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Context Evaluation in Nanotechnology Courses: A Context, Input, Process, and Product (CIPP) Model Perspective

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ABSTRACT

This study aims to evaluate aspects of the project-based nanotechnology lecture context to understand the description of the background conditions and course requirements that support the effectiveness and relevance of the curriculum applied to learning. The evaluation model used is Context, Input, Process, Product (CIPP), with a qualitative analysis design for documents such as Semester Learning Plans (SLP) and learning outcomes assessments. The evaluation results show that the existing curriculum and learning outcomes instruments do not fully reflect the needs of the growing nanotechnology industry. These findings indicate a mismatch between learning outputs and industry expectations, suggesting the need for regular curriculum updates and the integration of real applications and industry cases in teaching methods. Obstacles faced include students still not being familiar with the application of project-based laboratory inquiry learning and a lack of related knowledge. This study provides recommendations for strategic improvements in the curriculum aimed at increasing the relevance and effectiveness of nanotechnology learning, in line with the latest innovations and developments in the field.

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1. INTRODUCTION

Nanotechnology is the most impactful and innovative scientific discipline in recent decades, as its need and relevance in a globalized world become increasingly clear (Leigh, 2016). One very interesting aspect of nanotechnology is its growing impact throughout the world due to its widespread application in various fields, from health to energy and electronics. Thus, this topic is increasingly gaining recognition as a major part of supporting the world economy (Jackman *et al*., 2016). This creates an increasing need for nanotechnology education programs to meet current and future industrial and research demands (Barak and Usher, 2019).

To achieve the full potential of nanotechnology in society, currently, many schools (including primary and secondary education) and universities have provided exposure and reflection on the globalization of nanotechnology (Mandrikas *et al*., 2020; İpek *et al*., 2020; Curreli and Rakich, 2020; Khademhosseini *et al*., 2019) and nanoscience training. This course is offered primarily to students majoring in engineering fields (such as chemistry, mechanics, electricity and electronics, and even civil engineering) (Mohammad *et al*., 2012). In a university-level environment, the goal of this nanotechnology chemistry course is to equip students with a comprehensive understanding and technical and experimental skills necessary to work with materials at the nanoscale (including nanotechnology synthesis techniques and characterization) as well as motivate students to innovate and apply the principles nanotechnology principles in creating solutions to global problems, including health, environment, energy, and information technology.

Based on the previous perspective, the Nanotechnology Chemistry course offers excellent prospects for students to acquire chemical knowledge and apply skills through laboratory exercises. However, nanotechnology chemistry is different from other fields of chemistry (such as general and organic chemistry). This nanotechnology chemistry course includes the integration of various subjects (multidisciplinary) and approaches thus it demands great effort from students to understand it, especially when the relationship between the two is not explicitly visible, causing difficulties and challenges for students in understanding and applying their various knowledge thus ultimately has an impact on the decline in student interest in this course (Chu *et al*., 2023; Jackman *et al*., 2016). From this perspective, the challenges of nanoscience and nanotechnology education in a globalized world are very diverse.

Recently there has been a lot of interest in efforts to achieve 21st century skills where learning does not only focus on acquiring knowledge, such as incorporating project-based learning into chemistry laboratory courses considering the potential benefits of increasing scientific literacy, research skills, and scientific skills (Killpack *et al*., 2020; Grushow *et al*., 2021). The nature of a project in laboratory courses is identified by the inclusion of problems or questions, theory or background information, procedures or designs, analysis of results, communication of results, and conclusions (La Braca *et al*., 2021). As students are given increased independence and fewer answers (such as withholding experimental conclusions or guidance on communicating results), the depth of inquiry increases. This shift resembles the original scientific research process, which enhances the overall learning experience (Chu *et al*., 2023). Some research suggests that the use of project-based laboratories (laboratories that require students to utilize procedures and practices that professional scientists would use when developing new information) will increase students' enthusiasm and understanding of science (La Barca *et al*., 2021). Additionally, project-based laboratory experiments can demonstrate real-world situations and chemical imperfection reactions, allowing students to

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practice critical thinking and problem-solving skills. Additionally, project learning methodologies outperform standard laboratory practices that emphasize cookbook-style experiments (Morrison *et al*., 2020; Phillips *et al*., 2019).

One of the learning strategies in the nanotechnology course that has the potential to overcome challenges in nanotechnology learning is project-based learning (PBL). The application of PBL is due to centered on student activities whose learning output is producing products (Damayanti *et al*., 2014). Other studies also describe that PBL is learner-centered learning with a constructivist approach that allows students to work independently and collaboratively in the inquiry process to overcome complex and unstructured problems from real-life contexts. Then, the teacher's main role is to help configure their information during the process (Fidan and Tuncel, 2019). However, the effectiveness of a learning procedure depends on various factors, and aspects of educational management are closely related to comprehensive supervision of the learning process, which combines the application of various innovative learning models (Marlinda, 2012). Therefore, a comprehensive evaluation of nanotechnology courses is important to ensure the relevance and effectiveness of the educational material presented.

