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Developing problem-solving and creative competences for students through teaching biology with a stem education orientation in Vietnam

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ABSTRACT

This study uses a process of organising the teaching of biology for students following a STEM education orientation and examines the impact of this teaching process on the development of students' problem-solving and creative competences. Research and organize the implementation of three STEM lesson plans for 382 selected 11th-grade students in 3 schools in Hanoi, Vietnam, in 2023. To assess the development of the problem-solving and creativity competence of students, the research is based on the structure of problem-solving and creativity competence, including 4 skills: problem identification (KN1); proposing and selecting solutions (KN2); planning, implementation, and evaluation of solutions (KN3); and report presentation (KN4). Assessing these four skills will show the level of students' problem-solving and creative competence. This study documents the positive relationship between STEM-oriented biology teaching and the development of students' problem-solving and creativity competences. Specifically, teaching STEM-oriented subjects increases students' problem-solving and creativity competences. The interesting thing is that classes with a small number of students are more effective in developing problem-solving and creative competence. Research has suggested that in classrooms with fewer students, teachers have more opportunities to interact with each student. The research results are of interest and beneficial to educational policymakers, schools, and teachers in trying to develop students' learning competencies, especially core competencies like problem solving and creativity.

Contribution/ Originality: To the best of the author's knowledge, this is a study examining the impact of a STEM education-oriented organisation teaching biology to students on the development of problem-solving and creativity competence for that student. This research is very important because the Vietnamese government focuses on educational innovation to develop student competence.

1. INTRODUCTION

The core goal of the 2018 general education program in Vietnam is to cultivate learners' qualities and competencies, including five main qualities, three general competencies, and seven specific competences [1]. To achieve this, the organisation of teaching subjects as well as educational programmes in schools needs to be innovated in the direction of active learning activities, encouraging students to participate in discovery and experience activities. Students can apply their knowledge to discover and solve real-world problem, thereby developing their competencies. STEM education is one of the new educational models in the world, quickly spreading and being applied in many countries. It is important in helping learners increase their interest in Science, math, and technology subjects, such as engineering, and at the same time help them develop their competences.

Some reports indicate that the number of jobs related to STEM fields is growing rapidly in many countries around the world [2, 3]. However, research by STEM educators and industrialists in European countries shows that schools must pay attention and promote STEM skills training for students to prepare for career requirements in the future [4]. Currently, STEM education is being promoted in many countries around the world and is considered one of the measures to develop quality labour resources in STEM-related occupations, meeting the needs of economic development in the future trend of the Fourth Industrial Revolution [5].

Many studies around the world show positive results about the effectiveness of STEM education on academic achievement, stimulating student interest and motivation. STEM education has a positive impact on the development of scientific process skills, influencing motivation, STEM career interests, and 21st century skills such as collaboration, critical thinking, and critical thinking [6-9]. Teaching based on building and organising STEM lessons and topics also helps develop learners' competences such as self-study, communication, and collaboration, especially problem-solving and creativity. In Vietnam, the Prime Minister has directed the Ministry of Education and Training to *"promote the implementation of science, technology, engineering, and mathematics (STEM) education in the general education programme; Organise pilots at a number of high schools right from the 2017–2018 school year"* [1].

Biology is one of the foundational subjects of the natural sciences, playing an important role in implementing STEM education. Along with the development of the 4.0 Industrial Revolution, biology has achieved remarkable achievements in theory as well as modern technology to serve human life. Therefore, teaching biology needs to continue to be valued and promoted further. Applying STEM education in teaching biology not only helps achieve the goals of the subject but also provides many opportunities for students to connect biological knowledge with other S-T-E-M subjects to solve practical problems. This helps students develop biological competences while also developing general competences, especially problem-solving and creativity. However, research on STEM education-oriented teaching models and applications in teaching subjects in general or biology is still limited and needs continued research and development. Therefore, the goal of the research is to use the STEM teaching organization process and apply it to teaching biology in Vietnam to develop problem-solving and creativity competence for high school students.

Our study addresses the following research questions:

Question 1: How to implement the process to develop lesson plans and organise biology teaching according to STEM education orientation to develop problem-solving and creativity competence?

Question 2: What confirms that teaching biology with a STEM education orientation will develop problem-solving and creativity competencies for students?

The research results are worthy of attention from policymakers and teachers. It helps educational policymakers, educational administrators, and teachers develop students' learning competencies, particularly core competencies such as problem-solving and creativity.

2. LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

2.1. Research on STEM Teaching

STEM is an acronym initiated more than two decades ago by the US National Science Foundation to briefly express four fields: science, technology, engineering and mathematics. In the 2000s, STEM education was still not popular. Until Americans learned about the "Flat World," they quickly believed that China and India were on their way to surpassing them in the global economy, thanks to their remarkable development in STEM. Funding began to "flow" into STEM-related fields [10]. At the same time, America's educational focus officially expanded into four areas: S-T-E-M, instead of just focusing on math and science as before [11]. After that, STEM education quickly gained widespread support in many countries, and now it represents a movement in many educational systems around the world. Although STEM education does not have a long history, its growth rate is very strong. Searching with the keywords STEM, STEM education, and STEM education research on Google immediately yields a huge amount of information (more than 500,000,000 results), confirming the increasing trend. quickly research and discuss STEM education as well as show many diverse perspectives on this term.

Research on evaluating STEM education for the period 2007-2010 [12] and 2013-2015 [13]. Authors tend to believe that STEM education can refer to the education of individual STEM subjects in schools or imply interdisciplinary and cross-disciplinary connections and integration between S-T-E-M subjects. That means single-subject teaching or interdisciplinary integrated teaching of science, math, technology, and engineering subjects are all within the scope of STEM education. In particular, the trend of approaches in which students' study two or more STEM subjects in an integrated form, collectively known as integrated approaches to STEM education (iSTEM: integrated approaches to STEM education) is becoming increasingly popular in many countries. However, how to integrate STEM subjects is still a matter of discussion [14]. Another evaluation study covering the period 2000-2018 [15] shows that research in the field of STEM education has a wide range of topics, including the main issues: STEM teaching, learners, and the STEM learning environment from kindergarten to grade 12; training teachers and students in STEM fields; policies, programmes, and evaluation in STEM education; culture, society, and gender in STEM education; history, epistemology, and perspectives on STEM education. The book series "Advances in STEM Education" includes articles and review articles from leading experts in the field of STEM education around the world, demonstrating that the focus of research is on curriculum, student learning, and most importantly, articles on teachers' professional development [16].

Implementing STEM education-oriented teaching has piqued many scientists' interest in research. Research on STEM-oriented teaching focuses on how to integrate STEM subjects such as integrated principles, integrated content, and integrated methods. Bybee is one of the prominent authors researching STEM education and has pointed out a number of directions and challenges in STEM teaching, including [17]: (1) it is necessary to promote Technology and Engineering in the curriculum by expanding the scope of Technology and Engineering courses, integrating Technology and Engineering into Science and Math education is a reasonable way to do it ; (2) promote teaching methods that develop competence in solving situations and problems, not just focusing on conceptual and procedural knowledge in STEM subjects; (3) STEM education needs to put issues in the context of the times such as: energy efficiency, climate change, natural resources, environmental quality, risk reduction, etc. into a central position. These are problems that students, as global citizens, will have to face. The problems must be related and require knowledge and skills in S-T-E-M fields to solve. Bybee also provides a STEM lesson model framework that demonstrates the connection between STEM subjects to solve problems in a centrally placed context.

One of the integration efforts in the field of S-T-E-M must include the promulgation of the US Next Generation Science Standards (NGSS), which helps promote the integration of technology and engineering standards into US standards. Science subjects include core scientific knowledge (disciplinary core ideas), cross-cutting scientific concepts (cross-cutting concepts), and especially science and engineering practices (Science and engineering practices). Science and engineering practices include eight skills that clearly demonstrate the integration of Technology and Engineering standards into science teaching; therefore, these practices are also called STEM practices. STEM practice guides two popular approaches in STEM education: (1) scientific inquiry and discovery practice (enquiry-based): involves asking questions, conducting investigations, and developing models and theories to better understand the natural world; (2) engineering design-based practice: requires students to apply cross-cutting concepts and core scientific knowledge to design tasks; Shift your focus from memorising detailed information to understanding big ideas [18, 19]. These STEM practices can be taught individually in different contexts or can be combined in a complete scientific research or engineering design project.

Integrating engineering design and technology in STEM education continues to be emphasized in several other studies [20, 21]. An engineering design-based activity can take many forms. However, looking at current learning programmes and projects, the technical element tends to take on a single form as a modelling or design activity. Learning science content through engineering lessons shows moderate or large gains in test performance, impacting students' motivation, engagement, and attitudes towards science and engineering. However, these results need further research. Furthermore, integrating engineering practices into science teaching presents major challenges for teachers in many countries, including the United States. A survey study of 98 science teachers (in the United States) showed that all were unfamiliar with and lacked understanding about teaching according to the engineering design process [22]. Researchers have also investigated STEM teaching initiatives that utilize problem-base learning. Using complex real-world problems creates contexts for students to apply knowledge and skills from a variety of disciplines. Problem-based teaching in STEM education programmes also draws on engineering and technology education [23].

