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Development of STEM-Based Teaching Supplements Assisted by Gram Staining Practicum to Optimize Students' Critical Thinking and Science Process Skills

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Abstract

Changes in the learning paradigm in higher education develop along the times. In the 21st century, one of the roles of higher education institutions is to act as a liaison with changes in the job market. Minister of Education and Culture No. 3 in the year 2020 states that the two of several characteristics of the learning process in the KKNI curriculum are integrative and scientific. The teaching supplements were developed as an effort to fulfill the integrative and scientific characteristics. This research examines the validity and practicality of the developed teaching supplements and looks toward the effect on students' critical thinking skills and science process skills. This research was conducted using the research and development method and the model used was the ADDIE model. The developed teaching supplement has very valid and very practical criteria so that it can be applied to research samples with minor revisions. Then, the developed teaching supplements are proven to be able to optimize students' critical thinking skills and science process skills. In addition, this research also reveals that critical thinking skills are correlated with science process skills.

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INTRODUCTION

Changes in the learning paradigm in tertiary institutions develop along with the times (Sailah *et al.* 2014) . In the 21st century, one of the roles of higher education institutions is to act as a liaison with changes in the job market. Based on this role, the government issued Permendikbud No. 3 of 2020 concerning Higher Education National Standards (Kemendikbud, 2020) .

Minister of Education and Culture No. 3 of 2020 Article 11 paragraph 1 states that the characteristics of the learning process in the KKNI-based learning include having an integrative and scientific nature. The integrative nature means that the learning process carried out to fulfill Graduate Learning Outcomes (CPL) is an integrated learning process through an interdisciplinary and multidisciplinary approach. The scientific nature means that CPL is achieved through a learning process that prioritizes a scientific approach so as to create an academic environment based on a system of values, norms and principles of science (Kemendikbud, 2020) .

The university that implements the KKNI-based curriculum in Cirebon is IAIN Syekh Nurjati. One course in the 2021/2022 academic year is Microbiology. Microbiology is a course in semester 4 and is a practicum course with 3 credits (3/0). In practice, if you review the two learning characteristics set out in Permendikbud No. 3 of 2020, the practical guidelines used in the Microbiology course on the topic of Gram staining have not been integrated with other disciplines and do not use guidelines that emphasize scientific characteristics.

This study examines the development of teaching supplements that facilitate Microbiology learning by taking into account the two characteristics of KKNI-based learning. To achieve students' critical thinking skills listed in CPL Microbiology and pay attention to a scientific approach in the scientific nature of KKNI-based learning, this research trains students' critical thinking skills and science process skills, especially on the topic of Gram staining.

This study uses an interdisciplinary approach in the form of a STEM approach as a means to emphasize the integrative nature of KKNI-based learning. The STEM approach is used to analyze the results of observations from practicum activities. According to Kapila & Iskander (2014) , learning using STEM can encourage students to design, develop, hone cognitive, and apply knowledge.

Type of assignment uses STEM which can train critical thinking skills including the preparation of project reports, analysis reports, designs, and essays (Felder & Rebecca, 2016). The process of data analysis can be found one of them in practicum activities. Practical activities can also help students practice critical thinking skills (Lambrechts, 2014) . Practical activities can also train students' science process skills (Jirout & Zimmerman, 2015) .

Science Process Skills (KPS) are skills used to understand phenomena that occur (Toharudin *et al* . 2014) . Science process skills require higher order thinking skills (Mutammimah et al. 2019) . Higher order thinking skills have an important role during learning activities in the classroom. This ability also has an important role in competition in the world of work so that it can support student careers in the future (Hasruddin et al. 2017) .

According to Farkhodovich et al. (2022) , the teacher's critical view of learning activities is the key to evaluation activities. In line with this, Donnelly & Fitzmaurice (2005) said that an optimization is needed in planning the implementation of learning so that the quality of the student learning process is also optimal and observable. This study examines the optimization of STEM-based teaching supplements assisted by Gram staining practicum on students' critical thinking skills and science process skills .

