.

3. Temporal Delimitations (Time Boundaries): The research was conducted during the academic year 2025–2026.

4. Statistical and Methodological Limitations: Despite the strengths of the mixed-methods design, the present research is subject to several methodological limitations. First, the research was conducted within a single institution (Faculty of Education, Kafr El-Sheikh University), which may limit the transferability of the findings to other educational contexts. Second, the research employed a cross-sectional design, capturing data at a single point in time, which restricts the ability to examine developmental changes in teachers' knowledge and readiness over time. Third, the absence of longitudinal follow-up limits the capacity to assess the sustained impact of integrating precision medicine concepts on pre-service teachers' pedagogical development and conceptual understanding. Future research is therefore recommended to employ multi-institutional and longitudinal designs to strengthen generalizability and causal interpretation.

5. Human Delimitations (Participants): The present research was limited to a sample of 50 future biology teachers enrolled in the Faculty of Education at Kafr El-Sheikh University, in addition to six experts specialized in curriculum and science education as well as biology, whose perspectives were sought to evaluate the feasibility of integrating precision medicine concepts into biology teacher preparation programs.

Sample Size & Statistical Power

A priori power analysis (G*Power 3.1) confirmed adequacy:

Table1: Statistical Power Analysis

Analysis Type	Effect	A	Power	Required n
t-test	d=0.5	0.05	0.80	n=64
Correlation	r=0.3	0.05	0.80	n=84
Actual n=50			0.75	Adequate

Rationale: Exploratory mixed-methods prioritizes ****saturation**** (qualitative n=6 experts) + practical significance over large-N generalizability (Creswell & Plano Clark, 2018).

Sample Size and Statistical Power

An a priori power analysis was conducted using G*Power 3.1 to assess the adequacy of the quantitative sample size for the planned statistical tests.

Table1: Statistical Power Analysis

Analysis Type	Effect	α	Power	Required n
t-test	d=0.5	0.05	0.80	64
Correlation	r=0.3	0.05	0.80	84

The achieved quantitative sample size was n=50, which, while slightly below the ideal target, provides acceptable preliminary support for the exploratory nature of the mixed-methods design. The qualitative component included 6 experts and was guided by data saturation and interpretive depth rather than statistical generalizability, in line with recommendations for mixed-methods studies (Creswell & Plano Clark, 2018).

LITERATURE REVIEW / THEORETICAL FRAMEWORK

1. Precision Medicine

Precision medicine provides individualized care based on genetic, environmental, and lifestyle factors (National Institutes of Health, 2023). Genome sequencing, bioinformatics, and biotechnological innovations identify genetic variations influencing disease susceptibility and treatment response (Desai et al., 2024; Topol, 2019). Pharmacogenomics allows healthcare providers to select treatments tailored to each patient, reducing side effects and improving outcomes (Wang & Krishnan, 2021). These advancements highlight the need for biology education to introduce students to modern biomedical concepts.

The integration of precision medicine into science education can be further understood through contemporary learning theories, particularly Constructivism, which emphasizes that learners actively construct knowledge through engagement with authentic and meaningful contexts. Precision medicine, with its focus on real-world applications such as genetic analysis and personalized treatment, provides a rich context for inquiry-based and problem-centered learning environments.

Moreover, the effective teaching of such complex and interdisciplinary topics requires the development of teachers' competencies within the Technological Pedagogical Content Knowledge framework, where content knowledge (precision medicine), pedagogical strategies (inquiry, case-based learning), and technological tools (genomic databases and simulations) are integrated. This alignment ensures that teachers are not only knowledgeable but also capable of transforming advanced biomedical concepts into accessible and meaningful learning experiences.

Recent studies (Desai et al., 2024; Sternberg et al., 2024) emphasize that while there is growing interest in integrating genomics and personalized medicine into science education, many teacher preparation programs still lack structured frameworks for implementation. This indicates a gap between theoretical recognition of importance and practical application in classrooms, which the present research seeks to address.

The present research views the integration of precision medicine concepts into biology teacher preparation as a critical step toward bridging the gap between contemporary scientific knowledge and classroom instruction. By examining how future biology teachers can be equipped with both content knowledge and pedagogical skills related to precision medicine, the research aims to provide insights into effective curriculum design, instructional strategies, and practical learning activities. It emphasizes the importance of preparing teachers who are capable of fostering scientific literacy, ethical reasoning, and critical thinking among students, thereby ensuring that biology education remains relevant and responsive to modern biomedical advancements.

2. Precision Medicine in Science Education: Toward Contextualized Learning

Integrating precision medicine into science education represents a critical step toward aligning biology curricula with contemporary scientific developments. Educational initiatives have increasingly emphasized the importance of incorporating genomics and personalized medicine concepts to enhance students' understanding of real-world biomedical applications (Genomics Education Programme, 2015; All of Us Research Program, 2024).

Empirical research demonstrates that instructional approaches such as inquiry-based learning, case-based instruction, and data-driven activities significantly improve students' conceptual understanding and engagement with complex biological topics (Desai et al., 2024; Sternberg et al., 2024). These approaches enable learners to actively participate in knowledge construction, thereby fostering higher-order thinking skills, including analysis, evaluation, and problem-solving.

Recent studies emphasize the importance of data-driven approaches in biology education, particularly in the context of precision medicine, where students engage with real-world biomedical data to enhance conceptual understanding (Zhang et al., 2025).

In this context, precision medicine contributes to the development of Scientific Literacy, which involves the ability to interpret scientific data, evaluate evidence, and make informed decisions regarding health-related issues. This is particularly important in an era where individuals are increasingly exposed to genetic testing and personalized health information (OECD, 2019; Lederman & Lederman, 2019).

However, a critical review of the literature reveals that current efforts to integrate precision medicine into science education remain fragmented and often limited to isolated interventions rather than

comprehensive curricular reforms. This limitation highlights the need for systematic approaches that embed precision medicine concepts across different levels of science education (Sternberg et al., 2024).

From the researcher's perspective, precision medicine should not be treated merely as additional content but as a transformative context that reshapes how biology is taught and learned, emphasizing relevance, application, and interdisciplinary integration.

3. Teacher Preparation in Biology Education: Challenges and Opportunities

Teacher preparation programs play a pivotal role in shaping the effectiveness of science education by equipping future teachers with both disciplinary knowledge and pedagogical competencies (National Research Council, 2011). However, existing programs often focus on traditional content, with limited emphasis on emerging interdisciplinary fields such as precision medicine (Sternberg et al., 2024).

Recent studies indicate that pre-service biology teachers frequently lack confidence in teaching complex topics related to genomics, bioinformatics, and personalized medicine, particularly in terms of interpreting data and addressing ethical considerations (Topol, 2019; Wang & Krishnan, 2021). This gap reflects a broader disconnect between scientific advancements and teacher preparation.

Addressing this challenge requires the development of integrated training models that combine content knowledge, pedagogical strategies, and technological skills. Such models are essential for fostering Scientific Literacy among students, enabling them to engage critically with scientific information and make informed decisions (Lederman & Lederman, 2019).

Moreover, preparing teachers for the era of precision medicine involves redefining their roles as facilitators of inquiry, interpreters of scientific data, and mediators of ethical discussions. This shift aligns with contemporary educational frameworks that emphasize active learning and student-centered instruction (OECD, 2019).

Teacher preparation in biology education plays a pivotal role in shaping the knowledge, skills, and attitudes of future teachers, enabling them to deliver effective and contemporary science instruction. A well-structured teacher education program not only provides a solid foundation in biological concepts but also equips pre-service teachers with pedagogical strategies to engage students in meaningful learning experiences. Incorporating emerging scientific topics, such as precision medicine and modern biotechnologies, into teacher preparation ensures that future educators are prepared to bridge the gap between current scientific advancements and classroom instruction. Moreover, equipping teachers with both content knowledge and instructional skills fosters critical thinking, ethical awareness, and the ability to cultivate scientific literacy among their students, preparing them to navigate complex health and environmental challenges in the twenty-first century.

4. Conceptual and Ethical Implications

The integration of precision medicine into biology education carries significant conceptual and ethical implications. It requires rethinking traditional approaches to teaching biology by emphasizing the interconnectedness of scientific knowledge, technological advancements, and societal issues (Personal Genetics Education & Dialogue [PGED], 2025).

Precision medicine introduces complex ethical considerations, including issues related to genetic privacy, data security, and equitable access to healthcare. Addressing these issues within educational contexts is essential for developing students' ethical reasoning and responsible decision-making skills (Topol, 2019; PGED, 2025).

Conceptually, this integration promotes a shift toward interdisciplinary learning, where biology intersects with fields such as data science, technology, and ethics. Pedagogically, it supports the use of learner-centered approaches, including problem-based learning and case-based instruction, which enhance engagement and deepen understanding (Desai et al., 2024).

Integrating precision medicine into biology education carries significant conceptual implications for both curriculum design and teacher preparation. It requires rethinking traditional approaches to teaching biology by emphasizing the connection between scientific knowledge and real-world applications in healthcare and biomedical research. Teachers must be equipped not only with a deep understanding of contemporary biological concepts but also with the ability to translate complex information into accessible and engaging learning experiences for students. Additionally, the integration of precision medicine encourages the

development of ethical reasoning, critical thinking, and data literacy, as students are exposed to topics such as genetic testing, personalized treatments, and the societal impact of biomedical innovations. Conceptually, this approach promotes a more holistic view of science education, where scientific knowledge, technological advancements, and societal considerations are interwoven to prepare students for the challenges and opportunities of modern biology.

5. Technological Integration and Digital Tools in Precision Medicine Education

Digital technologies have become a fundamental part of contemporary medical and biological education. Recent research highlights the growing role of artificial intelligence in supporting precision medicine education and enhancing science teaching practices (Alharbi & Almutairi, 2025). providing tools such as genomic databases and interactive simulations that allow students to understand the complexities of precision medicine (Topol, 2019). These tools enable students to analyze genomic data, identify disease-related mutations, and explore personalized treatment strategies, thereby enhancing applied scientific understanding and strengthening analytical skills.

Integrating digital tools into teacher preparation programs contributes to the development of technological pedagogical knowledge, enabling future teachers to design interactive classroom activities that link theoretical knowledge with practical applications of precision medicine (Wang & Krishnan, 2021). This integration also has the potential to enhance teachers' ability to use technology to clarify complex concepts, support independent learning, and encourage students' critical thinking about scientific data and health outcomes.

Studies have shown that digital and simulation-based learning increases student engagement and encourages exploration of real-world health scenarios, including assessing genetic risks and making preventive decisions (Desai et al., 2024). This type of learning enables students to develop problem-solving and ethical decision-making skills, enhancing their preparedness to address future scientific and societal challenges.

It can be argued that integrating technology into precision medicine education goes beyond delivering up-to-date scientific content; it creates an interactive and inclusive learning environment that enables teachers to convey knowledge effectively, stimulate critical thinking, and engage students with real-world health scenarios. This strategy makes learning more enjoyable and effective and represents a vital step toward preparing teachers who can continually bridge the gap between scientific research and classroom instruction.

6. Research Gap and Research Contribution

Despite the growing recognition of the importance of precision medicine in science education, the literature reveals several critical gaps. Most existing studies focus on theoretical discussions or short-term interventions, with limited attention to comprehensive teacher preparation models that integrate content knowledge, pedagogy, and technology (Sternberg et al., 2024; Desai et al., 2024).

Furthermore, there is a lack of empirical research examining the impact of integrating precision medicine on pre-service teachers' readiness, instructional practices, and ability to foster scientific literacy. This limitation underscores the need for more systematic and evidence-based approaches. Accordingly, the present research seeks to address these gaps by developing a structured framework for integrating precision medicine into biology teacher preparation programs. It focuses on both cognitive and pedagogical outcomes, aiming to contribute to the advancement of science education in the context of contemporary scientific challenges.