This study aims to evaluate the contextual aspects of project-based nanotechnology lectures at a university in the city of Bandung using the context, input, process, and product (CIPP) method. It is hoped that this analysis will provide valuable recommendations for other universities wishing to update or develop their nanotechnology programs.

Implementing evaluation in project-oriented nanotechnology courses has significant urgency in the current educational context, as it helps identify the strengths and weaknesses of current learning methods. In this way, educational institutions can make the necessary adjustments to improve the quality of learning and ensure that students are equipped with important skills. This evaluation helps in ensuring that the material taught remains relevant to the latest developments in nanotechnology; thus, this evaluation not only improves the quality of students' education and learning experience but also prepares them to enter the competitive world of work with the necessary skills. In addition, the evaluation also provides insight into new and innovative teaching methods that may be more effective in teaching nanotechnology courses.

2. METHODS

This research was designed to evaluate a project-based nanotechnology course at a university in Bandung City using the Context, Input, Process, Product (CIPP) evaluation method. Here, the evaluation is limited to context aspects, which focus on analyzing important information in program planning; thus, it provides a better picture of the background of this course, which is analyzed qualitatively and quantitatively. Analysis of input, process, and product aspects will be carried out in subsequent studies.

The parameters evaluated regarding project-based nanotechnology courses in terms of context include: (i) analysis of nanotechnology learning objectives from the results of semester learning plan (SLP) analysis at the university being evaluated; (ii) comparing the nanotechnology learning curriculum at the evaluated university with other universities as a standard through SLP analysis; (iii) analysis of the form of assessment of mastery of concepts and skills expected from students; (iv) analysis of lecture challenges; and (v) expectations of skills developed after implementing nanotechnology courses. Here, the universities used as references or standards are University 1 (University in the Sumatra Region), University 2

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(University in the Central Java Region), and State University 2 (University in the West Java Region).

Apart from that, this evaluation involved 7 seventh-semester students of the chemistry study program. The data collection methods used include providing questionnaires (as seen in **Tables 1**, **2**, and **3**) to find out the responses of students who have passed this course regarding the implementation of project-based inquiry learning and interviews to find out the obstacles that confront students during the learning implementation process (see **Table 1**). An evaluation regarding how nanotechnology chemistry courses can improve students' perceptions of project-based lectures, as well as students' interests and skills (especially research skills), whose respective questions are shown in **Tables 2** and **3,** was also carried out. The instrument used in this research is a questionnaire sheet to determine expectations of student responses after carrying out learning and interview guidelines. Quantitative analysis was carried out after recapitulating the questionnaire for each question item based on the criteria of very good (score 4), good (score 3), poor (score 2), and not good (score 1).

Table 1. Example of student obstacle survey questions.

No	Question	Percentage (%)
1	I did not experience significant obstacles in planning my project tasks.	
2	I had no difficulty collecting data for my project assignment.	
3	I am having difficulty organizing my project assignment data.	
4	I am having difficulty processing my project assignment data.	
5	I encountered problems presenting my project assignment data.	
6	Through learning with project assignments, I was unable to understand the chemistry of nanomaterials.	
7	I don't like learning nanomaterial chemistry through project assignments.	
8	I am confused about my project assignment grading system.	
9	I am happy with the implementation of project appraisals.	
10	I am interested in taking part in further project-based learning.	

Table 2. Example of survey question related to project-based learning and overall experiences.

Theme	No	Questions
Project-based learning course	11	The project-based learning part of this course was a good way to learn about the subject matter.
	12	The project-based learning part of this course enhanced my problem-solving skills.
	13	The project-based learning part of this course enhanced my critical thinking skills.
Overall experiences	14	This course motivated me to search for scientific information.
	15	I am more motivated to learn course materials when I see a potential application to society.
	16	I get personal satisfaction when I can combine my chemistry knowledge with applications.

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Table 3. Example of survey question related to students' research skills and students' interest (i.e., students' interest, research skills).

Theme	No	Questions
Interest in chemistry	17	I am interested in the field of chemistry
	18	I am interested in the field of nanomaterial chemistry.
	19	I know where I can find resources, including scientific literature, for a research project.
	20	I can generate research questions for a project.
	21	I can analyze and interpret the meaning of data/ observations from my lab experiments.
Research skills	22	I can create explanations for the results of experiments.
	23	I can solve problems in inorganic chemistry research.
	24	I can think critically about inorganic chemistry research.
	25	Whether the science content is difficult or easy, I am sure that I can understand it.
	26	I have come to think of myself as a "scientist".