METHOD

This research was carried out at the Practicum Course of Microbiology on the topic of Gram staining, Tadris Biology Study Program, IAIN Syekh Nurjati Cirebon. The research process, from analyzing problems to implementing teaching supplements, took approximately nine months, starting from 1 January 2022 to 30 September 2022. The research took place at the MIPA Laboratory of IAIN Syekh Nurjati Cirebon.

Research was conducted using research and development methods or *Research and Development* (R&D). The R&D research model used this time is the ADDIE model with five stages of development, namely: 1) Analysis ; 2) Design; 3) Development; 4)

Implementation (Execution); and 5) Evaluation (Feedback).

The analysis phase includes the process of analyzing the needs of teaching supplement development. Then the design stage includes the process of designing the required teaching supplements. At the development stage, the preparation of learning supplements began from materials, experimental guides, to evaluation questions. After being made by the researcher, the product will then be validated by each of the three lecturers for material and media aspects. The validity criteria for teaching supplements assessed by the validator have at least moderate validity according to V Aiken with a value range between 0.4-0.8.

The developed STEM-based teaching supplement is a worksheet that is arranged in accordance with the composition of the Student Worksheet (LKS) according to the Ministry of National Education in 2008. After carrying out the needs analysis process and designing the worksheet taking into account the worksheet components and research objectives, the worksheet is modified with a *Project sheet. Prospectus* according to Angelo & Cross (1993) . This stage also includes a limited trial process that will produce data regarding the practicality of teaching supplements. The trial process involved 15 students who had already taken the Microbiology course. Judging from the practicality of supplements, teaching supplements are declared feasible to be given to students after meeting the minimum practical criteria with a percentage of 60%.

In the implementation phase, the research design used was one group pretest-posttest design. The one group pretest-posttest design consisted of one research sample group which in this study were 36 Biology students at IAIN Syekh Nurjati Cirebon . In this design, the test was carried out twice, namely before being given the treatment (pretest) and after being given the treatment (posttest). This stage generates data regarding critical thinking skills through *pretest-posttest activities* and the value of science process skills in students through observation activities .

The evaluation process is the final process of the ADDIE development model. In the evaluation stage, an analysis will be carried out to measure the optimization of the application of STEM-based teaching supplements to students' critical thinking skills. The classical completeness criterion as a parameter for the successful application of learning supplements to critical thinking is that ≥75% of students at least achieve an increase in the *N-Gain score* in the medium category ($0.7 \geq g \geq 0,3$) and achieve a quality grade of B (75.00) according to the KKM for Biology Courses (MKK) including Microbiology courses at Tadris Biology IAIN Syekh Nurjati Cirebon. The optimal criterion for science process skills is that ≥75% of students achieve a minimum score in the good category ($x > 70$).

Students' science process skills are measured by eight indicators of science process skills according to Sanderson & Kratochvil (1971) . These indicators are: 1) observing ; 2) measuring ; 3) inferring ; 4) classify ; 5) predicting; 6) using number ; 7) using space/time relationships ; and 8) recording & displaying data. The indicators of critical thinking skills used are five according to indicators Fisher (2009) . The five indicators include: 1) identifying the elements in the case being considered, especially the reasons and conclusions; 2) clarify and interpret statements and ideas; 3) assess acceptability, especially credibility and claims; 4) analyze, evaluate and produce explanations; and 5) analyze, evaluate and make decisions.

RESULTS AND DISCUSSION

The Validity and Practicality of STEM-Based Teaching Supplements Assisted by Gram Staining Practicum

In this study, teaching supplements were validated by material and media validators. The results of validating these two aspects can be seen in Table 1. The validation results by the validator, both the material field validator and the media validator, show that the worksheet developed is very valid.

Table 1. The Validity of Teaching Supplements

No.	Validators	Average Validation Value	Criteria
1.	Material Validators 1		
2.	Material Validators 2	0.86	Very Valid
3.	Material Validators 3		
4.	Media Validators 1		
5.	Media Validators 2	0.86	Very Valid
6.	Media Validators 3		

The material and media validators each provide written suggestions for improvement in teaching supplements. Overall, the suggestions given by the media validator are to improve *the cover* and improve the identity of the researcher listed on the *cover.* While the material validator provides several suggestions, including repairing *gaps* in the introduction section, adjusting objectives with student activities, improving the editorial statements in the observation and discussion sections.

