QUBAHAN ACADEMIC JOURNAL
VOL. 4, NO. 3, September 2024
https://doi.org/10.48161/qaj.v4n3a794

Enhancing Complex Problem-Solving Skills through STEM-Based Spatial Geometry E-Modules

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ABSTRACT: Learning spatial geometry is still abstract, thereby it is boring and less meaningful. As a result, learning outcomes in terms of skills and cognitive aspects become less optimal. Currently, students no longer rely on textbooks as a learning resource. E-modules are digitally designed learning resources that support independent learning. The e-module would be integrated with the STEM approach. STEM learning activities are very important and need to be familiarized with learning because the activities help prospective teachers build the concepts learned as well as practice solving complex real-world problems. The method was research and development using the ADDIE model. The research subjects were 78 2nd semester students of prospective mathematics teachers in the Mathematics Education Study Program, Universitas Tidar. Data were collected by using observation sheets, interview guides, questionnaires, and complex problem-solving tests. There are three main results from the study; first, the STEM-based spatial geometry E-module is declared to be strongly valid according to expert validators. Second, based on student responses, this e-module is practical, and third, based on the results of the complex problem-solving skills test, this STEM-based spatial geometry e-module is effective.

Keywords: Complex Problem Solving, E-Module, Spatial Geometry, STEM, Prospective Mathematics Teacher.

I. INTRODUCTION

In general, the material taught to students in the Department of Mathematics Education is still abstract. Especially for students of the Department of Mathematics Education, they must be able to become professional mathematics educators after graduation. Additionally, there are significant changes that must be made in the realm of mathematics education in light of the Industrial Revolution 5.0. As a result, a learning tool that is simple to use and can help pupils study on their own is required. The application of knowledge that is not constrained by time or place is the right learning in handling it. Students no longer have to fully rely on textbooks or material literacy in the era of Industrial 5.0. Students can quickly and conveniently access the study material by customizing their smartphones. The Indonesian government has pushed colleges to partially adopt online education. Universities that still offer traditional education will eventually close if they are unable to effectively adapt to technological advancements. The mathematics education curriculum at Universitas Tidar and Universitas Negeri Semarang has one compulsory course, namely Spatial Geometry. To date, learning has not been optimal when experiencing changes caused by the COVID-19 pandemic [1]. Learning spatial geometry is still abstract, so it is boring and less meaningful; so that learning outcomes become less optimal, both in terms of skills and cognitive aspects. This is a concern not only for academic performance but also for the critical cognitive abilities and skills that aspiring math teachers need to have. In fact, a prospective mathematics teacher must have cognitive capabilities and skills as a provision for teaching his/her students in the future [2].

Spatial geometry is crucial in mathematics education as it enhances spatial reasoning, critical thinking, and problem-solving skills [3]. It enables students to visualize and manipulate shapes, understand dimensions, and apply geometric concepts to real-world situations, such as architecture and engineering. However, teaching spatial geometry poses challenges due to its abstract nature, requiring students to grasp complex ideas like transformations and three-dimensional thinking. Effective teaching demands intuitive visualization tools, concrete models, and engaging methods to bridge the gap between abstract concepts and practical understanding, making it challenging for educators to convey and students to internalize.

One of the most important aspects to be prepared for is complex problem-solving (CPS) skills. CPS skills are important because they are closely related to educational achievement [4] and play a role in building non-routine problem solving [5]. Complex problem-solving skills as 21st century skills are needed by students to solve dynamically changing problems [6]. Complex problem solving is closely related to education, mathematics education, and learning [7]. Based on this, it is necessary to develop a new innovation regarding learning resources that focus more on student independence, so that it is effective in improving complex problem-solving skills.

One of the innovations developed is e-module-based learning. The requirement for an adaptable and easily accessible learning resource drives the selection of an e-module [8]. A 5.0 Industrial Revolution e-module is in line with the needs of the modern educational environment, where e-learning is essential. It gets around the disadvantages of conventional teaching methods and enables students to learn on their own. Additionally, a Spatial Geometry e-module attempts to overcome the difficulties brought on by the abstract nature of the subject, enhancing the interaction and significance of learning.