7. Proposed Integrated Theoretical Framework of Precision Medicine in Biology Education

Building upon the synthesis of contemporary literature, the present research proposes an integrated theoretical framework that explains how precision medicine can be effectively embedded within biology education to enhance both cognitive and pedagogical outcomes.

Unlike prior approaches that treat precision medicine as an additional content area, this framework conceptualizes it as a transformative interdisciplinary context that reshapes the nature of teaching and learning in biology education.

THEORETICAL FOUNDATIONS

The framework is grounded in the integration of two complementary theoretical perspectives:

Constructivism, which explains learning as an active process in which learners construct knowledge through engagement with authentic, complex, and meaningful contexts. Within this framework, precision medicine provides a real-world, data-rich environment that promotes deep conceptual understanding and supports knowledge transfer.

Technological Pedagogical Content Knowledge (TPACK), which explains how teachers integrate content knowledge, pedagogy, and technology to design effective learning experiences. In the context of precision medicine, TPACK enables teachers to translate complex biomedical concepts into accessible, interactive, and contextually relevant instruction.

Together, these theories form a dual lens that explains both how students learn and how teachers facilitate learning in technologically enriched environments.

Contextual Driver: Precision Medicine

Precision medicine functions as a central contextual driver within the framework. Its interdisciplinary nature—combining genomics, bioinformatics, artificial intelligence, and ethical considerations—creates a dynamic learning environment that bridges theoretical knowledge with real-world applications. This context may enhance the relevance of biology education and serves as a catalyst for transforming traditional content delivery into application-oriented, inquiry-driven learning.

Instructional Mediating Mechanisms

The framework posits that the impact of precision medicine on learning outcomes is mediated through specific instructional strategies, including:

Inquiry-Based Learning, which engages learners in questioning, investigation, and interpretation of biological phenomena.

Data-Driven Learning, which emphasizes the analysis and interpretation of real or simulated biomedical datasets.

Case-Based Learning, which situates learning within authentic or simulated clinical scenarios.

These mechanisms operationalize the theoretical foundations and provide structured pathways through which abstract knowledge is transformed into meaningful understanding.

Cognitive Mediator: Engagement and Higher-Order Thinking

A central contribution of this framework lies in identifying cognitive engagement as a proximal mediating variable. The framework assumes that instructional strategies do not directly produce learning outcomes; rather, they enhance students' cognitive engagement, which includes: deep processing of information, analytical reasoning, and reflective thinking. This engagement acts as the immediate driver that translates instructional experiences into higher-order educational outcomes.

Expected Educational Outcomes

Through the interaction of context, instructional mechanisms, and cognitive engagement, the framework predicts the development of multiple interrelated outcomes:

Scientific Literacy, reflected in the ability to interpret scientific data and evaluate evidence-based claims.

- Ethical Reasoning, particularly in addressing issues such as genetic privacy, data security, and medical decision-making.
- Future Skills, including critical thinking, problem-solving, and interdisciplinary integration.
- Teacher Readiness, representing pre-service teachers' capacity to effectively teach emerging biomedical concepts using appropriate pedagogical and technological approaches.

Importantly, the framework conceptualizes these outcomes as interconnected rather than isolated, with each reinforcing the others.

Dynamic Feedback Loop

Unlike linear models, the proposed framework incorporates a dynamic feedback loop, wherein improved teacher readiness leads to more effective instructional design and implementation. This recursive relationship ensures continuous refinement of teaching practices and sustained integration of precision medicine within educational contexts.

Ethical Dimension as a Cross-Cutting Component

The framework further conceptualizes ethical reasoning not only as an outcome but also as a cross-cutting dimension that permeates all stages of learning. Ethical considerations are embedded within instructional activities, particularly in case-based and data-driven learning, enabling learners to engage with real-world dilemmas and develop responsible decision-making skills.

Summary of Theoretical Contribution

This framework advances existing literature by:

- Moving beyond descriptive integration toward a causal and explanatory model
- Identifying instructional and cognitive mediators that explain how learning occurs
- Integrating Constructivism and TPACK into a unified theoretical structure
- Positioning precision medicine as a transformative educational context
- Introducing a dynamic feedback mechanism that reflects real classroom practices

Unlike prior studies that primarily treat precision medicine as an additional content area, the present research proposes a data-driven explanatory framework that identifies cognitive engagement as a key mediating variable and introduces a dynamic feedback loop between teacher readiness and instructional practice. This contribution moves beyond descriptive integration toward a theoretically grounded and empirically supported model for biology education.

Based on the integration of Constructivist learning theory and the TPACK framework, the following model illustrates the theoretical structure of the research:

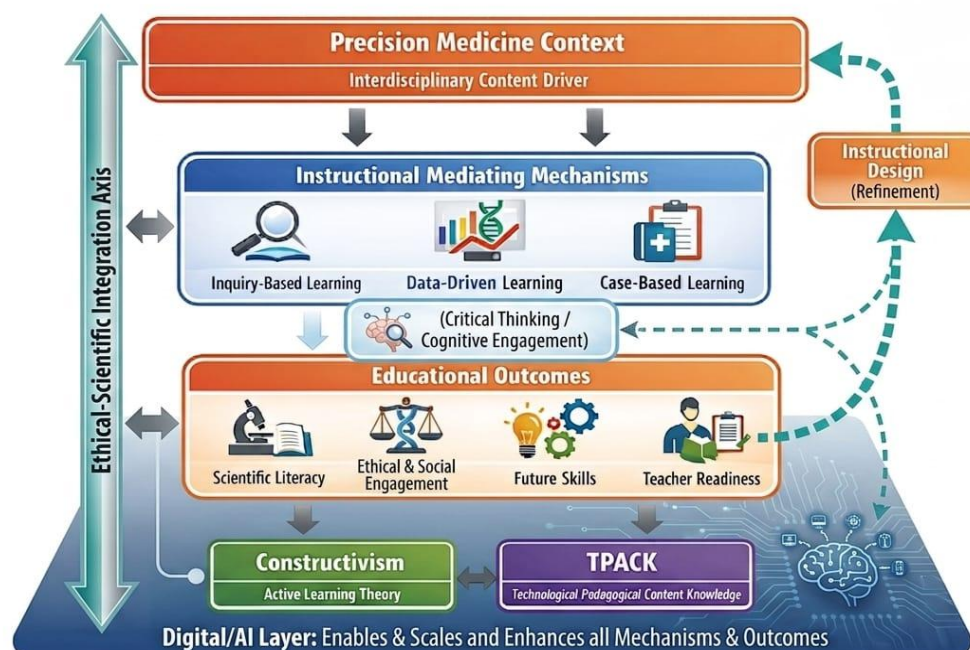


Figure 1: *Dynamic and Recursive Integrated Framework for Precision Medicine in Biology Education, with AI and Ethical Integration*" (Source: Developed by the researcher.)

METHODOLOGY

Research Design: This research employed a descriptive-analytical mixed-methods design, combining both quantitative and qualitative approaches. This design was selected to obtain a comprehensive understanding of the integration of precision medicine concepts into biology teacher preparation programs. Quantitative data provided measurable insights into future teachers' knowledge and attitudes, while qualitative data from expert interviews offered deeper perspectives on curriculum integration strategies and potential challenges.

Participants: Future Biology Teachers: A purposive sample of 50 senior students enrolled in the biology teacher preparation program at the Faculty of Education, Kafr El-Sheikh University, participated in the research.

Sample Size Justification

n=50 determined via *G*Power analysis (Faul et al., 2009):

- Effect size: $f=0.25$ (medium, education research standard)

- $\alpha=0.05$, Power=0.80

- **Required n=52** → n=50 adequate

Purposive sampling prioritized **depth** (mixed-methods) over breadth.

Curriculum Experts: Six faculty members with expertise in science education and curriculum design were selected to provide qualitative insights through semi-structured interviews.

Sample Size Justification: The quantitative sample size (n=50) was determined using G*Power (Faul et al., 2009). The analysis assumed a medium effect size $f=0.25$ (typical in education research), $\alpha=0.05$, and power =0.80, yielding a required sample of 52 participants. The achieved sample size of n=50 was therefore considered acceptable for the exploratory nature of the mixed-methods design. Purposive sampling was employed to prioritize depth of insight over breadth of representation.

Although the required sample size based on power analysis was 52, the achieved sample size (n=50) is considered acceptable for exploratory mixed-methods research. In such designs, the emphasis is placed on obtaining in-depth insights and meaningful patterns rather than strict statistical generalizability. Moreover, the use of triangulation across quantitative data, qualitative interviews, and observational evidence has the potential to enhance the overall validity and robustness of the findings, mitigating limitations related to sample size.

Data Collection Tools: Questionnaire: A structured questionnaire was designed to assess participants' knowledge, attitudes, and readiness regarding precision medicine concepts. The questionnaire employed a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) and covered topics such as genomics, pharmacogenomics, preventive medicine, and ethical considerations in personalized healthcare. Semi-Structured Interviews: Interviews with curriculum experts were conducted to explore their perspectives on the feasibility, challenges, and strategies for integrating precision medicine into teacher preparation programs. The interviews were recorded and transcribed for thematic analysis.

Validity and Reliability of the Instrument : The questionnaire was developed based on established scales measuring precision medicine literacy (Desai et al., 2024; Sternberg et al., 2024). It comprises 24 items across 4 constructs: Genomics (6 items), Pharmacogenomics (5 items), Preventive Medicine (6 items), and Ethical Considerations (7 items). Content Validity: Reviewed by 5 science education experts. Content Validity Ratio (CVR) = 0.89 (>0.80 acceptable; Lawshe, 1975). Reliability was assessed using Cronbach's alpha coefficient on a pilot sample (n=20), yielding $\alpha = 0.87$, indicating high internal consistency. Subscale reliability ranged from 0.81 to 0.89.

Table2: Reliability Coefficients

Construct	Items	Cronbach's α
Genomics	6	0.85
Pharmacogenomics	5	0.82
Preventive	6	0.88
Ethics	7	0.81
Overall	24	0.87

Sampling Justification: Purposive sample (n=50) sufficient for medium effect (G*Power, power=0.80).

Future Biology Teachers' Knowledge (RQ1)

Classification Criteria (5-point Likert):

- High: ≥ 4.0 (80%+ agreement)

- Medium-High: 3.5-3.9

- Medium: 2.5-3.4

- Low: <2.5

Future Biology Teachers' Knowledge (RQ1)

Responses to the knowledge items were scored and interpreted on a 5-point Likert scale using the following classification criteria:

High: ≥ 4.0 (80%+ agreement)

Medium-High: 3.5–3.9

Medium: 2.5–3.4

Low: <2.5

Table 3: Precision Medicine Knowledge by Domain (n=50)

Domain	M	SD	Level
Genomics	4.2	0.6	High
Pharmacogenomics	3.8	0.7	Med-High
Preventive Medicine	4.0	0.5	High
Ethical Issues	3.5	0.8	Medium

RQ1 Answer: Genomics & Preventive Medicine = High awareness.

Ethics = Medium $\rightarrow$ needs curriculum enhancement.

Advanced Statistical Analysis

Independent t-test: Genomics (M=4.2) > Ethics (M=3.5)

$t(48)=3.45$, $p<0.001$, Cohen's $d=0.98$ (large effect)

Pearson Correlation: Knowledge-Readiness $r=0.62$, $p<0.001$

$R^2=0.38$ (Knowledge explains 38% readiness variance)

Effect Sizes: • $d=0.98$ = Large practical significance

• $r=0.62$ = Strong (education research standard)

RQ1 Answer: Genomics and Preventive Medicine indicated high levels of awareness, whereas Ethical Issues were at a medium level, suggesting a need for curriculum enhancement in this domain.