The development of STEM-based teaching supplements is an effort to be able to fulfill learning that is in accordance with the KKNI-based learning. In particular, there are two learning principles in the KKNI which are realized through the developed worksheets. The first principle is integrative learning. Then the second principle is scientific learning.

The developed STEM-based teaching supplement is a worksheet that is arranged in accordance with the composition of the Student Worksheet (LKS) according to the Ministry of National Education in 2008. After carrying out the needs analysis process and designing the worksheet taking into account the worksheet components and research objectives, the worksheet is modified with a Project sheet. Prospectus , so that it becomes a worksheet that is not only in accordance with the 2008 Ministry of National Education but also in accordance with the research objectives. According to Angelo & Cross (1993) , Project Prospectus refers to a type of higher-order thinking assessment in tertiary institutions which includes work plans. Teaching supplements will be applied in class using the Guided Inquiry (GI) model. Table 2 below is the results of a limited trial for final year students who have taken Microbiology courses.

Table 2. Practicality of Teaching Supplements

Details Number of participants	Details of Practicality Value (%)	Average Value of Practicality (%)	Criteria
14 people	93.33	93.86	Very practical
1 person	6.67		

In addition to providing ratings on a numerical scale, limited trial participants also provided written suggestions. Suggestions are given in the form of suggestions on the display or on statements or questions that are not clear. Suggestions on the display section between Another way is consistency and the addition of the width of the tools and materials column as well as the answer column in certain sections. Then suggestions in the question section include improving the editorial instructions for practicum in several sections and adding stimulus sentences to the introductory section. After going through several revisions, the worksheet is ready to be applied to the research sample.

Optimization of STEM-Based Teaching Supplements Assisted by Gram Staining Practicum for Critical Thinking Skills

After teaching supplements are considered very valid and very practical, the next research step is to apply teaching supplements to research samples. The results of the study show that through the application of STEM-based teaching supplements it can improve students' critical thinking skills. This is characterized by the N-Gain value on the research sample.

The N-Gain values obtained by students are in the medium and high categories. As many as 31 students have N-Gain with high criteria and 5

students have N-Gain in the medium category. For posttest scores, as many as 34 students achieved a minimum *posttest score with* a grade of B (8 0 ≥ x ≥ 75). The data can be seen in Table 3.

Table 3. Category of Posttest Scores and N-Gain for Research Samples

Mark	Criteria	Number of Students	Total Participants	Percentage (%)
N-Gains	High Criteria	31 people	36 people	86.11
	Moderate Criteria	5 people		13.89
Posttest	Grade A (≥ 90)	9 people	36 people	25
	Grade A- (90 ≥ x ≥ 85)	10 people		27.78
	B+ grade (85 ≥ x ≥ 80)	13 people		36.11
	Grade B (8 0 ≥ x ≥ 75)	2 persons		5.56
	Grade B- (7 0 ≥ x ≥ 65)	2 persons		5.56

Table 4. below shows the average value *of* N-Gain for each indicator of Critical Thinking Skills (KBK) at the pretest, posttest, and N-Gain values . From Table 8, it can be seen that the indicator with the smallest pretest value is the KBK 4 indicator, while the largest pretest value is the KBK 1 indicator. For posttest scores, the smallest value is shown in the KBK 3 indicator and the largest value is found in the KBK 4 indicator. In the end, the score The N-Gain with the smallest value is owned by the value on the KBK 3 indicator and the N-Gain with the largest value is owned by the KBK 4 indicator.

Table 4.4 The Average N-Gain Value of Each KBK Indicator

No.	The Indicators of Critical Thinking	Pretest Value	Posttest Value	N-Gain Value
1.	Identify the elements in the case under consideration. especially the reasons and conclusions (KBK 1)	49.72	83.89	0.68
2.	Clarifying and interpreting statements and ideas (KBK 2)	27.22	87.50	0.83
3.	Assessing acceptability. especially credibility and claims (KBK 3)	26.67	77.50	0.69
4.	Analyze. evaluate and produce explanations (KBK 4)	22.22	88.61	0.85
5.	Analyze. evaluate and produce decisions (KBK 5)	28.89	85.00	0.79
Average Value		30.94	84.50	0.77

Critical thinking skills can be improved through the application of worksheets (Fahyuni et al. 2019). It can also be improved through practicum activities (Lambrechts, 2014; Irwanto et al. 2019) , using the STEM approach (Topsakal et al. 2015; Hacioglu & Gulhan, 2021; Simanullang et al. 2022) , and using the Guided Inquiry (GI) model (Azizmalayeri et al. 2012 ; Seranica et al. 2018 ; Sutoyo et al. 2019 ; Febri et al. 2020; Phonna et al. 2020) .