Several studies have addressed the types of knowledge used in the context of STEM education; in addition to analyzing the challenges of integrating the engineering design process into STEM oriented teaching. Integrated STEM is very meaningful in determining the content of STEM teaching in general subjects. In biology, based on the level of abstraction and complexity of the knowledge content, it allows the integration of the technical design process within a narrow range of relevant and meaningful issues such as human biology, engineering, genetic engineering, geoengineering, bioprocessing, agriculture, environmental science, building sustainable biological systems, designing, and building vehicles inspired by human bodies and animal movements [24]. Another study by Yuanli [25] on the principles of integrating STEM education in teaching Biology, includes the following: principles of integration (maximum integration of S-T-E-M knowledge in the teaching process so that students can apply biological knowledge to solve practical problems in the learning process), practical principles (valuing practice and applying knowledge to practice), and social principles (expanding learning tasks practice on a number of topics related to real society, guiding students to think about and care about the community) [25]. In particular, the principle of practice is emphasised as being beneficial for building abstract concepts and developing students' interest in learning biology, making it suitable for implementation in teaching science and design subjects. Elaborately designing hands-on activities in teaching is essential; letting students try something for themselves often leads to deeper memories. The author also highlights a range of STEM-oriented teaching activities, including investigation, experimentation, data analysis, problem discussion, model building, and test sample design. However, the integrated teaching of science, technology, engineering and mathematics in biology also faces many challenges, such as: teachers lack professional knowledge of STEM; time constraints because students need a lot of time to discuss and communicate to come up with solutions or iterate on designs to improve products; students' attitude in the classroom lack positivity and imitative, despite the need to encourage student-centered learning activities and student imitative [26].

2.2. Biology Lesson Plans Follow STEM Education Orientation to Develop Problem-Solving and Creativity Competences

This study identifies the process of building a STEM education-oriented lesson plan to develop problem-solving and creative competences for students, including the following steps: (1) Determine the goals and duration of teaching; (2) Determine STEM teaching content; (3) Determine teaching methods and techniques, media, and materials; (4) Determine the teaching process; (5) Expect inspection and evaluation. Here is a detailed description of each step:

* Determine the STEM lesson's objectives and teaching duration: We determine the objectives of the STEM lesson based on requirements of the biology programme, with the aim of developing general competencies and critical qualities. Weak, especially the competence to solve problems and be creative through STEM problem-solving. The classroom teaching time of STEM lessons is determined based on the suggested teaching time for each content in the programme and the number and difficulty level of the requirements to be met. A STEM lesson's teaching time can include both the time students study in class and the time they work outside of class in an

appropriate way, without overloading students.

* Determine STEM teaching content: You need to choose problems corresponding to Biology teaching content. Select the content of integrated subjects (background knowledge): integrated knowledge and skills from subjects in the general education programme to solve STEM problems, including biology, physics, chemistry science, natural sciences, technology informatics, and mathematics in the general education program. The characteristics of STEM problem to solve determine the number of subjects required: not all STEM subjects need to be present at all times.

* Identify teaching methods, techniques, and teaching aids: In STEM-oriented teaching, the main teaching methods and techniques include problem-solving teaching, discovery teaching, teaching project learning, and so on. Depending on the duration and nature of the STEM problem that needs to be solved, choose appropriate teaching methods. Teaching aids are often technological means commonly used to collect and process information, such as computers, the internet, software (Ms.Office, SPSS, graphic design, etc.), measuring machines (sensors, thermometers, etc.), laboratory equipment (microscopes, test tubes, etc.), types of material processing machines (cutting devices, drilling machines, 3D printers, etc.), videos, images, etc.

* Determine the teaching process: Investigate how to teach STEM lessons based on the STEM problem-solving process, which consists of four steps that correspond to four activities: (i) Explore STEM problems; (ii) Solution design; (iii) Data collection and processing; (iv) Report, assessment, and conclusion. Determining the process of teaching biology in the direction of STEM education is to design these teaching activities to develop students' biological competences, problem-solving competences, and creativity competences. To design STEM-oriented biology teaching activities, it is necessary to determine the logical relationship between STEM-integrated content (in which biology plays a key role), the STEM problem-solving process, and goals. The STEM education-oriented teaching model aims to develop biological competence, problem-solving competence, and creativity. Designing STEM education-oriented teaching activities includes determining space and time, means, methods, and teaching organisation techniques to ensure goal achievement.

Specifically, the steps are described in Table 1.

Table 1. Designing activities in the biology teaching process according to STEM education orientation.

Target	Product	Facilities and learning materials	Facilities and learning materials
Activity 1: Explore STEM issues			
Students are interested, curious, and have a need to solve problems. Students can analyse aspects of the problem, identify steps to solve the problem, products to be implemented, criteria for product evaluation, or scientific hypotheses.	Problem-solving steps, product evaluation criteria table, or scientific hypothesis proposed by students.	Videos, images, situations, and current affairs. Problem analysis tools such as fishbone diagrams, the 5Whys and 5W1H question forms, and the problem-solving criteria proposal form.	- Question. - Problem analysis: identify steps to solve the problem, products to be implemented, product evaluation criteria, or a scientific hypothesis. - Conclude.
Activity 2: Solution design (Scientific or technical)			
Refer to resources to design problem-solving solutions based on biological and other scientific knowledge.	Solution design sheet (Overview of relevant knowledge, scientific hypotheses, experimental design, process/Model drawings, materials to be prepared, implementation plan, assignment, collection methods) data collection),	- Videos, pictures, reference materials, websites. - Design and translation solutions for work groups. - Software to support design on computers/Utility devices on paper.	- Research and mobilize knowledge - Design solutions. - Present, discuss, and suggest solutions. - Conclude.