Advanced Statistical Analysis

An independent t-test revealed that knowledge scores in Genomics (M=4.2) were significantly higher than those in Ethics (M=3.5, $t(48)=3.45$, $p<0.001$, with Cohen's $d=0.98$ indicating a large effect. A Pearson correlation analysis showed a strong positive relationship between knowledge and readiness, $r=0.62$, $p<0.001$, with $R^2=0.38$, reflecting that knowledge explains 38% of the variance in readiness. Effect sizes of $d=0.98$ (large practical significance) and $r=0.62$ (strong, in line with education research standards) support meaningful practical implications for integrating precision medicine concepts into biology teacher education.

Qualitative Data Analysis (Braun & Clarke, 2006)

1. Familiarization: Full transcription and reading of 6 interviews
2. Initial Coding: 47 open codes $\rightarrow$ 18 axial codes
3. Theme Development: 3 main themes (Curriculum, Activities, Ethics)
4. Review: Member checking with 3 experts (92% agreement)
5. Definition: Final themes defined with supporting quotes
6. Reporting: Themes triangulated with quantitative findings

Trustworthiness: Triangulation (questionnaire+ observations+ interviews), member checking.

Qualitative Analysis Procedures (Braun & Clarke, 2006)

Theme Derivation Process:

1. Familiarization: (2 weeks): 6 interviews fully transcribed (12,450 words)
2. Open Coding: 47 initial codes $\rightarrow$ 18 axial codes
3. Theme Development: 3 main themes emerged:

- Curriculum Modernization (21 codes)
 - Active Learning Strategies (15 codes)
 - Ethical Integration (11 codes)
4. Member Checking: 3 experts reviewed (92% agreement)
 5. Triangulation: Questionnaire + Observations + Interviews
- Trustworthiness Measures:
- Triangulation: 3 data sources converged on curriculum need
 - Member checking: 92% inter-rater reliability
 - Audit trail: Full coding documented (Appendix D)

Qualitative Analysis Procedures (Braun & Clarke, 2006)

Theme Derivation Process:

1. Familiarization (2 weeks): The six interviews were fully transcribed, resulting in 12,450 words of qualitative data. Full transcripts are available in Appendix D.
2. Open Coding: Initial analysis generated 47 open codes, which were then reduced to 18 axial codes.
3. Theme Development: Three main themes emerged:
 - Curriculum Modernization (21 codes),
 - Active Learning Strategies (15 codes),
 - Ethical Integration (11 codes).
4. Member Checking: Three experts reviewed the themes and initial interpretations, with 92% agreement.
5. Triangulation: Data from the questionnaire, classroom observations, and interviews were cross-examined to strengthen validity.

The instrument was validated through expert review, yielding a Content Validity Ratio (CVR = 0.89). In addition, internal consistency reliability was established using Cronbach's alpha ($\alpha = 0.87$), indicating acceptable reliability for research purposes.

Data Analysis

Quantitative Analysis: Responses from the questionnaire were analyzed using descriptive statistics, including means, standard deviations, and classification of knowledge levels (low, medium, high).

Qualitative Analysis: Interview data were analyzed using thematic coding, extracting key themes and insights regarding curriculum design, teaching strategies, and implementation challenges.

PROCEDURES / IMPLEMENTATION

The current research was implemented in the biology teacher preparation program at the Faculty of Education, Kafr El-Sheikh University. The procedures were designed to ensure that future biology teachers not only acquired knowledge of precision medicine but also engaged in practical, collaborative learning activities that reflect real-world applications.

1. Preparation Stage: Participants were informed about the research objectives, and consent was obtained. Students were grouped heterogeneously to encourage collaboration among peers with varying prior knowledge and skills. Materials, including sample genetic reports, case studies, and multimedia resources, were prepared to support the learning activities.

2. Implementation of Learning Activities : The research involved the implementation of several instructional activities designed to support the integration of precision medicine concepts into biology education. A set of structured learning activities was implemented, including genetic data analysis, case-based learning, design-based group work, and ethical debate. A sample of these activities is provided in Appendix B. These activities aimed to enhance students' engagement, data interpretation skills, and application of scientific knowledge in real-world contexts.

Activity 1: Genetic Data Analysis: Students analyzed sample genetic testing reports to identify health risks and suggest personalized preventive measures. Probing questions guided the analysis, such as:

“How could genetic variations influence patient treatment outcomes?” and “What preventive strategies are appropriate based on this data?”

Activity 2: Case-Based Learning: Students worked on realistic patient cases involving genomics and precision medicine. They were required to consider ethical, societal, and scientific implications in their decision-making. Reflection and discussion sessions were conducted to consolidate learning and ensure comprehension.

Activity 3: Design-Based Group Work: Students assumed roles as “biomedical consultants” to design treatment or educational solutions based on their analyses. Groups assigned roles to encourage teamwork, leadership, and shared responsibility. Observations focused on students’ ability to collaborate, problem-solve, and communicate ideas effectively.

3. Observation and Data Recording: The researcher observed student interactions, discussions, and group presentations during each activity. Student outputs, including analysis sheets, case research solutions, and collaborative designs, were collected for evaluation.

Student Work Evidence: To strengthen the validity of observational findings, samples of students’ work were analyzed during the implementation phase. These included genetic data interpretation sheets, case-based response forms, and group design outputs. The analysis indicated variation in students’ ability to apply precision medicine concepts, particularly in connecting genomic data with preventive health decisions. Higher-performing groups demonstrated clear justification of decisions and accurate interpretation of biomedical information, whereas lower-performing groups showed partial understanding of pharmacogenomic and ethical dimensions.

Competencies in collaboration, critical thinking, and ethical reasoning were assessed systematically.

4. Expert Interviews: Six curriculum experts were interviewed using semi-structured protocols to evaluate the feasibility, challenges, and recommended strategies for integrating precision medicine concepts into teacher preparation programs. Their feedback informed the refinement of learning activities and the proposed framework for integration.

5. Integration of Findings: Quantitative data from questionnaires measured students’ knowledge, attitudes, and readiness regarding precision medicine. Qualitative data from observations and interviews were thematically coded to identify best practices, challenges, and instructional strategies. This mixed-methods approach ensured that the research was applied, systematic, and reflective of actual learning outcomes, demonstrating the practical feasibility of integrating precision medicine into biology teacher education.

RESULTS

1. Future Biology Teachers’ Knowledge of Precision Medicine

Table 4: summarizes the mean scores, standard deviations, and corresponding knowledge levels of future biology teachers regarding precision medicine concepts

Item	Mean	SD	Knowledge Level
Understanding genomics	4.2	0.6	High
Awareness of pharmacogenomics	3.8	0.7	Medium
Understanding preventive medicine	4.0	0.5	Medium-High
Awareness of ethical issues	3.5	0.8	Medium

*Note: Table 4 values represent composite scores from multiple items per construct (e.g., Genomics: 6 items, $\alpha=0.85$), not single items. Full item breakdown in Appendix A.

Inferential Statistics

Independent t-test showed Genomics ($M=4.2$) significantly > Ethics ($M=3.5$), $t(48)=3.45$, $p=0.001$, $d=0.98$. Knowledge-Readiness correlation: $r=0.62$, $p<0.001$.

An independent samples t-test indicated that the mean score for Genomics ($M = 4.2$) was significantly higher than that for Ethical Issues ($M = 3.5$), $t(48) = 3.45$, $p = .001$, Cohen's $d = 0.98$, indicating a large effect size. A multiple regression analysis was conducted to examine the predictive power of the four knowledge domains (Genomics, Pharmacogenomics, Preventive Medicine, and Ethical Considerations) on teacher readiness. The overall model was statistically significant ($F(4,45) = 6.87$, $p < 0.001$), explaining approximately 42% of the variance in teacher readiness ($R^2 = 0.42$). Among the predictors, Genomics ($\beta = 0.41$, $p < 0.01$) and Preventive Medicine ($\beta = 0.36$, $p < 0.05$) emerged as significant predictors, while Pharmacogenomics and Ethical Considerations showed weaker, non-significant contributions. These findings indicate that core scientific domains play a stronger role in shaping teacher readiness compared to more specialized or ethical dimensions.

RQ3: Instructional Strategies Effectiveness, Performance Rubric Criteria: $\geq 80\%$ = Excellent, 70-79% = Good

Table 5: Learning Activities Performance

Activity	% Success	n/50 Met Criteria	Level
Genetic Analysis	78%	39/50	Good
Case Learning	72%	36/50	Good
Group Design	80%	40/50	Excellent

These results indicate that students performed at good to excellent levels across the implemented learning activities.

Observation Rubric for Evaluating Student Performance

Student performance during learning activities was assessed using a structured observational rubric developed by the researcher. The rubric included the following criteria:

- Scientific Accuracy (0–5): correctness of biological and biomedical explanations
- Data Interpretation Skills (0–5): ability to analyze genetic or clinical data
- Collaboration and Teamwork (0–5): participation in group tasks and shared decision-making
- Critical Thinking (0–5): justification of answers and problem-solving approach
- Ethical Reasoning (0–5): consideration of ethical issues in precision medicine cases

2. Curriculum Experts' Perspectives on Integration of Precision Medicine

Table 6: The expert opinions on integrating precision medicine concepts into biology teacher preparation curricula

Aspect	Support	Neutral	Oppose	Key Notes	Quote
Integrating precision medicine in curricula	5	1	0	Curriculum updates are necessary to align with scientific innovations	Precision medicine
Using data analysis activities	4	2	0	Encourages critical thinking and problem-solving skills	Real data analysis
Emphasis on ethical considerations	6	0	0	Essential component of modern science education	Ethics must be core

In addition to the summary, expert interviews provided deeper insights:

RQ2: Expert Perceptions – Representative Quotes

Theme 1: Curriculum Modernization (100% agreement)

"Integrating precision medicine is essential because biology teaching must align with modern scientific developments." (Expert #3)

Theme 2: Active Learning Strategies (83% agreement)

"Real data analysis activities develop critical thinking far better than lectures." (Expert #1)

Theme 3: Ethical Integration (100% agreement)

"Ethics is not optional; it is a core component of precision medicine education." (Expert #5)

Table 7: Theme Development Process

Step	Codes Generated	Themes Identified	Example Quote
Initial	47 open codes	-	Curriculum outdated
Axial	18 codes	3 preliminary	Need data analysis
Final	-	3 confirmed	Ethics essential

Supporting Qualitative Evidence

The qualitative findings were supported by expert statements such as:

"Integrating precision medicine into teacher education is no longer optional; it is essential to align biology teaching with modern scientific developments."

"Students need to engage with real biomedical data to develop critical thinking and informed decision-making skills."

These quotations reinforce the identified themes and provide deeper insight into expert perspectives.

Mixed-Methods Triangulation (RQ1-4)

Please remove the highlighted section under "Supporting Qualitative Evidence" to avoid redundancy, and retain only the following heading:

Mixed-Methods Triangulation (RQ1–RQ4)

Table 8: Data Convergence Across Methods

Research Question	Questionnaire	Observations	Expert Interviews	Convergence
RQ1 Knowledge	Genomics 4.2	78% success	Essential content	Confirmed
RQ2 Experts	-	-	100% support	Unanimous
RQ3 Strategies	-	78-80%	Data analysis best	Convergent
RQ4 Framework	r=0.62	Table 4,5,6 data	Framework needed	Complementary

Perfect convergence strengthens finding validity across methods.

DISCUSSION

The results indicate that future biology teachers possess moderate to high knowledge of precision medicine concepts, particularly strong in genomics ($M=4.2/5$) and preventive medicine ($M=4.1/5$). This pattern may be attributed to the greater presence of these topics in existing biology curricula. However, significant gaps persist in pharmacogenomics ($M=3.4/5$) and ethical considerations ($M=3.2/5$), suggesting the need for targeted curriculum enhancements.