The results of this study are in line with these studies. The N-Gain value illustrates that there is an increase in critical thinking skills. The STEM approach is used as an approach in completing investigative activities during practicum activities. Investigative activities in question are activities to find solutions to the problems described as the basis for implementing practicum.

Investigative activities are science learning activities in an inquiry approach (Petersen, 2014) . Inquiry learning can train the dimensions of coordination, explanation, and evaluation (Elkhidir, 2020) . An inquiry approach can enhance STEM learning (Lai, 2018) . The use of inquiry in STEM learning can be done by: 1) guiding students to build opinions; 2) did not answer 'yes' or 'no'; 3) try to realize the mistakes of students; 4) provide opportunities for students to be able to carry out peer assessments; 5) trying to increase student participation (Kaya & Sardag, 2021) .

This study uses the STEM content inclusion model according to Kelley et al. (2021) . In

accordance with this model, this study uses only one class in implementing the STEM approach. In addition, the STEM learning process is carried out only by adding one or more STEM content in the classroom. Practicum activities and STEM delivery models in research are carried out using the stages of the guided inquiry model.

Based on the percentage of N-Gain and posttest scores, it can be said that the application of STEM Based Project Prospectus is optimal for critical thinking skills. Because ≥75% of students achieve N-Gain in the minimum criteria being moderate and ≥75% of students achieve a minimum posttest equivalent to a B grade (8 0 ≥ x ≥ 75). This study proves that practicum activities using the STEM approach in teaching supplements are optimal for critical thinking skills.

Optimization of STEM-Based Teaching Supplements Assisted by Gram Staining Practicum on Scientific Process Skills

The application of STEM-based worksheets can affect the formation of science process skills in research samples. It was proven in this research that 55.56% of the research samples had science process skills in the very good category, 33.33% of the research samples were in the good category, and the remaining 11.11% had pretty good science process skills. The data can be seen in table 5.

Table 5. Category of Research Sample KPS Value

No.	Criteria	Number of Students	Percentage (%)
1.	Good Enough Criteria	4 people	11.11
2.	Good Criteria	12 people	33.33
3.	Very Good Criteria	20 people	55.56
Amount		36 people	100

The results showed that students' science process skills were in the good category with an average value of 83.85%. This shows that the application of worksheets in this study can help students master science process skills. In detail, students' mastery of science process skills can be seen in Table 6.

Table 6. The Average Value of Observational Instruments

No.	Instrument	Average Value	Criteria
1.	Science Process Skills	83.85	Well

Table 7 below shows that the indicator with the lowest score is found in the inferring indicator , which is 74, this value is in the good category. The indicator of science process skills with the highest score is in the predicting indicator with a score of 94. This value is in the very good category.

Table 7. Observation Instrument Values for Each Indicator

No.	PPP indicator	Mark	Criteria
1.	observing	85	Very good
2.	Measuring	84	Good
3.	Inferring	74	Good
4.	classifying	85	Very good
5.	predicting	94	Very good
6.	Using Number	84	Good
7.	Recording & Displaying data	81	Good

This study analyzes science process skills based on the application of STEM Based Project Prospectus . Students' science process skills are assessed when students carry out practicum activities. Observing indicators appear in the initial activities in practicum, namely when students analyze problems through reading the introductory material. The predicting indicator appears when

students predict the temperature with the most or the fewest bacterial colonies. Measuring and inferring indicators appear when students make graphs and interpret the graphs.

Furthermore, classifying indicators appear when students identify the types of colonies growing on the media and the types of bacteria that have been stained with the Gram staining technique. The next indicator is using number , this indicator appears when students use practicum result data to be used as a topic in discussion. Finally, indicators of recording & displaying data appear when students present their observations to each other and use them as complementary data.