Target	Product	Facilities and learning materials	Facilities and learning materials
	group work minutes.		
Activity 3: Collect and process data			
Implement the designed solution and collect and process relevant data.	- Data record. - Photos and implementation diary (Difficulties, experiences, ...) - Data has been processed and presented in appropriate diagrams and tables.	- Data collection form. - Data processing tools: Excel, SPSS. - Raw materials to implement the solution (Utensils for testing/Manufacturing/...)	- Plan and implement solutions. - Data collection: Observe, measure, and record data, take photos, write a diary, and detect problems during data collection. - Process and represent collected data; recognise and interpret patterns, trends, and relationships.
Activity 4: Report, evaluation, and conclusion			
Interpret the data to draw the necessary conclusions. Evaluate the effectiveness of the solution. Learn lessons learned.	- Report (Slides, posters, website, magazine, fan page, etc.) - Evaluation and adjustment copy (If any). - Draw knowledge about concepts, processes, and biology.	- Report form. - Discussion questions (To help students re-evaluate the solution and draw on subject knowledge) - Software to support report presentation (Word, PowerPoint, Canva, etc.)	- Students compare performance results with scientific hypotheses and problem-solving criteria to draw the necessary conclusions. - Build and present reports. - Discuss, evaluate, adjust, and draw knowledge. - Conclusion and comments on students' work processes.

* Expected testing and assessment: With the goal of teaching and developing competence, assessment needs to combine process assessment and periodic assessment with many diverse methods and forms of testing and assessment. Process assessment is carried out continuously throughout the process and assessed through the activities in Table 1, using observation, questioning, product evaluation, and report presentation through assessment tools. Assessment tools include study sheets, checklists/criteria sheets, questionnaires, questions, and exercises. We conduct periodic assessment by testing and by answering students' to gauge their achievement of biology subject's requirements, as well as their proficiency in problem-solving and creativity.

3. METHODOLOGY

3.1. Research Design

Research and organise the implementation of three STEM lesson plans built on 382 selected students; carry out observations and collect data to evaluate the manifestations of problem-solving and creative competences, and conduct end-of-lesson tests to combine the assessment of students' Biology competences. Take part in experiments. Specifically, the experimental steps include:

Step 1: Discuss with teachers teaching experimental classes and transferring materials. Discuss and agree with teachers on experimental teaching's purpose, content, methods, and requirements. Provide the necessary documents to the teachers for their research and experimental teaching, as needed. (1) Document No. 1: General theory of teaching according to STEM education orientation; STEM education-oriented teaching model; The process of designing and organising STEM-oriented biology teaching; problem-solving and creativity competence in teaching biology according to STEM education orientation; (2) Document No. 2: Experimental STEM lesson plans; (3) Document No. 3: Tool to evaluate performance criteria of skills in problem solving and creativity (questionnaire, observation sheet); (4) Document No. 4: Test questions after each experimental lesson (3 lessons).

Step 2: Conduct experiments: Teachers organise their teaching according to the proposed process, using the provided lesson plans. In the experiment, teachers collect student data through tools including questionnaires and observation sheets on students' problem-solving and creativity skills. Teachers combine the use of information from learning records such as results of study sheets, group minutes, presentations, and reflective writing of students, and conduct 3 tests after each lesson to evaluate students. Evaluate the level of achievement of students' biological competences, problem-solving competences, and creativity.

3.2. Research Population

The study conducted experimental teaching with 382 11th grade students at 3 schools: Olympia High School, Ly Thuong Kiet High School, and Minh Khai High School in Hanoi, Vietnam. The experimental period is from February 2023 to May 2023. The experiment is organised in three Grade 11 Biology lessons Table 2.

Table 2. Lessons organized for experimental teaching.

Lesson name	Duration (Hours)
Lesson 1. Induction in plants	4
Lesson 2. Application of growth and development in plants	4
Lesson 3. Asexual reproduction in plants	4
Total number of experimental periods	12
Ratio to the total number of periods	17.14%

3.3. Instrument, Validity and Reliability Tests

To collect data to analyse and evaluate to verify the proposed scientific hypothesis, research uses tools and testing methods as shown in Table 3. SPSS software is used. Use the processing of results obtained through statistical parameters and a paired T-test to test the difference in the levels of competence achieved after each training session (impact).