3. RESULTS AND DISCUSSION

3.1. Analysis Results of Learning Objectives and Comparison of the Nanotechnology Curriculum with Standard Universities

Nanotechnology courses are facilitated in chemistry departments at the evaluated universities. The SLP for nanotechnology chemistry courses from the evaluated universities can be seen in **Table 4**. The nanotechnology chemistry courses are held in semester 7 with a workload of 3 credits as elective courses in the chemistry department at the evaluated university. However, this course becomes mandatory when the 7th semester students take the materials chemistry study group. Based on the SLP, there are seven materials related to nanotechnology at the evaluated university, which are distributed at each meeting as shown in **Table 5**. The course materials at the universities studied are compared with other universities as standards (Universities 1, 2, and 3, as mentioned in the method).

Based on **Table 5**, when compared with three other universities in Indonesia (based on SLP chemistry nanotechnology course in Sumatra (**Table 6**), in Central Java (**Table 7**), and West Java (**Table 8**)), the nanotechnology course at the evaluated university only presents the surface, not in depth, and is not broad, which shows that the study material is not relevant to the scientific study program and the demands in the field to train 21st century skills. The lack of depth and breadth of the study materials at the universities studied is proven by there are studies (listed in the standards) that are not discussed at the evaluation university, such as studies 1, 2, 3, 5, 6, 7, 8, 9, and 10.

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Table 4. Learning outcomes in nanotechnology from the universities studied

Classification within the curriculum:	Elective course / Elective Expertise Courses of Study Program (MKKPPS)
Workload:	Total workload is 90 hours 40 minutes (3.2 ECTS) per semester, which consists of 26 hours 40 minutes (0.9 ECTS) lecturer, 32 hours (1.1 ECTS) structured activities, and 32 hours (1.1 ECTS) self-study per week for 16 weeks.
Credit points:	4.8 ECTS (3 SKS), 1 SKS = 1.6 ECTS
Prerequisites cource(s):	(KI321) Introduction to Material Chemistry
Course learning outcomes (CLO):	After taking this course, the students have ability to: • CLO1. Explain the rules, description, syllabus, and course plans • CLO2. Analyze the overview of chemistry and nanotechnology, the definition, and the scope of nanomaterials • CLO3. Explain the basic principles of nanomaterial synthesis that consist of top-down process and bottom-up process • CLO4. Explain the principles of materials characterization • CLO5. Explain the process to synthesis and characterize materials for particle and film making • CLO6. Interpret how to purify nanomaterials (gas, liquid, and aerosol), including: centrifugation, filtration, and electrostatic filtration • CLO7. Explain the nanocomposites synthesizes

Table 5. Nanomaterial chemistry study content.

Meeting	Learning Materials	
	Evaluated University	**Standard University**
1	The term of nanomaterial	Introduction to nanotechnology and nanomaterials
2	Synthesis of nanomaterials through bottom up and top down methods	Molecular and intermolecular interactions
3	Nanomaterial characterizations	Basic principles of Nanotechnology (quantum effects and influence of size of matter)
4	Synthesis and structuring of materials to make films	Fundamental techniques in nanomaterial fabrication
5	Nanomaterial purification	Development of nanomaterials: Dimensions of nanomaterials (0D, 1D, 2D and 3D)
6	Synthesis of nanocomposites	Development of nanomaterials: Applications of nanomaterials
7	Nanomaterial applications	Nanomaterial composites
8		Functionalization of nanomaterials
9		Chemical and physical characterization of nanomaterials
10		Nanomaterial characterization techniques

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Table 6. Learning outcomes in nanotechnology chemistry at standard universities in the Sumatra region.

Learning Outcomes	**Study program learning outcomes imposed on nanotechnology courses**	
	Affective-9	Demonstrate a responsible attitude towards work in their field of expertise independently
	Affective-12	Disciplined, honest, objective and responsible for the development of chemistry based on biological and non-biological natural resources, motivated and responsive to environmental changes
	General Skill-1	Able to apply logical, critical, systematic and innovative thinking in the context of developing or implementing science and technology that pays attention to and applies humanities values in accordance with their field of expertise
	Psychmotor-1	Understand and be able to apply the concept of clean surfaces and how to obtain them, thermodynamics and dynamics of surfaces, spectroscopic methods to observe surfaces, solid surface and surface chemistry from catalysis, reaction mechanisms on surfaces and characterization of catalysis and its surface.
	Course Learning Outcomes (CLO)	
	CLO-1	1. Able to understand the size effect on nanomaterials
	CLO-2	2. Understand and apply nanomaterial synthesis methods
	CLO-3	3. Able to explain and understand the chemical and catalytic aspects of nanomaterials
	CLO-4	4. Able to apply the use of nanomaterials to solve environmental problems and other fields
Course Description	Master and understand the importance of nanomaterials for human welfare, size effect, general methods for nanomaterial synthesis, oxide nanomaterials, and optical properties of metal oxide nanomaterials, as well as environmental aspects of nanomaterials	
Study Materials: Learning Materials	1. Size effect on nanomaterials 2. General methods of nanomaterial synthesis 3. Chemical and catalytic aspects of nanomaterials 4. Use of nanomaterials to solve environmental problems and other fields	

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Table 7. Achievements of nanotechnology chemistry learning at standard universities in the Central Java area.