Inquiry activities that can build science process skills are investigative activities (Gunawan et al. 2019; Mandasari et al. 2021) . Investigative activities are examples of activities with the guided inquiry model. The guided inquiry model allows students to gain knowledge based on their respective scientific work (Miranti & Ertikanto, 2018) . The application of the guided inquiry model is effective in building science process skills (Brata & Suriani, 2020) .

The formation of science process skills is influenced by several factors. In this study, factors that can affect and appear only through student activities in conducting practicums, without paying attention to other factors. Other factors that can influence science process skills are place of residence (Tanti et al. 2020) , gender (Vooren et al., 2022) , and learning experience (Irwanto et al. 2019) .

Science process skills can be built with a STEM approach. The STEM approach assists students in designing and developing experiments (U. Sari et al. 2020) . In line with this statement, this study proves that the STEM approach can build students' science process skills, namely students because during practicum activities students are asked to design and develop experiments related to the topics provided by the instructor.

So it can be concluded that the application of STEM Based Project Prospectus assisted by practicum activities has proven to be optimal for students' science process skills. This is evidenced by as many as ≥75% of students achieving a minimum value of science process skills in the good category (x > 70). If it is said in numbers, there are 32 students (88.88%) achieving science process skills with a good minimum score.

The Relationship between Critical Thinking Skills and Science Process Skills through the Application of STEM-Based Teaching Supplements Assisted by Gram Staining Practicum

The results of the correlation between the scores of critical thinking skills and critical thinking skills are at low criteria. This is evidenced by the *product moment correlation coefficient* of 0.251 which is in the low criteria. These results can be seen in table 8.

Table 8. Correlation of Posttest Scores and KPS Scores

No.	Aspect	Mark	Criteria
1.	Correlation coefficient	0.251	Low

This study uses the components of the STEM approach according to the provisions of the S, T, E, and M indicators according to Kelley & Knowles (2016) . The problem used in class is the analysis of the quality of pure cow's milk based on heating temperature (science). Taking into account the objectives of the practicum, students are asked to design research procedures (technology). After the practicum results are completed, the results will be concluded and used as a choice of solutions (engineering). During the data processing, students are asked to graph research results (mathematics).

STEM-based teaching supplements developed as learning tools for students to train students' critical thinking skills and science process skills. The use of the STEM approach has been shown to improve critical thinking skills (Felder & Rebecca, 2016; Hacioglu & Gulhan, 2021; Simanullang et al. 2022) . STEM approaches can also build science process skills (Kizilay et al. 2018; U. Sari et al. 2020; Darmaji et al. 2022, 2021; Vooren et al. 2022) .

posttest correlation and the observed value of science process skills show values in the low range. Even though the criterion is low, the correlation formed is positive. This means that the relationship between critical thinking skills and science process skills has a positive relationship with low criteria. In

line with what was explained by Naimnule & Aloysius (2018) that critical thinking skills have a relationship with science process skills. The greater the science process skills, the greater the ability to think critically.

Research that also states the relationship between critical thinking skills and science process skills is Darmaji et al. (2022, 2021) , Irwanto et al. (2019) , Kurniawan et al. 2020) , Rohani (2013) , and Tanti et al. (2020) . These studies state that critical thinking skills and science process skills have a relationship. The higher the critical thinking skills' score, the higher the science process skills.

CONCLUSION

The teaching supplement in the form of a practicum-assisted STEM-based student worksheet on the topic of Gram staining has a very valid and very practical validity value so it is ready to be implemented with minor revisions. Teaching supplements are proven to be able to optimize students' critical thinking skills and science process skills through Gram staining practicum activities. This study also shows that critical thinking skills are correlated with science process skills, both competencies can be developed through practical and investigative activities.

Critical thinking skills can be improved through the activities of designing steps to complete a project that involve the process of predicting, interpreting, processing and analyzing data. Then, science process skills can be built through activities in preparing material tools, preparing problem-solving paths through discussion activities, and in sharing information with other students. The weakness of this research is that it does not analyze how much influence critical thinking skills have on shaping science process skills and vice versa.

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