Recognizing the urgency to bridge this gap and align with the dynamic nature of the educational landscape, we propose an innovative solution—STEM-based spatial geometry e-module learning. The choice of STEM is deliberate, acknowledging its proven effectiveness in combining science, technology, engineering, and mathematics in a contextual manner [9]. Integrated STEM education makes learning more connected and relevant for students, contributing to their future success [10]. STEM is an approach to the learning process that combines the concepts of science, technology, engineering, and mathematics that are contextual [11]. In addition to being essential for the country's competitiveness in the global economy, STEM education helps students develop 21st-century skills like collaboration, communication, and complex problem-solving [12]. STEM not only enriches the learning experience by connecting theoretical concepts to practical applications but also prepares prospective teachers to tackle complex, real-world problems.

This research is supported by previous research, namely 1) the development of CAI-based e-module learning strategies that are feasible to use [13]; 2) the designed digital module on mathematical communication skills is feasible to use [14]; and 3) the developed math e-module using Kvisoft Flipbook Maker Pro with a scientific approach is a feasible and effective learning tool for senior high school students [15]. Another study states that the electronic book, in addition to having a good effect on other 21st-century learning skills, STEM PjBL is legitimate and crucial in developing students' critical thinking abilities [16]. Based on this research, it appears that a STEM-based spatial geometry e-module for prospective mathematics teachers has not been developed yet.

This research is important to carry out considering that the online learning process carried out must be maximized so that the achievement of student learning goals can be manifested. Online learning must be supported by digitally designed learning tools that maximize the independent learning process but can develop students' abilities. The E-module was developed by taking into account the demands of the industrial revolution era 5.0 so that universities prepare graduates who are not only able to master the understanding of concepts but also must be able to master other skills and abilities such as STEM and complex problem solving. Based on the background above, the problem statements of this study are:

1. How to produce a valid and practical STEM-based spatial geometry e-module to enhance students' complex problem-solving skills?
2. How to analyze the effectiveness of a STEM-based spatial geometry e-module to enhance students' complex problem-solving skills?

II. LITERATURE REVIEW

1. E-MODULE

E-learning, which can be defined as teaching and learning using technology, includes e-modules [17]. Learning materials with quite brief and targeted content that have been developed to meet learning objectives are called modules. Modules typically consist of a number of well-organized tasks pertaining to media, materials, and assessment [18-21]. E-modules are technologically helped digital learning resources with comparatively quick and targeted content. Students are encouraged to learn independently within modules that are systematically created and grounded in learning objectives [22]. With e-modules, students can become less reliant on their teachers and boost their knowledge on their own.

Research on e-modules highlights their positive impact on learning outcomes, particularly in mathematics education. Comprehensive reviews show that e-modules enhance student engagement, understanding, and retention of mathematical concepts [23]. They offer interactive and adaptive learning experiences, allowing personalized pacing and feedback.

Research showing swarm intelligence algorithms effectively solve problems has sparked interest in using similar technologies to enhance educational methods and learning outcomes [24]. Other studies reveal significant potential to revolutionize learning with technology, making online education more interactive and engaging [25]. Research focused on the use of e-books in education has shown that they effectively enhance students' creative thinking and independent learning skills, making them valuable tools in modern learning environments [26]. Studies consistently demonstrate that e-modules improve academic performance, especially when integrated with traditional teaching methods, making them an effective tool in modern education.

2. SPATIAL GEOMETRY

One of the courses offered in the 2nd semester of the Universitas Tidar Mathematics Education study program is geometry of space. The spatial geometry course is developed and continued in this course. The Mathematics Education Study Program curriculum states that this course covers topics such as measurements involving objects and forms of spatial geometry, spatial drawing construction techniques, and relationships between objects of spatial geometry. It also covers polygons, pyramids, prisms, cones, cylinders, and spheres. The course's competency standards include the ability for students to clearly understand concepts, have good spatial responsiveness, and solve problems involving spatial figures. Many students still finish spatial geometry in its implementation [27].

3. STEM EDUCATION

The STEM approach is one of the teaching procedures that helps students gain 21st century skills [28]. STEM learning is defined as the application of ideas or the solution of multidisciplinary problems in real-world contexts through the integration of several concepts, procedures, and content attitudes through a set of STEM skills [29]. Contextualized concepts of science, technology, engineering, and mathematics are combined in the STEM learning approach [30]. Based on their existing knowledge, STEM learning may reduce the load that students have when they encounter a variety of real-world issues [30]. Furthermore, STEM education has been shown to boost students' motivation and interest in the learning process [31].