Graduate Learning Outcomes (GLO)	
Learning Outcome Code	**Elements of Learning Outcomes**
Affective (A)	Affective-9. Demonstrate a responsible attitude towards work in their field of expertise independently
General Skill (GS)	General Skill-1. Able to apply logical, critical, systematic and innovative thinking in the context of developing or implementing science and technology that pays attention to and applies humanities values in accordance with their field of expertise.
Knowledge (K)	Knowledge-1. Master theoretical and practical concepts
Special skill (SS)	Special Skill-2. Able to solve science and technology problems related to structure, properties and chemical changes at the micro and macromolecular levels, through experimental approaches, theoretical deduction or computing/simulation, and inter- or multidisciplinary approaches, characterized by producing work that has the potential to be applied in solving related problems science and technology
Course Learning Outcomes (CLO)	Students are able to review molecular interactions as a basis for understanding nanostructured materials (nanomaterials), then be able to connect the effects of quantum size and material size on the properties of nanomaterials from the development of nanomaterial studies, and design and develop top down and bottom up synthesis methods to obtain nanomaterials with dimensions (0D, 1D, 2D, and 3D) with their respective character traits.
Scientific Study Materials	Introduction to nanotechnology and nanomaterials, molecular interactions (intramolecular interactions and intermolecular interactions), basic principles of nanotechnology, quantum size effects, influence of material size, fundamental techniques in nanomaterial fabrication (top down and bottom methods), development of nanomaterials and their applications, material characterization (surface, structure, magnetic properties, thermal properties, etc.)

Apart from the depth and breadth of the course material, based on the results of the analysis in **Table 9**, the teaching materials also do not accommodate learning outcomes based on the curriculum and competency standards where the study of the material does not link to science, technology and everyday life, and the content of the teaching materials is not related to development of student skills such as logical thinking skills, critical thinking, and problem solving as stated in the learning objectives in the SLP of the university being evaluated. In essence, the teaching materials used in nanotechnology chemistry courses from the universities being evaluated are not relevant to current developments, because these teaching materials only present studies or general theories that students can actually search for themselves through googling.

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Table 8. Achievements of nanotechnology chemistry learning at standard universities in the West Java area.

Study program learning outcomes imposed on nanotechnology courses	
Knowledge	a. Understand concepts and applications in the fields of bioscience and materials chemistry to solve problems in the field of chemistry and its applications (CLO 5) b. Understand concepts and applications in the fields of bioscience and materials chemistry to solve problems in the field of chemistry and its applications (CLO 6)
Study Materials/Main Topics	
a. Introduction to nanoscience, nanomaterials, and nanotechnology	1. Understanding and development of nanoscience, nanomaterials and nanotechnology 2. Technology based on nanomaterials
b. Physical and chemical properties of nanomaterials	1. Nanomaterial size and physical properties and material performance (color, material characteristics, conductivity, magnetic effects and quantum effects) 2. Reactivity of nanomaterials 3. Explain the types and characteristics of nanomaterials based on their dimensions
c. Types of nanomaterials	Explain the types and characteristics of nanomaterials based on their dimensions
d. Applications and commercialization potential of nanomaterials	Applications and commercialization of nanomaterials
e. Ethics and risks of nanomaterial commercialization	1. Industrialization of nanomaterials 2. Development of research in the field of nanomaterials

Then, learning outcomes also only accommodate levels C1-C3 based on Bloom's Taxonomy when compared with standard SLP at three other universities in Indonesia (see **Table 4** and **Tables 6-8**). In fact, this nanotechnology chemistry course should be able to accommodate and train students' 21st century skills such as students' logical, critical, systematic, innovative and problem-solving thinking skills. Based on this, the Course Learning Outcomes (CLO) are assessed as not in accordance with the affective aspect (A), knowledge aspect (K), general skills aspect (KU), special skills aspect (SS), and the expected final ability.

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Table 9. Rubric for feasibility analysis of teaching materials.