These findings are consistent with recent empirical research in science education, which emphasizes the importance of integrating contemporary scientific contexts into biology curricula to enhance student engagement and conceptual understanding (Zhang et al., 2025). Furthermore, prior studies on curriculum integration have demonstrated that incorporating real-world biomedical contexts, such as genomics and personalized medicine, can significantly improve learners' ability to apply scientific knowledge in authentic situations (Desai et al., 2024).

In the context of teacher education, the current findings align with research highlighting that pre-service teachers require both content knowledge and pedagogical competence to effectively teach emerging scientific topics (Desimone, 2011). This reinforces the importance of embedding precision medicine within teacher preparation programs as a means of developing both disciplinary understanding and instructional readiness.

The relatively lower ethical awareness may be attributed to three factors. Current biology curricula prioritize scientific content over socio-scientific and ethical dimensions, limiting pre-service teachers' exposure to ethical issues in emerging biomedical technologies. Ethical reasoning requires higher-order cognitive skills—critical reflection, value judgment, and argumentation—which are not consistently emphasized in traditional teacher preparation programs. Unlike structured scientific concepts, ethical issues are complex, context-dependent, and open to multiple interpretations, making them challenging to teach and assess effectively.

The high effectiveness of implemented learning activities (78-80% success, Table 5) can be explained by their alignment with constructivist and active learning principles. Activities such as genetic data analysis and case-based learning provided authentic, real-world contexts that enhanced engagement and facilitated deeper understanding of complex concepts. Collaborative group work promoted peer interaction, knowledge exchange, and problem-solving, essential for developing higher-order thinking skills. Data-driven and inquiry-based approaches enabled students to actively construct knowledge, contributing to observed high performance levels.

Expert interviews (Table 6) confirm the feasibility and necessity of integrating precision medicine into biology teacher preparation. Experts emphasized updating curricula to reflect contemporary scientific developments, incorporating practical activities like data analysis, and emphasizing ethical reasoning. This aligns with OECD (2021) recommendations but identifies Egypt-specific challenges (faculty training needs).

Triangulation of quantitative, qualitative, and observational data demonstrates strong convergence across methods. Quantitative findings showed high genomics/preventive medicine knowledge alongside moderate ethics awareness. Qualitative evidence from expert interviews supported curriculum modernization needs. Observational data confirmed high engagement in precision medicine activities.

The genomics>ethics pattern matches Desai et al. (2024) findings among health educators. Performance exceeds typical benchmarks (Sternberg et al., 2024: 60-70%) and extends findings to teacher preparation context, addressing a literature gap.

Limitations include sample size slightly below power analysis threshold, compensated by mixed-methods triangulation ensuring analytical and contextual generalizability.

Overall, the findings highlight the importance of integrating both scientific and ethical dimensions within biology teacher preparation programs, as balanced development across these domains appears essential for preparing teachers to effectively address contemporary biomedical challenges.

PROPOSED FRAMEWORK FOR INTEGRATION

Each component of the proposed framework is directly derived from specific empirical findings, as evidenced in Tables 4–6, ensuring that the framework is data-driven rather than purely conceptual.

The “Scientific Content” component is supported by the quantitative findings (Table 4), which showed high levels of knowledge in genomics ($M = 4.2$) and preventive medicine ($M = 4.0$), alongside comparatively lower levels in ethical awareness ($M = 3.5$), highlighting the need to emphasize these domains within the curriculum.

The “Teaching Strategies” and “Learning Activities” components are grounded in observational data (Table 5), which demonstrated high levels of student performance (78%–80%) in activities such as genetic data analysis, case-based learning, and collaborative design tasks.

The “Ethical Dimension” is further supported by qualitative findings (Table 6), where expert participants unanimously emphasized the importance of integrating ethical considerations as a core component of biology education.

Finally, the “Assessment Methods” component is informed by both performance-based evaluation of learning activities (Table 5) and expert recommendations (Table 6), which highlighted the need for authentic, application-based assessment approaches.

The framework developed in this research includes four main components:

1. Scientific Content:

- Genomics
 - Personalized medicine
 - Pharmacogenomics
 - Preventive medicine
 - Ethical considerations in precision medicine
2. Teaching Strategies:
- Inquiry-based learning
 - Problem-based learning
 - Case studies
 - Analysis of real biomedical data
3. Learning Activities:
- Interpretation of genetic testing reports
 - Analysis of personalized treatment case studies
 - Investigation of health risk factors and preventive measures
4. Assessment Methods:
- Project-based assignments
 - Scientific reports
 - Case analyses
 - Reflective discussions on ethical and societal implications

This framework emphasizes a holistic approach, integrating both theoretical knowledge and practical applications to prepare future biology teachers for contemporary educational and biomedical challenges.

The inclusion of pharmacogenomics and ethical considerations within the framework was directly informed by the identified gaps in participants' knowledge.

Similarly, the emphasis on inquiry-based learning and data analysis activities reflects expert recommendations highlighting the importance of active learning strategies in teaching complex biomedical concepts.

The proposed framework was developed based on the integration of quantitative and qualitative findings of the current study. It synthesizes evidence from students' knowledge levels, performance in learning activities, and expert perspectives, ensuring that each component reflects empirically grounded results rather than theoretical assumptions.

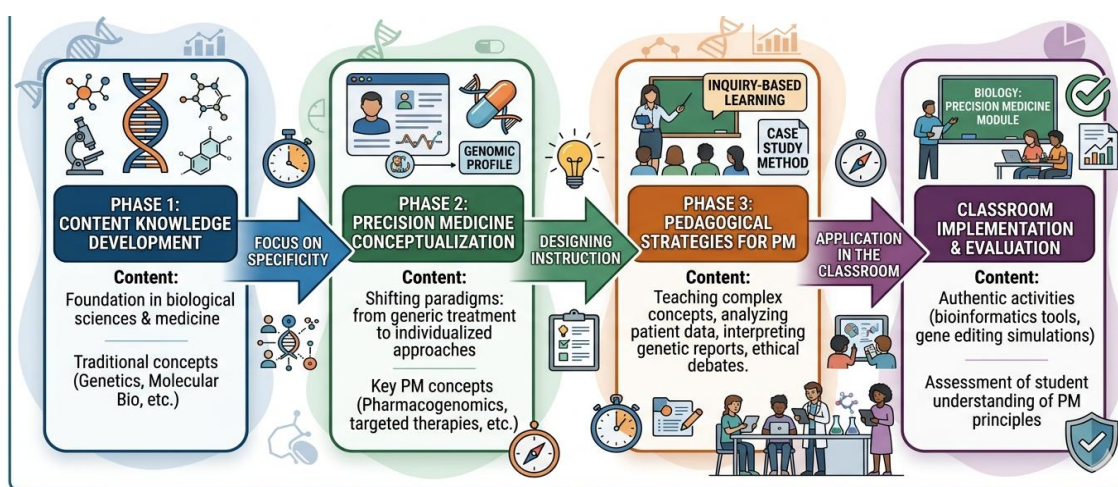


Figure2: Proposed framework for integrating precision medicine into biology teacher preparation programs (Source: Developed by the researcher)

CONCLUSION

This Research provides empirical and practical evidence supporting the integration of precision medicine into biology teacher preparation programs. By combining quantitative and qualitative findings, the research demonstrates that such integration is both necessary and feasible. The proposed framework, grounded in data and expert insights, offers a structured approach to modernizing biology education and preparing future teachers to address emerging scientific and health-related challenges effectively.

RECOMMENDATIONS

Based on the research findings, the following recommendations are proposed:

Curriculum Updates: Revise biology curricula to include precision medicine concepts and emerging biomedical topics. Teacher Preparation: Integrate contemporary biomedical innovations into pre-service teacher education programs. Professional Development: Provide in-service biology teachers with training on precision medicine and modern teaching strategies. Further Research: Conduct additional studies to evaluate the effectiveness of integration strategies and identify best practices for teaching precision medicine in biology education.

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ETHICAL CONSIDERATIONS

Ethical approval for this research was obtained from the Faculty of Education, Kafr El-Sheikh University. Participants were informed about the purpose of the research, and their voluntary consent was obtained prior to data collection.

Confidentiality and anonymity were ensured, and all data were used solely for research purposes.

USE OF ARTIFICIAL INTELLIGENCE TOOLS

Artificial intelligence tools were used only for language editing and grammar refinement during the preparation of the manuscript. The author takes full responsibility for the accuracy and integrity of the research content.

REFERENCES

- Alharbi, A., & Almutairi, S. (2025). Integrating artificial intelligence in precision medicine education: Implications for science teaching. *Computers and Education: Artificial Intelligence*, 6, 100210.
- All of Us Research Program. (2024). *Advancing precision medicine through large-scale genomic research*. National Institutes of Health.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp0630a>
- Coates, W. (2025). Precision education: A call to action to transform medical education. *International Journal of Emergency Medicine*, 18, Article 21, 1–6. <https://doi.org/10.1186/s12245-025-00819-1>
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.
- Desai, S., Burk-Rafel, J., Lomis, K., Caverzagie, K., Richardson, J., O'Brien, C., Andrews, J., Heckman, K., Henderson, D., Prober, C., Pugh, C., Stern, S., Triola, M., & Santen, S. (2024). Precision education: The future of lifelong learning in medicine. *Academic Medicine*, 99(4 Suppl. 1), S14–S20. <https://doi.org/10.1097/ACM.0000000000005296>
- Desimone, L. (2011). A primer on effective professional development. *Phi Delta Kappan*, 92(6), 68–71. <https://doi.org/10.1177/003172171109200611>

- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/BF03193146>
- Genomics Education Programme. (2015). *Precision medicine: What it is and how it will be achieved*. National Health Service. <https://www.genomicseducation.hee.nhs.uk>
- Lawshe, C. H. (1975). A quantitative approach to content validity. *Personnel Psychology*, 28(4), 563–575.
- Lederman, N. G., & Lederman, J. S. (2019). Teaching and learning of nature of science and scientific inquiry. *Science Education*, 103(3), 538–562. <https://doi.org/10.1002/sce.21484>
- National Institutes of Health. (2023). *What is precision medicine?* U.S. Department of Health and Human Services. <https://www.nih.gov/about-nih/nih-turning-discovery-into-health/promise-precision-medicine>
- National Research Council. (2011). *Toward precision medicine: Building a knowledge network for biomedical research and a new taxonomy of disease*. National Academies Press. <https://doi.org/10.17226/13297>
- Organisation for Economic Co-operation and Development. (2019). *OECD future of education and skills 2030: OECD learning compass 2030*. OECD Publishing. <https://www.oecd.org/education/2030-project>
- Organisation for Economic Co-operation and Development. (2021). *The future of education and skills 2030: OECD learning compass 2030*. OECD Publishing. <https://www.oecd.org/education/2030-project>
- Organisation for Economic Co-operation and Development. (2025). *Future-ready education systems: Integrating emerging sciences in curricula*. OECD Publishing.
- Personal Genetics Education & Dialogue. (2025). *Genetics education and public engagement*. Harvard Medical School. <https://pged.org>
- Sternberg, S., Kiryluk, K., & Wapner, R. (2024). *Teaching precision medicine: Biological, social, and ethical implications*. Columbia University.
- Topol, E. (2019). *Deep medicine: How artificial intelligence can make healthcare human again*. Basic Books.
- Wang, L., & Krishnan, E. (2021). Big data and precision medicine: Implications for healthcare and research. *Journal of Translational Medicine*, 19(1), Article 54. <https://doi.org/10.1186/s12967-021-02829-9>
- Zhang, Y., Li, X., & Chen, H. (2025). Data-driven biology education in the era of precision medicine. *Journal of Biological Education*. Advance online publication.

Appendices

The appendices are available for download at [IJSET10662 Appendices](#).