4. COMPLEX PROBLEM-SOLVING

Nowadays, the idea of solving complex problems is well-established and has even impacted large-scale tests like PISA [32]. Complex problem solving is one of the most crucial skills that will be needed in the future, according to the World Economic Forum [33]. Another complex cognitive skill [34] is solving complex problems, which is defined by two main cognitive processes: 1) the requirement to learn more about an unclear problem scenario; and 2) the application of knowledge to accomplish specific goals in problem solving [35]. Academic achievement and the ability to solve complex problems are highly correlated [2]. There are two steps in the process of solving complex problems: 1) knowledge acquisition, where the problem solver applies the knowledge acquired to make a series of dynamic decisions and continuously monitors the consequences of these decisions in order to systematically solve the problem at hand; 2) knowledge acquisition, where the problem solver has to systematically generate information (search for informative data), properly integrate this information into a model of the situation (search for adequate hypotheses), and selectively focus on the most relevant aspects. The ability to solve non-routine problems, particularly in mathematics, requires a set of complex problem-solving techniques [3].

The requirements of a simple problem are quite distinct from the needs for a complex problem [36].

a. Complexity of the problem situation: Complexity is defined by the number of variables in a given system. Of course, this is only the first orientation for estimating the difficulty of the problem. Complexity demands from problem solvers simplification through reduction to important information.
b. Connectivity between involved variables: Connectivity between the variables involved requires the construction of a problem model of all variables that are connected to each other.
c. Intransparency: An opacity that demands systematic information generation.
d. Dynamics of the situation: Dynamics that demand prediction and control of future developments. It indicates that in many situations' problems change on their own over time; and
e. Polytely: Evaluate and prioritize. In a complex situation, achieving a goal can be complicated.

III. METHOD

1. RESEARCH SUBJECT

The subject of this research is a 2nd semester student of the 2022/2023 academic year. Then the research sample was selected by purposive sampling technique so that it was grouped into an experimental group (class 01) and a control group (class 02). The research subjects are selected by purposive sampling, which is the selection of research subjects selective based on certain objectives. The selection of subjects is based on the consideration that semester 2 is the beginning for prospective teacher students to learn. The experimental group received the application of the STEM-based spatial geometry e-module and the controlled group received the commonly applied learning application. In both groups, pretests and posttests were carried out to obtain a comprehension of how to enhance complex problem-solving skills. In addition, response questionnaires were also distributed to obtain data on the responses of prospective mathematics teachers. Furthermore, the data were analyzed and discussed to obtain research results.

2. RESEARCH DESIGN

The research was conducted using ADDIE (Analysis, Design, Development, Implementation, Evaluation). The philosophy of ADDIE's application is that the learning developed should be student-centered, innovative, authentic, and inspirational [37]. Product-oriented research in the form of a STEM-based Spatial Geometry e-module to enhance students' complex problem-solving skills for prospective mathematics teachers. At the analysis stage, a literature study on e-modules and STEM was conducted. In addition, it also observed and analyzed the needs of teaching materials for the Spatial Geometry course. Then, at the design stage, the subject matter design and competency achievement were carried out so that sub-chapters of e-module design were arranged. At this stage, research instruments were also prepared in the form of questions, response questionnaires, validation sheets from material experts, and validation sheets from media experts. At the development stage, the STEM-based e-modules that have been prepared are validated by experts to obtain input in order to improve the products that have been developed. The implementation stage was carried out at Universitas Tidar. Field trials were carried out using the quasi-experiment method with a non-equivalent control group design conducted at the Spatial Geometry course. The complete research design can be seen in Figure 1.