Table 3. Time and measurement tools.

<table>
<tr><th>Content</th><th>During the teaching process</th><th>After experimenting with each lesson 1, 2, and 3</th></tr>
<tr><td>Content rated</td><td colspan="2">• Problem-solving and creative competences
• Biology competence</td></tr>
<tr><td>Testing tools</td><td>• Questionnaire and interview
• Observation sheet
• Student records</td><td>• Tests 1, 2, 3</td></tr>
<tr><td>Evidence of assessment</td><td>• Answer sheet
• Interview minutes
• Teaching records</td><td>• Student test</td></tr>
<tr><td>Data relicompetence</td><td colspan="2">• Questionnaire, observe and check many times
• Use equivalent lesson formats</td></tr>
<tr><td>The value of the tool</td><td colspan="2">• Cronbach's alpha relicompetence test
• Professional solution
• Test and adjust tools</td></tr>
</table>

4. RESULTS AND DISCUSSION

4.1. Assess Biology Competence through a Test

To assess students' biology competence through performing tests, we use SPSS software for descriptive statistics. Table 4 presents the results.

Table 4. Values of statistical parameters assessing biology competence through tests.

Values	Test 1	Test 2	Test 3
Medium score	5.630	6.362	7.136
Median score	5.500	6.000	6.900
Outstanding point	5.6	6.0	6.4
Standard deviation	1.0419	0.9979	0.9534
Variance	1.086	0.996	0.909
Min. value	3.4	5.0	5.4
Max. value	10.0	10.0	10.0

The statistical analysis of the test results shows that since the second impact, there have been no more weak students (scores below 5), and the average score of students has increased from 5.63 to 7.13. It shows that students have made progress in their biology competence and understanding of the subject's knowledge. The average score, median score, and dominant score values are relatively close to each other, proving that the level of achievement of the required requirements and the expression of biological competence are relatively uniform and highly concentrated. The test results' standard deviation and variance are not large.

Continue to draw a graph comparing the distribution of scores from the tests, the results are presented in Figure 1.

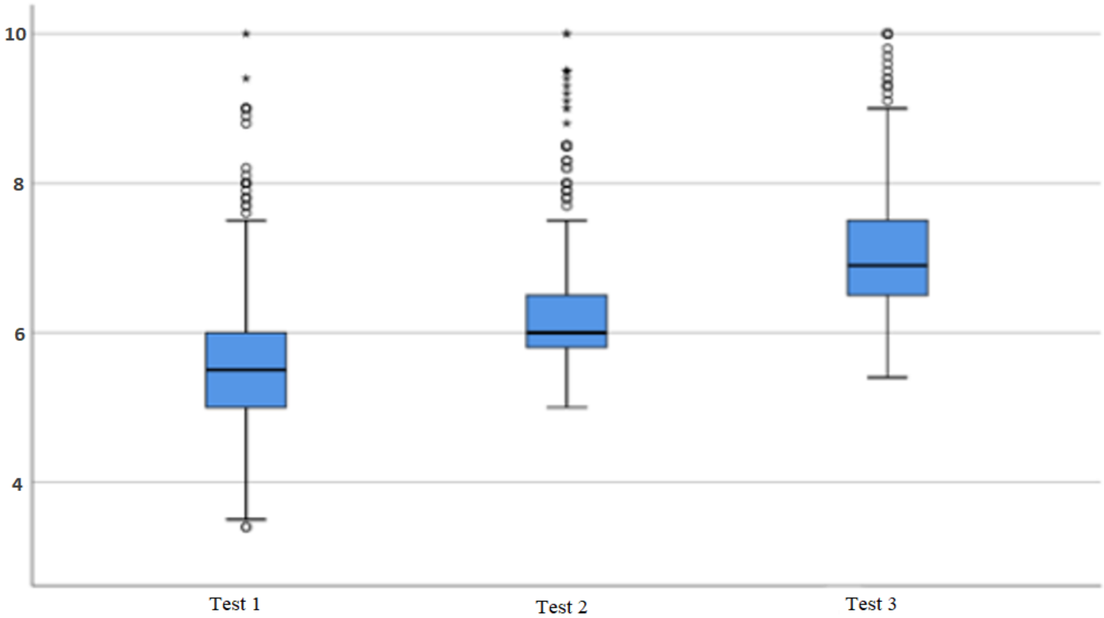

Figure 1. Boxplot graph representing test scores.

Note: * Bad data, can cause the model to be denormalized.

Figure 1's reveals that in the first test, the majority of students scored 6 or less, with a score difference ranging from strong to extremely strong. In the 2nd test, the proportion of students scoring 6 or less decreased to 50%, and in the 3rd test, there were only less than 25% of students with scores below 6, with no difference in the lower bound; scores from 9 or more are no longer a very strong difference in scores. Besides the average score of students increasing through the impacts, the group of students with poor scores no longer exists, and more students with high scores above 9 appear.