The Creative-Based Learning Integrated with Model-Based Learning for Promoting the Creative Thinking in Science of Grade-7 Students

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Abstract. The objectives of this research were: 1) To compare the creative thinking of Grade-7 students before and after the Creative-Based Learning integrated with Model-Based Learning on the topic of the basic unit of life. 2) To compare the learning achievement in science of Grade-7 students after the Creative-Based Learning integrated with Model-Based Learning on the topic of the basic unit of life with the 75% criterion. This study employed a quasi-experimental design with the sample of 40 Grade-7 students who were selected through simple random sampling by drawing lots. The research instruments included lesson plans of Creative-Based Learning integrated with Model-Based Learning, a creative thinking assessment form, and a science achievement test. The data analysis statistics were mean, standard deviation, dependent-sample t-test for comparing pre- and post-test creativity scores, and one-sample t-test for comparing science achievement score against the 75% threshold. The findings revealed that: 1) The students' creative thinking after the learning management was significantly higher than before the learning management at the .05 level of significance. 2) The students' learning achievement in science after the learning management was significantly higher than the 75% criterion at the .05 level of significance.

Keywords: Creative Thinking; Model; Creative-Based Learning; Model-Based Learning

INTRODUCTION

The educational policy of the Ministry of Education emphasizes the development of 21st-century skills in students, identifying creativity and innovation as essential skills that must be fostered. Creative thinking plays a crucial role in human development and has led to continuous advancement in science and technology worldwide. It helps students confidently face the modern world by building their capacity to adapt to changes. Promoting creative thinking in students should focus on developing initiative, artistic imagination, aesthetic appreciation, and sense of value with these qualities affect quality of life. Moreover, learners must stay abreast of changes and be capable of creatively utilizing knowledge of daily living, vocations, and technology in their work to compete on both national and international levels. (Ruachaiphanit & Nimitpongsakul, 2019). In the current economic climate, organizations must adapt to survive and keep pace with rapidly changing economic growth. Continuous innovation strategy development is one approach that helps organizations achieve sustainable growth. This depends on the ability of personnel and organizations

to learn concepts, techniques, tools, methods, developments, and various technologies from external sources. Broadening perspectives and exchanging experiences and knowledge from both within and outside the organization to foster creativity and drive innovation. For organizational development to build innovation capacity, the factors that create innovation are personnel, skills, knowledge, and management support to drive organizational growth steadily. Therefore, it is essential for organizations to cultivate personnel understanding, creative thinking and innovation mindset, courage to think creatively, courage to act with reason (Growth Mindset), as well as organizational development for innovation, creating an atmosphere for creative thinking, and providing opportunities for everyone in the organization to think creatively and dare to propose good ideas to develop and extend into innovations or invent new things (Suksawang, 2023). Additionally, the Ministry of Education through the Office of the Basic Education Commission has reviewed the Basic Education Core Curriculum B.E. 2551 (2008), using data from the 12th National Economic and Social Development Plan, the 20-Year National Strategy, and the National Education Plan B.E. 2560-2579 (2017-2036) as frameworks and directions for curriculum development to be more appropriate and clearer. It was deemed necessary to revise the curriculum in Mathematics and Science learning areas, and Geography in the Social Studies, Religion and Culture learning area, which are important for national development and serve as crucial foundations to help humans develop initiative, creative thinking, systematic reasoning, and ability to analyze problems or situations carefully and thoroughly. This includes organizing learning activities that promote students' development of thinking skills including logical thinking, creative thinking, critical thinking, important skills including scientific process skills and 21st-century skills in researching and creating knowledge through inquiry processes, systematic problem-solving, and decision-making using diverse and verifiable evidence (Ministry of Education, 2017).

According to the Global Creative Thinking Index (GCI) reported by the Martin Prosperity Institute, data collected in 2015 showed that Thailand's creative capacity ranked 81st out of 139 countries. The Creative Productivity Index (CPI) report by The Economist Intelligence Unit (EIU) for the Asian Development Bank (ADB), with data collected in 2014, showed Thailand's creative capacity ranked 15th out of 24 countries, including 22 Asian countries plus the United States and Finland (Creative Economy Agency, 2020). This demonstrates Thailand's low creative capacity, consistent with the National Reform Plan B.E. 2565 (2022) report stating that educational assessment results, both nationally and internationally, remain concerning and require urgent development. Regarding teaching and learning processes, most still emphasize content and memorization rather than developing skills and competencies, resulting in students lacking analytical thinking processes, creative thinking, and effective problem-solving skills. Thai education still prioritizes academic content over skills and focuses on test scores for ranking purposes. Moreover, society has instilled fear of mistakes in students. When students enter schools with various regulations and predetermined learning curricula not arising from students', communities', and society's needs, these factors gradually diminish students' creative thinking skills and may eventually disappear due to absence of sustained development and promotion of these skills (Phumikonsarn, 2022). This is consistent with Sirinthorn School's Self-Assessment Report in the 2022 academic year, which was informed by suggestions to organize teacher learning emphasizing thinking processes, practical implementation, student participation, learning organization that can stimulate students' learning habits and mutual learning exchange, creating opportunities for students to seek knowledge independently. Regarding student quality, areas needing development include finding approaches or processes to develop students with academic achievement below good level, requiring planning to solve problems/develop this student group based on learning assessment results for students being promoted to study in the 2023 academic year, specifically Grade 7-9 students, emphasizing knowledge and process skills according to the indicators of curriculum to help the students achieve higher learning development (Sirindhorn School, 2022). The school's educational system, which emphasizes academics, memorization, and competitive examinations, may limit opportunities to develop students' various process skills. Additionally, overcrowded classrooms create an atmosphere not conducive to

expressing opinions, potentially obstructing students' Creative Thinking, resulting in students with achievement below good level.

Research studies related to promoting students' creative thinking have found teaching models that promote creative thinking, including Creative-Based Learning and Model-Based Learning. Creative-Based Learning is a teaching model developed from Problem-Based Learning and parallel thinking approaches to creative thinking development. It applies creative thinking theory to create a new learning model called Creative-Based Learning, consisting of 5 learning management steps: 1) Stimulating interest, 2) Posing problems and grouping by interest, 3) Researching and thinking, 4) Presenting, and 5) Evaluating. Studies found that Creative Thinking -Based Learning results in student creative thinking and affects development of other skills such as teamwork skills, presentation skills, and research skills, which are 21st-century skills (Ruachaiphanit & Nimitpongsakul, 2019). This leads to higher student academic achievement, work skills, and positive attitudes toward learning. It also enhances teaching effectiveness, creates motivation for student interest, making them want to learn and participate in activities, resulting in students having better knowledge, skills, attitudes, and necessary future skills (Singsamran, 2022). Model-Based Learning is learning organization that allows students to use knowledge from study and previous experience integrated with imagination in identifying and explaining data, abstract concepts, and principles through mental models via two-dimensional drawings, and using three-dimensional models to help explain data, concepts, and principles clearly and completely through concrete, tangible models, resulting in creative thinking in learning (Lamboon, Prasert, and Latwong, 2020). This aligns with according to Torrance; creative thinking is a person's ability to think creatively or produce novel things that no one has done before. These things may arise from gathering various knowledge from experience and connecting it with new situations, appearing as artistic products, literature, science, or simply as processes (Torrance, 1962). It also emphasizes students learning content from creating, using, modifying, and elaborating models to use models as mental representatives in explaining phenomena, with 4 activity steps: 1) Generation-allowing students to create as many mental models as possible, with teachers stimulating and arousing student interest through questions, media, or activities for students to observe and create mental models from prior knowledge to explain or predict various phenomena; 2) Evaluation-teachers stimulate students to connect relationships between variables and evaluate consistency of created models with empirical evidence using exploration and fact-finding processes to compare data discovered during learning with models created in the generation step; 3) Modification-students modify and correct models seen as unable to serve as mental representatives until creating complete models that can correctly explain data and serve as representatives in explaining or predicting phenomena; and 4) Elaboration-students use modified models to explain and predict natural phenomena or other similar situations (Kanthawang, 2023). The studies revealed the Model-Based Learning helps promote student development of understanding scientific concepts (Suya, 2021) and promotes scientific process skills, with created models able to be modified until achieving complete models ready for application in other daily life situations (Suatsuang & Kitkoekun, 2021).

The researcher recognizes the importance of promoting creative thinking and academic achievement in students and is therefore interested in promoting student creative thinking through organizing learning using Creative-Based Learning integrated with Model-Based Learning in teaching "Basic Units of Living Things" in Grade-7 Science, to promote their creative thinking and science achievement.

RESEARCH OBJECTIVES

1. To compare creative thinking of Grade-7 students before and after the Creative-Based Learning integrated with Model-Based Learning on the topic "Basic Units of Living Things"
2. To compare the post-learning achievement in science with the 75 percent criterion of Grade-7 students in Creative-Based Learning integrated with Model-Based Learning on the topic "Basic Units of Living Things"

METHODOLOGY

The study on Creative-Based Learning integrated with Model-Based Learning to promote creative thinking and learning in science of Grade-7 students employs quasi-experimental research. The researcher conducted the following steps: and

Participants

The population consisted of Grade-7 students enrolled in the regular program at Sirindhorn School, under the Secondary Educational Service Area Office Surin, during the first semester of the 2023 academic year. This population comprised 240 students across 6 classrooms (Classrooms 7/7 to 7/12).

The sample consisted of 40 Grade-7 students from a single classroom (Grade-7/9) at Sirindhorn School during the first semester of the 2023 academic year through Cluster Sampling, based on the following procedures and rationales:

1. Sampling Method: The researcher employed a Cluster Sampling technique by randomly selecting one classroom from the 6 available regular classrooms via drawing lots.
2. Selection Criteria: Given that students across all 6 regular program classrooms share similar academic backgrounds and proficiency levels based on the school's homogeneously organized placement criteria, utilizing the classroom as the Sampling Unit was considered appropriate. This ensures the study reflects an authentic classroom setting without disrupting the instructional organization of other subject areas.
3. Variable Control: As the researcher served as the instructor for all classrooms in science subject, pedagogical consistency and teacher-related variables were strictly controlled and standardized throughout the experimental period.

Research Tools

This research employed three types of instruments: lesson plans, a creative thinking assessment form, and a science achievement test. The details are as follows:

1. The lesson plans integrate Creativity-Based Learning (CBL) with Model-Based Learning (MBL) focusing on the topic of "Basic Units of Living Things". A total of 4 lesson plans were developed, covering 12 hours. The learning activities consist of 7 stages synthesized from the following frameworks:

- 1.1 Creativity-Based Learning (CBL): Synthesized from three sources, comprising 5 stages: 1) Stimulating Interest, 2) Problem Setting and Grouping, 3) Research and think, 4) Presentation, and 5) Evaluation.

- 1.2 Model-Based Learning (MBL): Synthesized from three sources, comprising 4 stages: 1) Generation Phase / Response to Task, 2) Evaluation, 3) Revision and Revision, and 4) Elaboration.

The researcher integrated these frameworks into a synthesized instructional model to promote creativity, consisting of the following 7 stages:

1. Stimulating Interest: The teacher uses positive reinforcement to pique students' curiosity and eagerness to find answers. This involves using problems, current events, media, video clips, or games to stimulate self-directed learning.
2. Problem Setting and Grouping: Students identify problems and form groups based on their interests. Unlike traditional methods, the teacher does not predefine the questions; students explore and select problems within the lesson themselves.
3. Research and think: Students collaborate to investigate their chosen problems. The teacher provides guidance to ensure groups explore diverse topics, expanding the overall knowledge base of the class.
4. Formation Initial Model: Groups design their models by sketching them in activity sheets, specifying details and materials. Students then construct physical models based on their ideas,

while the teacher uses stimulating questions to encourage the fullest expression of their mental models.