No	Indicator	Score				Improvement sugesstion
		1	2	3	4	
	Organizing Teaching Materials Towards Achievement					
1.	Organization of main material and sub-material sequentially according to curriculum learning outcomes	√				
2.	Suitability of sub-material with main material in curriculum learning outcomes		√			
	Material Coverage					
3.	The material presented at least reflects the substance of the material contained in the competency standards		√			
4.	The depth of sub-material in teaching materials is in accordance with learning resources	√				
5.	The depth of sub-material depends on the maturity of students' thinking and whether or not there is material development			√		
	Concept Truth					
6.	Connecting science, technology and life		√			
7.	Suitability of sub-material in teaching materials with the concepts put forward by experts			√		
8.	Explanation of activity concepts according to the level of students		√			
9.	There are learning indicators for each activity	√				
	Contents of Teaching Materials					
10.	Concept relationships relate to everyday life	√				
11.	Emphasizes process skills	√				
	Teaching Material Innovation					
12.	Integrated one model that suits the curriculum	√				
13.	Innovative with a problem-based approach	√				

3.2. Analysis Results of Assessment Forms in Nanotechnology Lectures

In this nanotechnology chemistry course, there is no clear assessment rubric. In fact, lectures run with a project-based model which is expected to accommodate broad learning objectives, namely increasing knowledge and skills training (such as logical thinking, critical thinking, researching and solving problems) as stated in the standard SLP (Pratama *et al.*, 2023; Abdul *et al.*, 2022; Istiningsih *et al.*, 2024).

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Until now, assessments carried out in nanotechnology courses at universities that are evaluated only look at students' ability to write reports after they have carried out project-based lectures. It is felt that assessing only the report writing aspect does not appreciate the student's efforts because the assessment of the process when students complete the project is not included. In short, the assessment carried out is only a results-based assessment. In fact, an important aspect that must be criticized is the assessment when students complete a project (aside from looking at the results aspect) because it relates to the various skills that are deployed when students complete a project (Tolan *et al*., 2019). Based on field studies, the assessment rubric used in nanotechnology chemistry courses does not accommodate the assessment of all students' potential, especially the assessment of skills such as critical thinking, research, and problem-solving.

The solution needed regarding the assessment system in nanotechnology chemistry courses is to provide student performance-based and test-based assessments. It is hoped that this performance assessment can authentically assess students' ability to apply concepts in real situations and train students to have a positive mental attitude (Irma *et al*., 2023). This student performance assessment is obtained from the results of the assessment of pre-project activities, project activities, and project reports. Increased student preparation for actual activities during the project is known from pre and post-project results. Then, several test instruments also need to be designed to measure student skills such as logical thinking, critical thinking, and problem solving. These instruments can be very useful in academic settings to identify students' strengths and weaknesses in critical thinking and problem solving, as well as to improve curricula and teaching methods. However, it should be noted that when selecting instruments to measure skills (such as logical thinking, critical thinking, and problem solving, etc.), it is important to consider the relevance of the test to the specific needs and educational context at hand. This test instrument is also useful for analyzing concept mastery, which is designed to assess not only students' surface knowledge about a topic but, more importantly, students' deep understanding of these concepts, including the ability to explain, interpret, and integrate concepts in various situations.

To gain a comprehensive and holistic overview of student achievement and skills, it is critical to implement a balanced assessment approach. This balanced assessment combines various types of assessment, including performance assessments and traditional tests. Then, this combination of assessments also serves as more complete and varied feedback for students, supporting various learning styles and helping them develop a wider range of skills.

3.3. Analysis Results of Nanotechnology Course Challenges

Student responses regarding the obstacles to project-based learning as a whole were obtained from a questionnaire (details of the questions are in **Table 1**) given to students who had gone through project-based nanotechnology learning, which is presented in **Figure 1**. The results of the student response questionnaire in **Figure 1** show that question number 1, 2, 3, 4, and 5 represent students' responses to the stages of completing project assignments, question number 6 shows students' responses regarding self-assessment of material assignments through giving project assignments, question item number 7 represents students' responses regarding whether they like or not learning through project assignments, questions number 8 and 9 show students' responses regarding the implementation of the project assessment system, and question number 10 shows students' responses regarding their interest in participating in similar learning.

The results of the questionnaire in **Figure 1** show that several students still experience obstacles or difficulties during the project assessment-based learning process (based on

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percentages in questions 1-5). Based on the survey answers in **Figure 1**, most students experience problems in organizing (question number 3), analyzing and interpreting (question number 4), and presenting data (question number 5), which shows that project-based learning is still used very little in nanomaterials courses.