The study conducted a T-test (Paired Sample T-test) to verify the significance of the difference in the pair of students' average score values in the tests, whether it was random or due to effective effects of the pedagogical experimental teaching process. Test with hypothesis Ho: There is no difference between impacts; H1: There is a difference between impacts, shown by p-value (sig.) ≤ 0.05. Examines the t-test p-value at the 0.05 level, which corresponds to a significance level of 5% = 0.05 and a 95% confidence level. Table 5 presents the results.

Table 5. Paired mean value test of the average value of students' scores across tests.

Test	Mean	t-value	Sig. (2-tailed)
Test 1- Test 2	-0.7312	-34.221	<0.001
Test 2- Test 3	-0.7749	-34.044	<0.001

The results shown in Table 5 demonstrate that the average score of the post-test is always higher than the pre-test. At the same time, the average score difference between Test 3 and test 2 is higher than between test 2 and test 1. This proves that students have improved faster in test 3. With sig values <0.05 in all pairs of comparisons, this difference is statistically significant, occurring due to the impact of the training process.

Therefore, this result is similar to the one previously confirmed by Yuanli [25]: The process of integrating STEM education in teaching biology has a positive effect on the construction of abstract concepts and increases students' interest in learning.

4.2. Assess the Level of Development of Problem-Solving and Creativity Cap Competences

Problem solving and creativity competence include four skills: problem identification (KN1), proposing and selecting solutions (KN2), planning, implementing, and evaluating solutions (KN3), and report presentation (KN4). The level of problem solving, and creativity achieved through the impacts is shown in Figure 2. Chart analysis shows that the percentage of students at level 1 after the first impact is highest in all component skills, especially the problem identification component, which has the highest rate at level 1 (77.5%) and gradually decreases through impacts 2 and 3. Meanwhile, the percentage of students in Level 2 gradually increases from Impact 1 to Impacts 2 and 3. Through three impacts, the number of students reaching level 3 gradually increases in all skills. The increase in component competencies indicates that students' creative problem-solving competence has gradually improved through interactions.

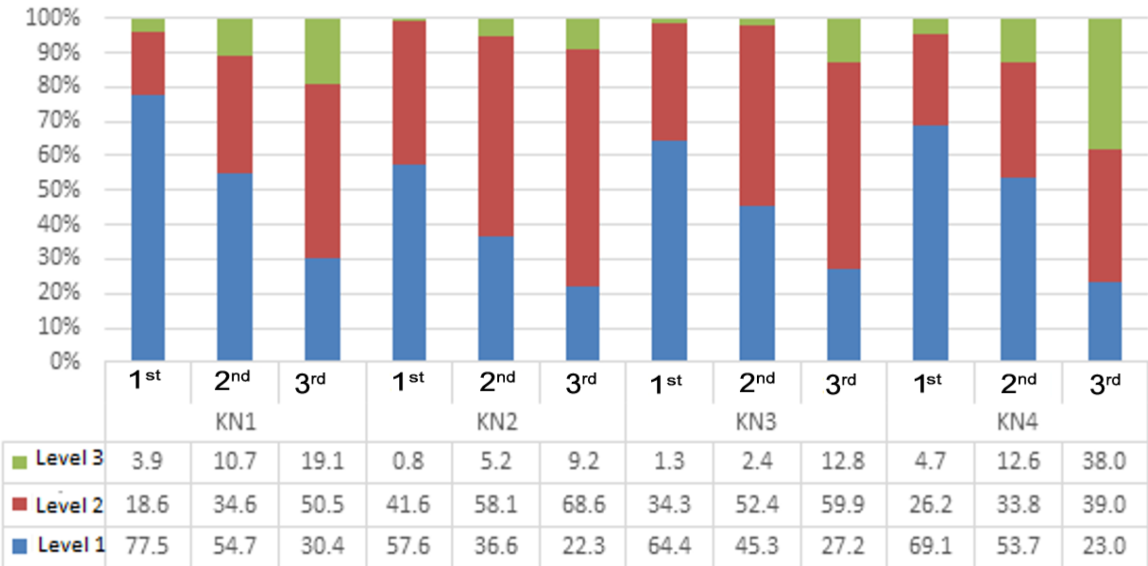

Figure 2. Graph of the percentage of students achieving different levels of the four skills of problem-solving and creativity through interactions.

The results of the average score of students in each skill and the average score of students on the overall 4 skills are also summarized and shown in chart Figure 3.