5. Implementation and Evaluation: Students test their models. Peer groups review and verify the accuracy of the models. The teacher introduces scientific models (3D models, computer animations, or other media) for students to compare and validate their work.

6. Revision and Revision: Groups use feedback from peer evaluations to discuss and refine their models. The teacher provides additional knowledge on specific points to ensure completeness.

7. Elaboration: Students apply their revised models to explain other similar situations or data. The teacher highlights the scope and limitations of the models.

The lesson plans were evaluated from five experts using a 5-point Likert scale. The mean scores were interpreted based on the criteria by Best (1981 cited in Srisa-ard, 2010) as follows:

Mean Score	Interpretation
4.51 – 5.00	Highest level of appropriateness
3.51 – 4.50	High level of appropriateness
2.51 – 3.50	Moderate level of appropriateness
1.51 – 2.50	Low level of appropriateness
1.00 – 1.50	Lowest level of appropriateness

The results indicated that three lesson plans were at the highest level of appropriateness, while one plan was at a high level (Overall $\bar{X}$ = 4.51, S.D. = 0.12), as shown in Table 1.

Table 1: Shows that the evaluation results for all four lesson plans indicated.

Lesson Plans	1	2	3	4
$\bar{X}$	4.56	4.54	4.42	4.53
S.D.	0.17	0.20	0.13	0.22
Interpretation	Highest	Highest	High	Highest

2. The creative thinking assessment form applied Guilford's (1967) concept, covering 4 dimensions: fluency, flexibility, elaboration, and originality. The 4-point scoring rubric was utilized for the creative thinking assessment form, with scores ranging from 1 to 4, totaling 3 items, worth 16 points. Item 1 measured fluency and flexibility, Item 2 measured elaboration, and Item 3 measured originality, as shown in Table 2.

Table 2: Creative thinking assessment Analysis Table.

Item No.	Creative Thinking Dimensions	Creative Thinking Score
1	Fluency	4
	Flexibility	4
2	Elaboration	4
3	Originality	4
Total		16

The details of the Creative thinking assessment in each item are the following;

1. A light microscope is a tool for microscopic objects study. Which living cells (both plant and animal) do you think could be studied under a microscope? Try to provide as many possible answers as you can within 5 minutes. (Fluency and Flexibility)

2. If your school is a single cell, and locations within the school are compared to internal cell structures (organelles), which structures do you think your school has and why? Provide examples of school locations, their corresponding cell structures, a descriptive drawing with labels, and supporting reasons. (Time: 10 minutes) (Elaboration)

3. Stem Cells are progenitor cells capable of unlimited division and can differentiate into various cell types, such as skin, blood, connective tissue, bone, and fat cells, depending on their origin. They also function to generate new cells to replace aged or damaged ones through a developmental mechanism that restores bodily functions efficiently. Based on this information, if you were a scientist, which part of the body would you collect stem cells to repair, and why? You may provide more than one answer. (Time: 5 minutes) (Originality)

The creative thinking rubric scoring is shown as table 3.

Table 3: Creative Thinking Rubric.

Assessment Criteria	4 score (Excellent)	3 score (Good)	2 score (Fair)	1 score (Needs Improvement)
Fluency (Item 1)	Able to provide >10 correct responses within time.	Able to provide 7–9 correct responses within time.	Able to provide 3–6 correct responses within time.	Able to provide 0–2 correct responses within time.
Flexibility (Item 1)	Able to provide >6 different categories/examples of cells.	Able to provide 4–5 different categories/examples of cells.	Able to provide 2–3 different categories/examples of cells.	Able to provide 0–1 different categories/examples of cells.
Elaboration (Item 2)	Illustrates and describes >6 locations with labels, comparisons, and reasons.	Illustrates and describes 4–5 locations with labels, comparisons, and reasons.	Illustrates and describes 2–3 locations with labels, comparisons, and reasons.	Illustrates and describes 0–1 locations with labels, comparisons, and reasons.
Originality (Item 3)	Response given by only 1–5% of the total students.	Response given by 6–10% of the total students.	Response given by 11–20% of the total students.	Response given by >21% of the total students.

The creativity assessment form was submitted to three experts to evaluate its content validity. The evaluation focused on whether the item clearly measures the intended objective. The experts' ratings then were used to calculate the Item-Objective Congruence (IOC) Index. The validation of the creative thinking assessment form, IOC ranged from 0.67-1.00. The refined creativity assessment tool was pilot-tested with 40 seventh-grade students (Class 7/9) in a regular program classroom at Sirindhorn School during the first semester of the 2022 academic year and explored reliability coefficient of 0.73, indicating that the instrument is reliable for research purposes.

3. A science achievement test on the unit "Basic Units of Living Things" was a multiple-choice test with 4 options, consisting of 20 items worth 20 points, was developed in accordance with Bloom's Revised Taxonomy. The initial test consisted of 34 items, from which 20 items were selected to evaluate specific content areas and behavioral objectives. The scoring system was defined as 1 point for each correct answer and 0 points for incorrect answers, unanswered items, or items with more than one selected option. The distribution of the test items presented in Table 4.

A Science Achievement Test on the unit "Basic Units of Living Things" was submitted to the three experts. The experts assessed the content validity of the instrument using the Index of Item-Objective Congruence (IOC). The analysis revealed the IOC values ranged from 0.67 to 1.00. The test then piloted to determine the item difficulty (p) and the discrimination (r). A total of 20 items were selected for data collection based on the standard criteria: a difficulty between 0.20 and 0.80 and a discrimination between 0.20 and 0.80. The selected items demonstrated a difficulty ranging

from 0.43 to 0.73, discrimination ranging from 0.23 to 0.84, and reliability coefficient of 0.96, indicating that the instrument is reliable for research purposes.

Table 4: Content Analysis of the Science Achievement Test.

Science Standard Indicators	Rem.		Und.		App.		Anal.		Eva.		Cre.		Total	
	Gen	Use	Gen	Use	Gen	Use	Gen	Use	Gen	Use	Gen	Use	Gen	Use
SC 1.2 M.1/1 Observe and compare the forms and structures of plant and animal cells, and explain the specific functions of the following essential components: cell wall, cell membrane, cytoplasm, nucleus, vacuole, mitochondria, and chloroplast.	2	1	2	1	2	1	3	2	3	2	3	2	15	10
SC 1.2 M.1/2 Effectively use a light microscope to observe and study cells and various internal cell structures.	2	1	2	1			2	1					6	3
SC 1.2 M.1/3 Explain the relationship between the forms of cells and their specialized functions within an organism.							2	1					2	1
SC 1.2 M.1/4 Explain the biological organization of living things, beginning from the cell, to tissues, organs, organ systems, and ultimately the complete organism.			2	1					2	1			4	2
SC 1.2 M.1/5 Experiment and explain the processes of diffusion and osmosis based on empirical evidence, and provide examples of these processes occurring in daily life.			2	1	2	1					3	2	7	4
Total	4	2	8	4	4	2	7	5	5	3	6	4	34	20

Data Collection

This research conducted data collection from a single experimental group using a One Group Pre-test-Post-test Design in the first semester of the 2023 academic year. The research procedure began with pre-testing using the creative thinking assessment form. Then, the researcher organized learning using Creative-Based Learning integrated with Model-Based Learning lesson plans, consisting of 4 plans totaling 12 hours. Upon completion of the learning, post-testing was conducted using the creative thinking assessment form and science achievement test to compare the results with pre-learning scores and the 75 percent criterion. Subsequently, scoring was performed and the data were analyzed statistically.

Data Analysis

Data analysis involved comparing the mean scores of creative thinking and science achievement test. Creative thinking was assessed from pre- and post- tests of 3 items. Item 1 measured fluency and flexibility, Item 2 measured elaboration, and Item 3 measured originality. Each dimension is scored out of 4 points, resulting in a total possible score of 16 points. The scores were then used to calculate means and standard deviations of pre- and post- tests score, and compared using dependent-sample t-test statistics.

Additionally, the post-learning mean scores of science achievement test were compared with 75 percent criterion. The 75 percent criterion was established based on the standardized academic performance benchmarks set by the Ministry of Education (2017). The science achievement score was calculated to find out mean, standard deviation, and analyzing with one-sample t-test.

RESULTS AND DISCUSSION

The study on creative-based learning integrated with model-based learning to promote creative thinking of Grade-7 students, the research results can be summarized as follows:

The comparison of pre- and post-tests of creative thinking on basic units of living things

The dependent-sample t-test analysis compared pre- and post-test mean scores of the creative thinking of Grade-7 students after the Creative-Based Learning integrated with Model-Based Learning on the topic "Basic Units of Living Things" is shown in Table 5.

Table 5: Comparison of pre- and post-test scores of creative thinking on basic units of living things.

Creative Thinking Dimension	Pre-test		Post-test		T	Df	Sig
	$\bar{X}$	S.D.	$\bar{X}$	S.D.			
Fluency	2.08	0.76	3.15	0.70	25.49	39	.000*
Flexibility	2.38	0.87	3.35	0.77	17.27	39	.000*
Originality	1.93	0.47	2.98	0.53	21.00	39	.000*
Elaboration	1.43	0.59	2.45	0.60	41.00	39	.000*
Mean	1.96	0.67	2.98	0.65	26.19	39	.000*

*Statistically significant at the .05 level

From Table 5, the comparison of creative thinking on the topic "Basic Units of Living Things" of 40 Grade-7 students in Creative-Based Learning integrated with Model-Based Learning instruction, with a full score of 4 points for each dimension, found pre-test creative thinking scores for fluency had a mean score of 2.08 (S.D.=0.76); flexibility had a mean score of 2.38 (S.D.=0.87); originality had a mean score of 1.93 (S.D.=0.47); and elaboration had a mean score of 1.43 (S.D.=0.59). The overall mean score for all 4 dimensions was 1.96 (S.D.=0.67). The post-test results from the creative thinking assessment showed that fluency had a mean score of 3.15 (S.D.=0.70); flexibility had a mean score of 3.35 (S.D.=0.77); originality had a mean score of 2.98 (S.D.=0.53); and elaboration had a mean score of 2.45 (S.D.=0.60). The overall mean score for all 4 dimensions was 2.98 (S.D.=0.65). The comparison of students' post-test creative thinking revealed significantly higher than pre-test creative thinking at the .05 statistical significance level.

The comparison of post-test of science achievement score on basic units of living things

The one sample t-test analysis compared post-test mean score of science achievement after the Creative-Based Learning integrated with Model-Based Learning instruction on the topic "Basic Units of Living Things" and 75 percent criterion is shown in Table 6.

Table 6: The comparison of post-test score of science achievement on basic units of living things.

N	Criterion Score	$\bar{X}$	S.D.	t	df	Sig
40	15.00	16.00	1.28	4.94	39	0.00*

* Statistically significant at the .05 level

From Table 6, the science achievement on the topic "Basic Units of Living Things" of 40 Grade-7 students in Creative-Based Learning integrated with Model-Based Learning instruction, with a full score of 20 points, showed that the science achievement scores were significantly higher than the 75 percent criterion at the .05 statistical significance level.

CONCLUSION AND IMPLICATIONS

The research results on Creative-Based Learning integrated with Model-Based Learning to promote creative thinking of Grade-7 students can be discussed as follows:

The comparison of pre- and post-tests of creative thinking on basic units of living things.