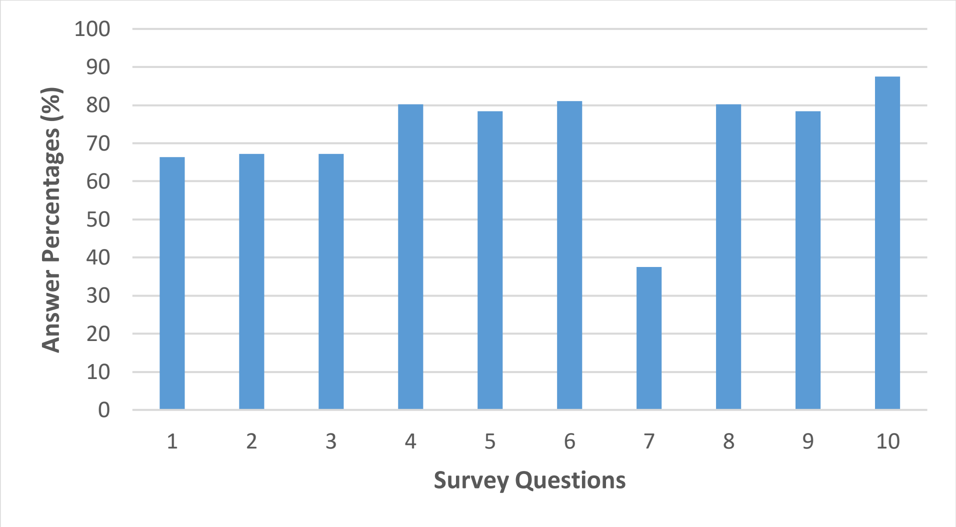

Figure 1. Responses to survey questions regarding overall barriers to implementing project-based learning in nanotechnology courses.

Barriers around their project data sources were developed during the data collection phase. Meanwhile, many students experience difficulties in compiling data because the format and data collection strategies are not mentioned in their project assignments. This is done for students can gain critical thinking skills in identifying appropriate formats and ways of organizing data for data sources and project tasks. These barriers can be overcome by offering scaffolding and suggestions regarding data organization approaches (Doo *et al*., 2022).

It was found that there were student obstacles in processing data caused by students' lack of understanding of data analysis. While not all students face this challenge, a lack of understanding of data analysis will hinder the completion of their projects. Another problem that arises is when students feel that the calculations are too difficult and have not been discussed in previous sessions. On the positive side, this can motivate students to learn more about data analysis concepts and be more careful in their calculations. In addition to these two challenges, some students believe that they still have little knowledge about how to use computer applications that can simplify and speed up their data processing.

Meanwhile, although almost all students said that they had no difficulty in presenting data (questions 1 and 2), some students argued that they experienced problems due to a lack of skills in presenting data. In this scenario, because the problem is only experienced by a small portion of the population, the implementation of learning can take advantage of the presence of peer tutors in the group (Moumoulıdou *et al*., 2020; Carvalho *et al*., 2022).

Based on the findings of the student response questionnaire regarding the implementation of project-based learning (items 6, 7, and 10), students gave "good" responses at the stages of completing project assignments, self-assessment regarding mastery of material through giving project assignments, whether they enjoyed/didn't learn through project assignments, and implementation of a project assessment system. Statements regarding students' interest in similar learning elicited different responses, especially "very good". Based on the student response criteria, the student response to each statement item in the questionnaire is

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included in the "good" or "very good" category, which shows that the student response to project-based learning in the nanomaterial chemistry course is good.

This good response from students may be because project-based learning is rarely included in daily lectures. Learning can take place on campus or off campus with project-based learning, so students are motivated to complete it. Furthermore, project-based learning focuses on applying knowledge to real-world problems. This encourages students to play an active role in developing their creativity and immediately apply what they learn in class. However, because the assessment methodology was unclear (questions 8 and 9), some students responded "not well" to this project-based learning. The assessment approach in this course is only based on the evaluation of report writing, which is deemed unfair for students who are not good at writing, and also unfair for students because the assessment does not reflect the learning process (Tolan *et al*., 2019).

Although students generally respond positively to project-based learning, there are still barriers to its implementation. Based on the interview results described in **Table 10**, it can be seen that students face problems at every level of project assignment completion. The most difficult challenge for students in the preparation stage is determining the theme to be discussed in the project assignment, and the feeling that they do not have enough time to design the project. This is because they are still not used to project assignments, which require them to determine and design their projects based on the tasks given to them. As a result, they need additional time to plan their tasks. In project-based learning, in addition to the ability to plan, collect, organize, process, and present data, solid time management skills are required to ensure projects are completed on time (Chu *et al*., 2023).

Table 10. Results of interviews with students regarding obstacles during project-based learning.

Learning activities	Obstacles
Project task planning	• Students are confused about deciding which topics related to nanomaterials will be discussed in the learning • Students are confused about determining the novelty of the topic raised • Students do not receive enough material provisions • Students receive less direction • Students feel that the time provided is not enough for planning
Project task data collection	• Students have difficulty obtaining data • Students have difficulty understanding data collection methods because what they learn is only based on reading literature • Students have difficulty operating tools when collecting data • The delivery of information on the use of tools is uneven, so that some students do not get the information
Data organization	• Students are confused about the format for organizing data • Students lack knowledge of data organizing techniques
Data processing	• Students lack understanding of interpreting data • The calculation process is complicated • Students lack knowledge regarding how to analyze data using computer-based applications
Data presentation	• Students lack knowledge of data presentation techniques

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3.4. Expectations of Skills Developed after Implementing the Nanotechnology Course

When asked about their overall course experience (questions 11–16 in **Figure 2**), nearly all students agreed or strongly agreed that the course motivated them to seek out scientific information and that they were more motivated to learn the course material when they saw the potential application of the learning in society or the environment. All seven students strongly agreed that combining their chemistry knowledge with applications would provide personal satisfaction, and six of the seven students strongly agreed that nanotechnology chemistry courses became more interesting when they connected with their own beliefs. These findings suggest that providing students with autonomy and opportunities to relate information to real-world applications, as we do in our courses, can result in more enjoyable experiences (Almulla, 2020; Nkerja *et al*., 2020; Rohm *et al*., 2021; Green & du Plessis, 2023).