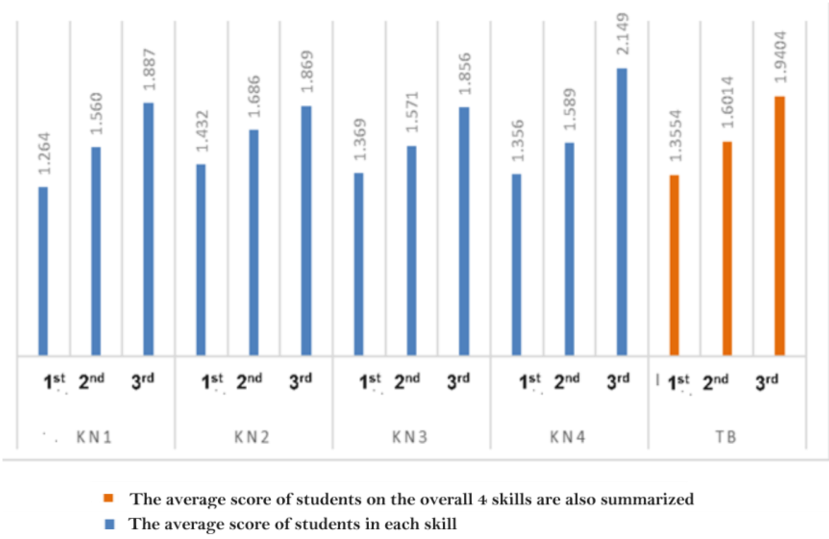

Figure 3. The average score for each skill and the average of all 4 skills of problem-solving and creativity through experimental assessments.

Thus, the average score achieved in all skill elements tends to increase over assessments in accordance with the change in the proportion of students at different levels of each skill on chart 3. The average results of general competence training across all 4 skills also tend to increase, respectively: 1.3554 in the 1st impact, 1.6014 in the 2nd impact, and 1.9404 in the 3rd impact. The Paired Sample T-test comparing the average value of 4 skills across impacts (Table 6) shows that the test coefficient Sig. (2-tailed) has a value less than 0.05, and the average value of the score in the next impact is greater than that in the previous impact, which is statistically significant (with a 95% confidence level), which shows that training results have increased.

Table 6. Test of pairwise average values of four skills across impacts.

Competence	Mean	t-value	Sig. (2-tailed)
Problem-solving and creativity 1 - problem-solving and creativity 2	-0.24607	-15.785	< 0.001
Problem-solving and creativity 2 - problem-solving and creativity 3	-0.33901	-21.162	< 0.001

Thus, the development of problem-solving and creativity competence in this study is consistent with the research of Hiğde and Aktamış [6]; Sarı, et al. [7]; Han, et al. [8] and Julia and Antolí [9]. These authors have confirmed that STEM education has a positive impact on students' scientific process skills as well as 21st century skills such as collaboration, critical thinking, and creative thinking. At the same time, this research result is also consistent with Bybee's research [17] that it is necessary to promote teaching methods to develop competence in solving problem situations, not just focusing on conceptual knowledge and processes in STEM subjects.

We conducted a One-way ANOVA analysis to test whether there is a difference in the average value of problem-solving and creativity competences (on the total of four component skills) in the three experimental schools. The results are shown in Table 7.

Table 7. Variance similarity test.

Competence		Levene statistics	Sig. value
Problem-solving and creativity 1	Based on average value	109.070	< 0.001
Problem-solving and creativity 2	Based on average value	36.376	< 0.001
Problem-solving and creativity 3	Based on average value	4.710	0.010

The value of sig. Levene's test < 0.05 shows that there is a difference in variance between schools, so use the

Welch test results in Table 8.

Table 8. Robust test for equality of mean values of problem-solving and creativity competences.

Competence		Statistics[a]	sig. value
Problem-solving and creativity 1	Welch	237.425	< 0.001
Problem-solving and creativity 2	Welch	50.124	< 0.001
Problem-solving and creativity 3	Welch	135.363	< 0.001

Note: a. Asymptotically F distributed.

The value of sig. Welch's test < 0.05 confirms that there is a difference in the average value of problem-solving and creativity between different schools. As a result, there are differences in the development of problem-solving and creative competence among different schools. Table 9 shows the descriptive parameters of problem-solving and creativity competence in each school.

Table 9. Statistical parameters describing problem-solving competence in experimental schools.

Competence	School	Average value	Standard deviation	Min. value	Max. value
Problem-solving and creativity 1	Olympia	1.769	0.549	1.00	3.00
	Minh Khai	1.430	0.219	1.00	2.00
	Ly Thuong Kiet	1.042	0.124	1.00	1.75
	Total	1.355	0.384	1.00	3.00
Problem-solving and creativity 2	Olympia	2.123	0.528	1.25	3.00
	Minh Khai	1.456	0.238	1.00	2.25
	Ly Thuong Kiet	1.538	0.299	1.00	2.50
	Total	1.601	0.407	1.00	3.00
Problem-solving and creativity 3	Olympia	2.571	0.364	1.50	3.00
	Minh Khai	1.899	0.291	1.00	2.75
	Ly Thuong Kiet	1.678	0.369	1.00	2.75
	Total	1.940	0.452	1.00	3.00