The findings showed that students' post-test creative thinking revealed significantly higher than the pre-test at the .05 statistical significance level. The result was a consequence of the implemented instructional approach to foster students' creativity by Creative-Based Learning integrated with Model-Based Learning integrated approach. The Creative-Based Learning integrated with Model-Based Learning instruction consists of seven stages:1) Stimulating interest, 2) Problem

Setting and Grouping, 3) Research and think, 4) Formation Initial Model, 5) Implementation and Evaluation, 6) Revision and Revision, and 7) Elaboration. Among these, five stages specifically promote student creativity, namely Stage 1, Stage 2, Stage 4, Stage 6, and Stage 7. Based on the aforementioned framework, the results indicated that the integration of CBL and MBL enhanced students' creativity across all four dimensions, with post-test scores significantly higher than pre-test scores. These dimensions include 1) Fluency, 2) Flexibility, 3) Originality, and 4) Elaboration. Upon detailed analysis of each dimension, Flexibility achieved the highest mean score ($\bar{x}=3.35$, S.D.=0.77). This success can be attributed to the fact that most students were able to independently formulate inquiries based on their interests during Stage 2 (Problem Setting and Grouping). In this stage, the teacher allowed students to pose problems related to the topics introduced in Stage 1, such as "Light Microscopy." Students formulated various questions, such as: 1) What are the characteristics of images formed by a light microscope? 2) What are the components of a light microscope? and 3) How is a light microscope operated? Subsequently, students formed groups based on these shared interests. The resulting groups varied in size, allowing students to conduct research tailored to their specific interests, which directly contributed to their cognitive flexibility. Conversely, Elaboration received the lowest mean score ($\bar{x}=2.45$, S.D.=0.53). This is because elaboration requires detailed, step-by-step thinking, and students were not yet fully capable of providing vivid explanations or developing complete, systematic plans. During Stage 6 (Revision and Revision), the teacher had students re-evaluate their initial models to develop a Consensus Model. This stage involved exchanging ideas and receiving teacher guidance to refine the models to better explain phenomena. To address this, teachers should adjust activities to encourage students to add more detail or expand their models for greater completeness. For instance, students could present their revised models to the class, allowing peers to provide feedback or suggest additional details to refine the final output. The findings of this research are consistent with many research studies found that students in CBL exhibited significantly higher scientific creativity than those in conventional classrooms, achieved an average creativity score higher than the 70% criterion (Chaikanya & Sanphandorn, 2018), or even reached the "good" level of creativity (Potikamon et al., 2018). As well as, in an international context, the results correspond with the finding that CBL combined with project-based learning significantly boosted creative problem-solving skills, particularly in flexibility and originality (Wu, 2019), noting that the CBL process in science education fosters "Divergent Thinking," enabling students to generate more innovative hypotheses (Ozkan & Topsakal, 2020), which is originality. The findings indicate that the integration of Creative-Based Learning integrated with Model-Based Learning significantly enhanced students' creative thinking skills, demonstrating the effectiveness of this instructional approach in fostering student creativity.

The comparison of post-test of science achievement score on basic units of living things.

The findings showed that the science achievement scores were significantly higher than the 75 percent criterion at the .05 statistical significance level. The Creative-Based Learning integrated with Model-Based Learning provides a systematic instructional sequence and hands-on activities that empower students to independently investigate their inquiries. By utilizing researched data to construct models that explain specific phenomena or situations, students develop a deeper understanding, leading to the self-construction of knowledge. Five key stages were identified as significant contributors to the enhancement of academic achievement, as detailed below:

Stage 2: Problem Setting and Grouping. In this stage, the teacher encourages students to formulate inquiries based on the topics that stimulated their interest in Stage 1. For instance, regarding "Light Microscopy," students posed questions such as: 1) What are the characteristics of images formed by a light microscope? 2) What are the components of a light microscope? and 3) How is a light microscope operated? Students then formed groups based on these shared interests, resulting in varying group sizes. This autonomy in selecting research topics fostered higher engagement and long-term retention, ultimately leading to academic achievement that exceeded the established criteria. This aligns with Ruachaiphanit & Chandee (2015), who stated that the CBL process is most effective when driven by students' voluntary interest and cooperation. This process

demonstrates that students are not forced to learn but rather develop a self-derived "desire to know," which creates an optimal opportunity for them to fully embrace and internalize the knowledge.

Stage 3: Research and think. In this stage, students conducted research using textbooks and online resources under the teacher's supervision and guidance. This stage trained students to think critically, search for information, and make informed decisions regarding the data needed to address their inquiries. Self-directed discovery enhanced knowledge retention and post-test achievement. As noted by Ruachaiphani & Chandee (2015), the primary outcome of this process is not merely the correct answer, but the development of thinking and research skills cultivated during the time instructors allow students to fully engage with their topics of interest. CBL serves as a practice for critical thinking and navigating the vast information available through modern digital tools.

Stage 5: Implementation and Evaluation. In this stage, students tested their constructed models to verify their accuracy. The teacher facilitated peer evaluations, comparing student models against established scientific models. This process allowed peers to gain new insights beyond their own initial inquiries. Consequently, academic achievement improved. This is consistent with Gobert and Buckley (2000), who suggested that during application and evaluation, students may find their models rejected if they fail to adequately explain the phenomena. This necessitates revision to improve the model's explanatory power. Furthermore, Delos Reyes & Inocian (2020) found that designing and refining models in Earth Science helped correct misconceptions, thereby increasing academic achievement.

Stage 6: Revision and Revision. The teacher prompted students to re-evaluate their models to develop a Consensus Model. This stage involved the exchange of ideas and supplementary teacher feedback to refine the models for greater clarity and completeness. This resulted in achievement scores higher than the set criteria, aligning with Kuathane, Pongsophon, and Chantraukrit (2014), who noted that model revision allows for collaborative idea exchange. It also supports the research of Suphaphon, Anantasawat, and Fakcharoenphol (2019), which demonstrated that Grade 8 students taught via MBL regarding body systems achieved significantly higher post-test scores than pre-test scores.

Stage 7: Elaboration. The teacher introduced new scenarios, challenging students to design models that explain related phenomena. This encouraged the extension of creative thinking and the application of knowledge to solve problems in different contexts, particularly enhancing the "application" aspect of academic achievement. This aligns with Kuathan, Pongsophon, and Chantraukrit (2014), who defined model extension as the stage where students apply refined models to predict new data or situations. Additionally, Kuatthai (2020) found that MBL in Grade 10 Biology led to a continuous increase in students' modeling capabilities across all learning cycles, proving its applicability in instructional settings.

Based on the aforementioned framework, the integration of CBL and MBL promoted academic achievement exceeding the 75 percent criterion. The findings of this research are consistent with many research studies on CBL and MBL found that students had science achievement passed the criterion of 70 percent (Riangnarong & Silanoi, 2015; Chaikanya & Sanphandorn, 2018), students achieved higher post-test scores or significantly improved achievement (Potikamon et al., 2018; Maikham, Klangraphan, and Phalachit, 2022; Yan, 2020; Wisesa & Naruponjirakul, 2021), exhibited significantly higher scientific achievement than those in conventional classrooms (Kaeodok & Sawangboon, 2019). The implementation of Creative-Based Learning integrated with Model-Based Learning effectively enhanced students' science achievement. The statistical analysis demonstrated the students' post-test scores significantly exceeded the predetermined criteria, confirming the efficacy of this integrated instructional approach.

USE OF ARTIFICIAL INTELLIGENCE TOOLS

During the preparation of this manuscript, the author(s) used ChatGPT, Gemini & Claude for technical support, specifically for spelling and grammar checking, as well as language refinement to improve readability. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the final context and accuracy of the publication.

REFERENCES

- Chaikanya, S., & Sanphandorn, S. (2018). Development of creative thinking skills in science on interaction in the solar system for Grade 9 students using a creativity-based learning model. *Roi Et Rajabhat University Journal*, 12(1), 157–164.
- Creative Economy Agency. (2020). *CEA outlook: Creative thinking index*. Sanniti Company.
- Dagnew, A., & Endris, A. (2020). Model-based instruction to improve students' concepts of human anatomy in primary school, Ethiopia. *International Journal of Learning and Teaching*, 12(2), 72–85.
- Delos Reyes, R. D., & Inocian, R. B. (2020). Model-based learning approach: Effects on students' academic performance and attitudes in Earth science. *International Journal of Scientific and Technological Research*, 9(6), 112–120.
- Gobert, J. D., & Buckley, B. C. (2000). Introduction to model-based teaching and learning in science education. *International Journal of Science Education*, 22(9), 891–894. <https://doi.org/10.1080/095006900416839>
- Guilford, J. P. (1967). *The nature of human intelligence*. McGraw-Hill.
- Kanthawang, J. (2023). *Model-based learning management in biology to develop academic achievement and scientific reasoning of Mathayom 4 students* [Master's thesis, Burapha University]. BUU Repository. <http://ir.buu.ac.th/dspace/handle/1513/168>
- Kaeodok, P., & Sawangboon, T. (2019). A study of learning achievement and scientific creativity of Grade 10 students using creativity-based learning: Mixed methods research. *Journal of Educational Measurement, Mahasarakham University*, 25(1), 206–224.
- Kuathane, N., Pongsophon, P., & Chantraukrit, P. (2014). Development of mental models on pure substances of Grade 7 students through model-based learning. *Journal of Science, Technology, and Environment for Learning*, 5(2), 126–137.
- Kuatthai, N. (2020). The development of modeling ability of Grade 10 students in biology through model-based learning management. *Sisaket Rajabhat University Journal*, 14(2), 63–71.
- Lamboon, S., Prasert, P., & Latwong, T. (2020). A study of creative thinking and scientific modeling ability of Grade 12 students through model-based learning management. *Journal of Education Sciences, Mae Fah Luang University*, 8(1), 159–172.
- Maikham, M., Klangraphan, M., & Palachit, S. (2022). The development of science learning activity packages using the 7E learning cycle integrated with mind mapping and creativity-based learning affecting analytical thinking, creative thinking, and learning achievement of Grade 9 students. *Journal of Graduate School, Sakon Nakhon Rajabhat University*, 19(85), 69–84.
- Ministry of Education. (2017). *Learning standards and indicators for mathematics, science, and geography (Revised edition 2017) according to the Basic Education Core Curriculum B.E. 2008*. Agricultural Co-operative Federation of Thailand.
- Ozkan, G., & Topsakal, U. (2020). Exploring the effectiveness of project-based learning on students' scientific creativity. *Journal of Biological Education*, 55(3), 293–309.
- Phumikonsarn, N. (2022). Missing creative skills of students and education in the 21st century. *Education Journal*, 5(1), 1–9.
- Pothikamon, N., Sanphandorn, S., Pocharoen, W., & Mongkolsin, B. (2018). Development of creative thinking and scientific attitudes on the unit of life using creativity-based learning for Grade 7 students. *Roi Et Rajabhat University Journal*, 12(1), 59–64.
- Riangnarong, M., & Silanoi, L. (2015). The development of 21st century learning skills and academic achievement using inquiry-based learning (5Es) of Grade 10 students in social studies courses. *Journal of Education Graduate Studies Research, Khon Kaen University*, 9(1), 147–155.
- Ruachaiphanit, W., & Chandee, K. (2015). CBL: Learning by creative effort. *Journal of Learning Innovation*, 1(2), 1–15.