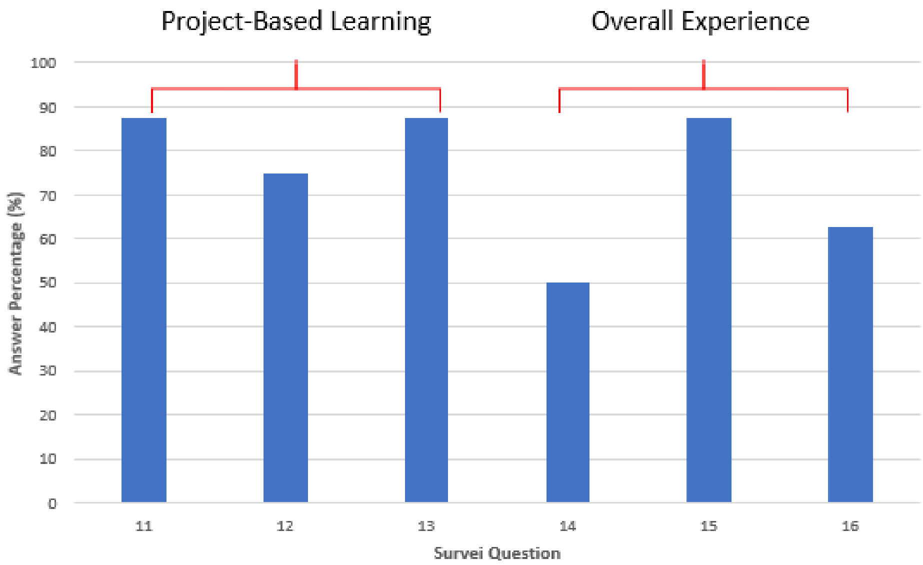

Figure 2. Frequency of student responses to the impact of project-based learning and overall experience.

Pre/post course survey data for questions about students' interests and science research skills, as shown in **Figure 3,** were also collected. Detailed questions related to student interests are shown in **Table 3**. The results of student interest in project-based nanotechnology courses show that students have a strong interest in chemistry in general, not an interest in nanotechnology. It is worth noting that these students started with a much stronger interest in Chemistry (average strongly agree) compared to Nanomaterials Chemistry (average disagree). The lack of student interest in these nanotechnology courses is because these courses generally cover a variety of topics and methodologies that require comprehensive efforts for students to understand, especially if they are not related (Chu *et al*., 2023). Except for questions 21 and 22, we found a significant increase in interest in most questions about students' research skills because this course tests their ability to search for resources for a research project (Question 19 in **Figure 3**), generating research questions for a project (Question 20 in **Figure 3**), solving problems in nanomaterials chemistry research (Question 23 in **Figure 3**), thinking critically about inorganic chemistry research (Question 24 in **Figure 3**), and understanding science content in general. Students also showed a slight increase in their self-perception as “scientists” (Question 26 in **Figure 3**).

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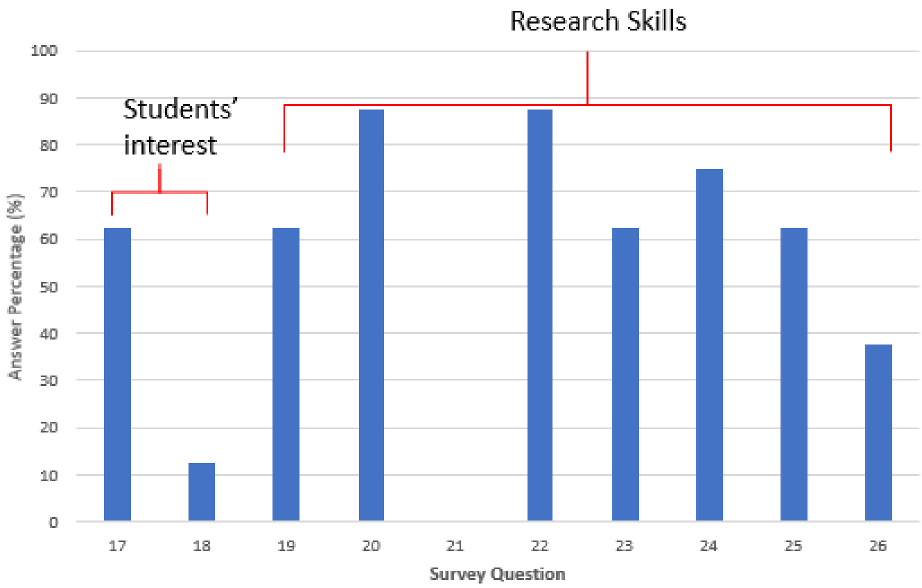

Figure 3. Survey data for questions about students' science research interests and skills.