The average value of Olympia School increased from 1.7687 - 2.579 after three impacts, showing the development of problem-solving and creativity competence quite clearly. Meanwhile, the average value of Minh Khai School increased from 1.4303 - 1.8989, and that of Ly Thuong Kiet School increased from 1.0417 - 1.6780 after three impacts, showing the competence to solve problems and the creativity of the students of these two experimental schools has also initially developed, although not yet strong, and needs to continue to maintain a continuous and long-term impact. The different numbers of students in each class in the three schools can account for the differences in problem-solving and creativity skills in the three schools. At Olympia School, each class has a small student population (less than 25 students/class), and teachers have many opportunities to interact with each student during the teaching process and observe and support their practice. By implementing the problem-solving process in STEM-oriented teaching, problem-solving and creativity competencies can be developed faster.

5. CONCLUSION

Developing problem-solving and creative competence in students is one of the core goals of Vietnamese education. The research proposes a structure of problem-solving and creativity competence that comprises four component skills: problem identification (KN1), proposing and selecting solutions (KN2), planning, implementation, and evaluation of solutions (KN3), and report presentation (KN4). To develop students' problem-solving and creative competences, it is necessary to focus on developing all four of these component skills. The study has established the process for developing lesson plans and organising teaching biology for students according to their STEM education orientation. This process includes the following steps: (1) Determine the goals and duration of teaching; (2) Determine STEM teaching content; (3) Determine teaching methods and techniques, media, and materials; (4) Determine the teaching process; (5) Expected inspection and evaluation. From there, apply this process to teach 382 11th-grade students in Hanoi, Vietnam. The results show that, through the teaching process, students' problem-solving and creative competences increase over time, increasing students' interest in and love of biology. In classes with a small number of students, the effectiveness of developing problem-solving and creative competences for students is higher than in classes with a larger number of students.

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Institutional Review Board Statement: The Ethical Committee of the Olympia High School, Ly Thuong Kiet High School, and Minh Khai High School in Hanoi, Vietnam has granted approval for this study on 25 February 2023 (Ref. No. 11/OHS; No 8/LTK; No 14/MK).
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
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APPENDIX

Appendix 1 presents the test questions used during the research process.

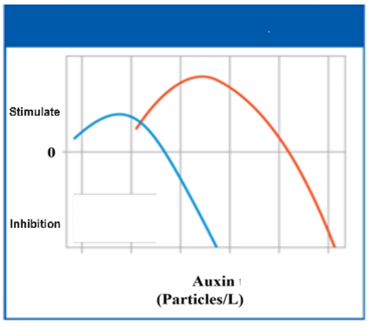
Test 1

Design an experiment to test which spectral components of light (monochromatic light) can cause light direction bending in plants. Answer the following questions:

1. (3 points) What basic knowledge do you need to design this experiment? Describe that knowledge in detail.
2. (1 point) What types of colored light will you investigate? Predict which color light causes the largest phototropic response?
3. (1 point) Design an experiment to find out which light color has the greatest influence on plant bending. (Illustrations can be drawn)
4. (1 point) How many experimental plants should be used for each color of light? What are the characteristics of the plants used in the experiment? Explain.
5. (1 point) What abiotic and biotic factors need to be investigated (observed and collected) in the experiment?
6. (1 point) How to connect and use Math tools, technology - information or other subjects to support you in the experimental process? Specify the specific subject or tool that supports that.
7. (1 point) How to control other factors so as not to affect the experimental results?
8. (1 point) The following image shows a student's experimental tray growing a type of vegetable. The tray is placed in a position where the light reaches the entire tray equally and is watered daily and evenly on the entire tray. Observing this image shows that: The vegetable plants at the edge of the foam box grow taller than in the middle of the box, tending to reach outside the box; Some vegetable plants in the middle area have white, softer stems and fall over. In your opinion, what factors could have influenced the growth of the vegetable plants in this experimental tray?

Test 2

1. If you remove the apical meristem from a plant, what will happen to the plant's growth afterward?
2. The following graph describes the results of an experiment on the growth of carrot cells grown in environments with different auxin concentrations. The blue line depicts the effect on root growth. The red line depicts the effect on stem growth.



a. What auxin concentration is the strongest stimulus for stem growth?

b. At the concentration of auxin that stimulates stem growth the most, what is root growth like?

c. If you were a carrot grower, what concentration of auxin would you use to stimulate the largest carrot roots (tubers) to grow? Explain.

3. Please tell us the factors that affect the growth of sprouts? In your opinion, which factor is the most important? Explain.

4. Design an experiment to test which parts of the plant respond to light.

Test 3

1. Compare the advantages and disadvantages of sexual and asexual reproduction in plants.

2. Apply knowledge about growth, development, and reproduction in plants, design experiments to evaluate the rooting of cuttings in a number of different types of plants.