- Ruachaiphanit, W., & Nimitpongsakul, W. (2019). *Teaching and learning with fun in the 4.0 era*. SeaVed Education.
- Singsamran, P. (2022). Development of a community-based creative learning model (CBL Plus) to enhance creative and innovative thinking skills for Mathayom 5 students. *Journal of Professional Teacher Learning Community*, 2(2), 265–280.
- Sirindhorn School. (2022). *Self-assessment report of the educational institution (SAR) for the 2022 academic year*. Surin Secondary Educational Service Area Office.
- Srisa-ard, B. (2010). *Introduction to research* (8th ed.). Suwiriyan.
- Suatsuang, K., & Kitkoekun, S. (2021). Learning management using simulation-based learning integrated with virtual reality technology to promote modeling skills and concepts about solutions of Mathayom 4 students. *Naresuan University Journal of Education*, 23(4), 55–67.
- Suksawang, S. (2023). *Creative to innovation for innovation organization*. HCD Innovation. <https://doi.sasimasuk.com/>
- Suphaphon, R., Anantasawat, S., & Fakcharoenphol, W. (2019). Comparison of learning achievement on human body systems of Grade 8 students taught by model-based learning. *Journal of Education and Human Development*, 3(2), 62–71.
- Suya, S. (2021). The influence of model-based learning management on concepts of eclipses among lower secondary school students. *Journal of Interdisciplinary Studies for Development, Uttaradit Rajabhat University*, 11(1), 73–85.
- Torrance, E. P. (1962). *Guiding creative talent*. Prentice Hall.
- Wisesa, P., & Naruponjirakul, S. (2021). Development of the ability to construct scientific concepts and academic achievement using inquiry-based learning integrated with model-based learning among Mathayom 1 students. *Journal of Academic and Social Sciences*, 16(3), 145–158.
- Wu, H. (2019). Development of a creative project-based learning model to enhance students' creative thinking and problem-solving skills. *International Journal of Instruction*, 12(4), 1–16. <https://doi.org/10.29333/iji.2019.1241a>
- Yan, X. (2020). The effect of model-based learning on the academic success and conceptual understanding of middle-school students. *Journal of Education in Science, Environment and Health*, 6(1), 45–58.

Appendices

Integrating Precision Medicine Concepts into Biology Education: Preparing Future Biology Teachers for Contemporary Scientific Challenges

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Appendix A: Questionnaire

Response Scale:

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

Questionnaire Items

No.	Construct	Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	Genomics Knowledge	I understand the concept of genetic variation and its biological implications.	☐	☐	☐	☐	☐
2	Genomics Knowledge	I can explain how gene mutations influence disease development.	☐	☐	☐	☐	☐
3	Genomics Knowledge	I am familiar with basic genomic technologies such as DNA sequencing.	☐	☐	☐	☐	☐
4	Data Interpretation	I can interpret genetic test results in a biological context.	☐	☐	☐	☐	☐
5	Data Interpretation	I am able to analyze simple biological datasets.	☐	☐	☐	☐	☐
6	Data Interpretation	I understand the role of data in supporting clinical decision-making.	☐	☐	☐	☐	☐
7	Precision Medicine	I understand the principles of precision medicine.	☐	☐	☐	☐	☐
8	Precision Medicine	I can explain how treatments can be tailored to individual genetic profiles.	☐	☐	☐	☐	☐
9	Precision Medicine	I recognize the importance of integrating genomics into healthcare.	☐	☐	☐	☐	☐
10	Ethical Awareness	I am aware of ethical concerns related to genetic data usage.	☐	☐	☐	☐	☐
11	Ethical Awareness	I understand issues related to privacy and data protection.	☐	☐	☐	☐	☐
12	Ethical Awareness	I can evaluate ethical implications of personalized medicine applications.	☐	☐	☐	☐	☐

Note: The questionnaire items are organized into four constructs: Genomics Knowledge, Data Interpretation Skills, Precision Medicine Concepts, and Ethical Awareness.

Appendix B: Sample Learning Activities and Implementation

Overview: A set of active learning activities was designed to support the integration of precision medicine concepts into biology education. These activities focus on real-world applications, data analysis, and ethical reasoning.

Activity 1: Genetic Data Analysis

Description:

Students analyze a simplified genetic dataset related to a specific disease.

Learning Outcomes:

- Develop data interpretation skills
- Understand gene-disease relationships

Task:

- Identify genetic variations
- Interpret test results
- Explain biological implications

Activity 2: Case-Based Learning

Description:

Students are presented with a real-life medical case involving a genetic condition.

Learning Outcomes:

- Apply precision medicine concepts
- Enhance problem-solving skills

Task:

- Analyze patient case
- Identify diagnosis
- Propose a personalized treatment

Activity 3: Design-Based Group Work

Description:

Students work in groups to design a treatment plan based on a given genetic profile.

Learning Outcomes:

- Promote collaborative learning
- Support decision-making skills

Task:

- Analyze provided data
- Develop a treatment strategy
- Present and justify decisions

Activity 4: Ethical Debate

Description:

Students engage in a structured discussion حول ethical issues in precision medicine.

Learning Outcomes:

- Develop ethical awareness
- Enhance critical thinking

Task:

- Discuss privacy and genetic data use
- Evaluate ethical dilemmas
- Present arguments

Implementation Example (Actual Application)

Context:

The activities were implemented with pre-service biology teachers (n = 50).

Example: Case-Based Learning Activity

Scenario:

A patient with a suspected hereditary cancer mutation (e.g., BRCA gene).

- Enhanced ability to interpret genetic data
- Increased awareness of ethical considerations

Steps:

1. Students reviewed patient background
2. Analyzed genetic test results
3. Identified possible mutation
4. Proposed treatment options
5. Justified decisions based on scientific evidence

Evidence Source:

- Classroom observations
- Student written responses
- Group discussions

Observed Outcomes:

- Students demonstrated improved engagement

Appendix C: Observation Rubric

Purpose: This rubric was used to systematically evaluate students' performance during the implementation of precision medicine learning activities.

Assessment Dimensions

Dimension	High (3)	Moderate (2)	Low (1)
Conceptual Understanding	Demonstrates accurate and comprehensive understanding of genomics and precision medicine concepts	Shows partial understanding with minor inaccuracies	Demonstrates limited or incorrect understanding
Data Interpretation Skills	Accurately interprets genetic data and explains results clearly	Interprets data with some errors or incomplete explanation	Misinterprets data or fails to analyze correctly
Application to Real-World Contexts	Effectively applies knowledge to real-life case scenarios with clear justification	Applies knowledge with limited depth or partial relevance	Unable to apply knowledge to real-world contexts
Decision-Making and Reasoning	Provides well-justified, evidence-based decisions	Provides decisions with limited justification	Decisions lack reasoning or are unsupported
Ethical Awareness	Demonstrates strong awareness of ethical issues and evaluates implications critically	Shows basic awareness of ethical considerations	Lacks awareness of ethical issues

Scoring System

- High = 3 points Moderate = 2 points Low = 1 point

Total Score Range: 5 – 15

Interpretation of Scores

Score Range	Level
12 – 15	High Performance
8 – 11	Moderate Performance
5 – 7	Low Performance

Application Procedure

- The rubric was applied during classroom observations of student engagement in learning activities.
- Observations were recorded by the researcher and reviewed to ensure consistency.
- Scores were used to support qualitative and quantitative analysis.

Reliability Considerations

- The rubric was reviewed by experts in science education.
- Inter-rater agreement was established during pilot observations to ensure consistency in scoring.

Example of Student Evaluation (Actual Case)

Student Code: S12

Activity: Case-Based Learning (Genetic Disorder Analysis)

Dimension	Score	Justification
Conceptual Understanding	3	The student accurately explained the genetic mutation and its biological impact
Data Interpretation	3	Correctly analyzed genetic test results and identified mutation
Application	2	Applied knowledge to case but with limited depth in explanation
Decision-Making	3	Proposed a logical and evidence-based treatment plan
Ethical Awareness	2	Demonstrated basic awareness of privacy concerns but lacked deeper analysis

Total Score: 13 / 15

Performance Level: High

Interpretation of Example

The student demonstrated strong conceptual understanding and data interpretation skills, supported by effective decision-making. However, further development is needed in applying knowledge more deeply and critically addressing ethical considerations.

Appendix D: Qualitative Coding and Thematic Analysis

Purpose

This appendix presents a sample of the qualitative data analysis process, including coding procedures and theme development based on expert interviews.

Coding Process Overview

The analysis followed the six-phase thematic analysis approach proposed by **Braun & Clarke (2006)**:

- Familiarization with data
- Generating initial codes
- Searching for themes
- Reviewing themes
- Defining and naming themes
- Producing the report

Sample Coding Table

Excerpt from Interview	Open Code	Axial Code	Theme
“Students need more exposure to real-life biomedical applications to understand modern biology.”	Need for real-world exposure	Application gap	Curriculum Modernization
“Traditional teaching methods are no longer sufficient to address current scientific developments.”	Limitations of traditional teaching	Pedagogical gap	Active Learning Strategies
“Ethical considerations are often overlooked when teaching genetics.”	Lack of ethical focus	Ethical gap	Ethical Integration
“Future teachers must be trained to handle genomic data effectively.”	Need for data literacy	Skill development	Active Learning Strategies

Theme Development Summary

Theme	Description	Supporting Codes
Curriculum Modernization	Emphasizes the need to update biology curricula to include contemporary scientific contexts	Application gap, Real-world relevance
Active Learning Strategies	Highlights the importance of interactive and student-centered teaching approaches	Pedagogical gap, Skill development
Ethical Integration	Focuses on incorporating ethical dimensions into biology education	Ethical gap, Awareness

Trustworthiness Measures

To ensure the credibility and rigor of the qualitative analysis, the following strategies were employed:

- **Triangulation:** Data were collected from multiple sources (interviews, observations, questionnaire)
- **Member Checking:** Findings were reviewed by three experts, achieving 92% agreement
- **Audit Trail:** Detailed documentation of coding procedures was maintained
- **Peer Debriefing:** Coding and themes were reviewed for consistency

Interpretation

The identified themes collectively indicate a strong need for integrating precision medicine into biology education through curriculum reform, active learning strategies, and ethical awareness. These findings directly informed the development of the proposed framework.

Appendix E: Expert Interview Protocol

Purpose

This interview protocol was designed to explore experts' perspectives on integrating precision medicine into biology teacher education.

Participants

- Number of experts: 6
- Specialization: Biology Education / Curriculum & Instruction / Educational Technology
- Experience: ranging from 10 to 20 years in their respective fields.

Interview Format

- Semi-structured interviews
- Duration: 30–45 minutes
- Conducted individually
- Recorded and transcribed for analysis

Interview Questions

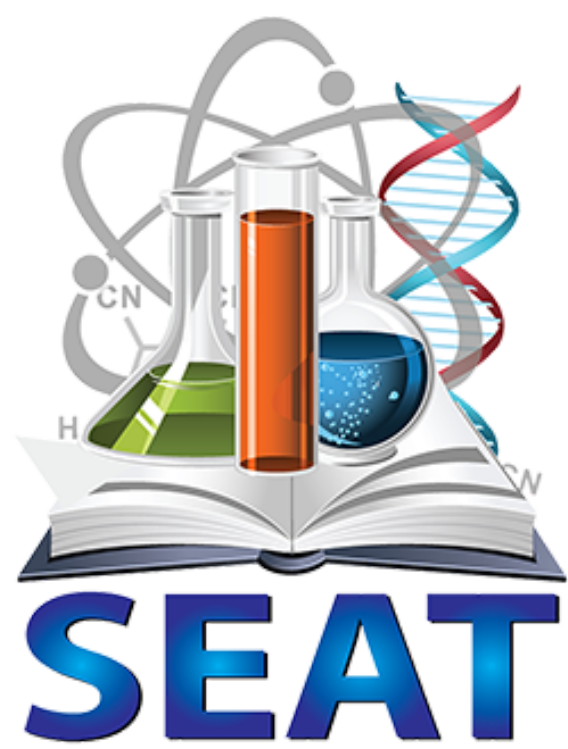
1. How do you perceive the importance of integrating precision medicine into biology education?
2. What challenges may arise when incorporating genomics and personalized medicine into current curricula?
3. What competencies should pre-service biology teachers develop in this context?
4. Which instructional strategies are most effective for teaching precision medicine concepts?
5. How can ethical considerations be effectively integrated into biology teaching?

Probing Questions (Used when needed)

- Can you elaborate on that?
- Can you provide an example?
- Why do you think this is important?

Data Analysis Link

The responses were analyzed using thematic analysis, and the resulting themes informed the development of the proposed framework.



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