Based on questions 21 and 22, students experience problems in analyzing, interpreting, and explaining the data obtained for several reasons, including:

(i) Students may only have limited experience, thus, students may lack exposure or experience in handling difficult data analysis tasks (Baghoussi and Zoubida El Ouchdi, 2019).

(ii) Lack of understanding of analysis tools and processes (Anazifa and Djukri, 2017).

(iii) Insufficient direction of data analysis techniques, thus they may have difficulty interpreting the information collected during the investigation project (Usman and Madudili, 2020).

(iv) The complexity of the data can be overwhelming for students, especially if they are not well prepared, because project-based learning requires students to manage complex data sets or disparate information, making it difficult for them to draw meaningful conclusions (Hilliard *et al*., 2020).

(v) Lack of critical thinking skills because understanding and interpreting data requires strong critical thinking skills. Students may have difficulty approaching data analysis systematically and in-depth if they have not developed these skills through previous educational experiences (Monalisa et al., 2019).

(vi) Limited exposure to the scientific process during the scientific investigation process, including how to formulate hypotheses, design experiments, and draw valid conclusions. This lack of understanding can interfere with their ability to examine and interpret data appropriately (Okyere *et al*., 2019).

(vii) The communication challenge of articulating findings and explanations coherently is an important aspect of the investigative process. Students may face challenges in expressing their thoughts and interpretations clearly and scientifically (Judge *et al*., 2011).

(viii) Time constraints and pressure to complete the project within a certain time frame can hinder their ability to analyze and interpret data thoroughly (Kindomba *et al*., 2021).

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4. CONCLUSION

Studies conducted to evaluate context aspects in project-based nanotechnology lecture programs using the CIPP evaluation model have provided an overview of how background conditions and educational requirements influence the effectiveness and relevance of the nanotechnology lecture curriculum. Document analysis, especially the SLP and learning outcomes assessments, shows that the curriculum is not yet in line with the current needs of the nanotechnology industry.

The teaching materials used in project-based nanotechnology learning at the evaluated universities still present only the surface part which is neither deep nor broad, which shows that the study materials are not relevant to the science of the study program and the demands in the field to train 21st century skills (such as logical thinking, thinking critical, and problem solving). The learning process has been accommodated through good methods, namely the project method, to achieve comprehensive learning goals (mastery of material and practicing 21st century skills. Although project-based learning methods are very good in developing practical skills and problem solving, deficiencies in the delivery of theoretical material can result in Inadequate conceptual understanding. Students need a strong theoretical understanding as a foundation for developing practical and innovative solutions. In addition, assessments that still focus on mastering concepts but are not supported by adequate theoretical teaching will cause difficulties for students in achieving good assessment scores. Furthermore, if the assessment does not measure general and specific skills that are relevant to future needs (even though learning is very accommodating for training those skills).

Some suggestions for improvement include: (i) design assignments and projects in such a way that theoretical learning is integrated with practical application. For example, before the project begins, students can be given intensive learning or workshops on the basic concepts that will be used; (ii) strengthen theoretical modules in the curriculum to ensure that students have a strong conceptual understanding before applying them to projects; (iii) develop assessment instruments capable of measuring not only theoretical mastery but also important skills such as problem solving, creativity, and collaboration. For example, using a project portfolio that includes documentation of work processes, innovative solutions, and students' reflections on challenges faced during the project to better measure the effectiveness of students' learning and skills holistically; and (iv) evaluate and revise the assessment methods used. Ensure that assessment methods include a comprehensive evaluation, not only of mastery of concepts but also of practical application, problem solving, and critical skills.

Based on the results of interviews, it turns out that students gave a "positive" response to project assessment-based learning. Obstacles always arise when trying new things, including carrying out learning. Obstacles faced by students in the project-based learning process include confusion in determining the project topic, lack of direction and planning time, difficulty obtaining data, confusion with data formats and organizing techniques, lack of understanding in data processing, difficulty in the complexity of the calculation process, and lack of analytical knowledge. Data using computer applications, as well as a lack of knowledge of data presentation. The obstacles that arise here are related to students' unfamiliarity with project-based learning and a lack of related knowledge. Additionally, based on the results of this research, project-based courses provide students with a more realistic and engaging experience of the nanotechnology course. We also state that this course provides learning opportunities that train students' research skills. The hope is that this course can have an impact on student activity in the learning process and improve their learning outcomes. By

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implementing this learning, we also hope that students can get used to planning, collecting, organizing, processing, and presenting data both in lectures and outside lectures/classes.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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