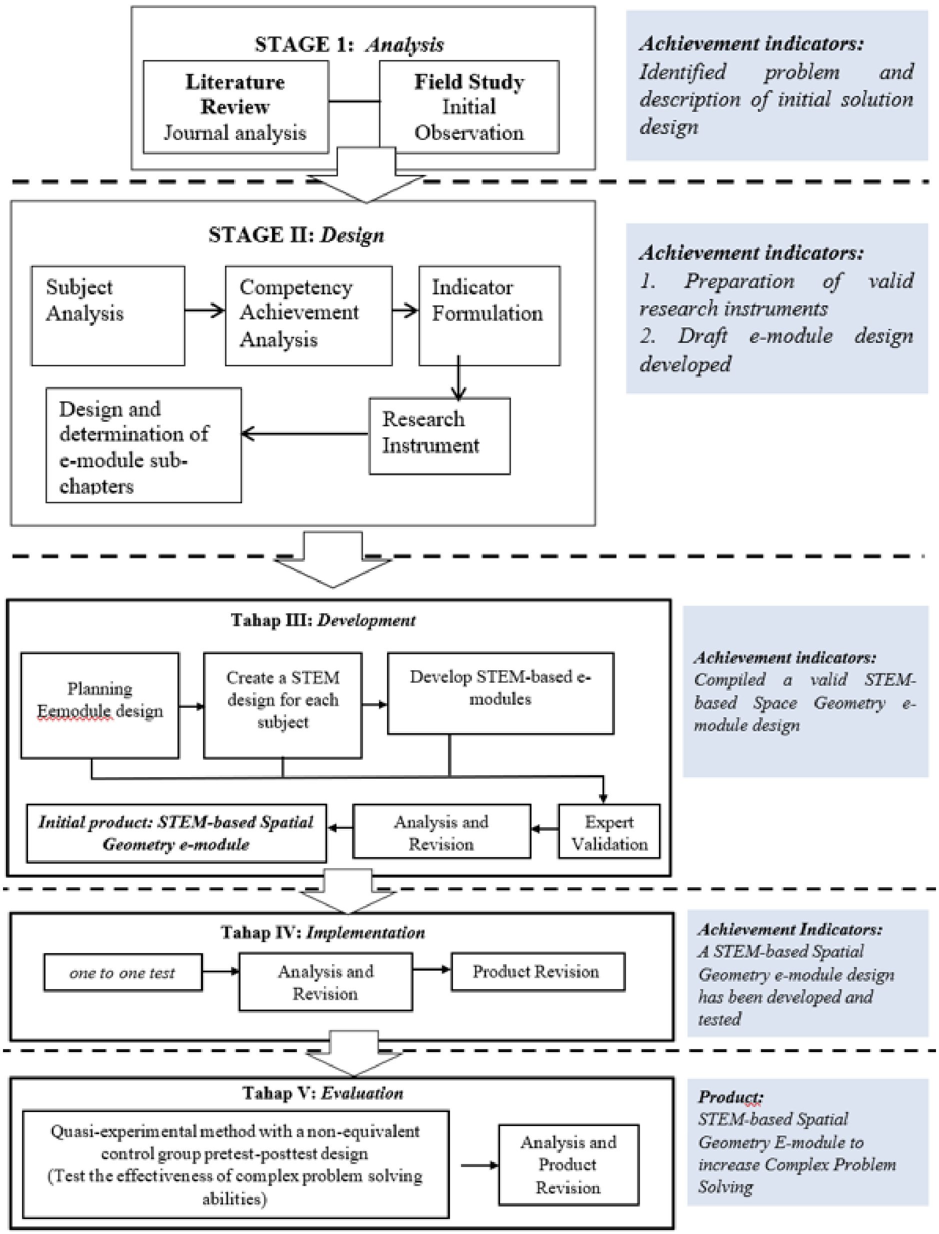


FIGURE 1. Research design

3. RESEARCH INSTRUMENTS AND DATA COLLECTION

The research instruments consisted of:

1. Expert validation questionnaire, used to collect product validity data. The selection of validators was carried out by selecting experts in the field of material and media.

2. Practicality questionnaires or responses of prospective mathematics teachers were used to explore student responses to learning carried out using the developed product.
3. Test instruments to measure complex problem-solving skills. The test instruments consisted of pretest and posttest. Complex problem-solving test instruments are validated and analyzed for reliability, differentiation, and difficulty so that they are suitable for use.

The validity of the test was carried out by 3 validators. The question items of the complex problem-solving test and the dynamic thinking test are declared valid if they meet all the existing criteria. The scores given are 1: disagree, 2: disagree, 3: quite agree, 4: agree, and 5: strongly agree. The data that has been filled in by the validator is analyzed using the V index formula from Aiken as follows:

$$V = \frac{\sum s}{n(c-1)} \quad (1)$$

with,

$$s = r - l_0 \quad (2)$$

r = score given by the validator, l_0 = lowest rating score, c = highest assessment score and n = the number of validators. From the results of the analysis using the index formula V, it can be categorized according to the index according to Table 1.

Table 1. Index criteria V

Index V	**Criterion**
$V > 0{,}8$	Highly Valid
$0{,}4 < V \leq 0{,}8$	Valid
$V \leq 0{,}4$	Less Valid

The results of the validator analysis of the complex problem-solving test obtained an index result of 0.8 has valid criteria. In addition to the validity of the test, a good test criterion is that the test has good reliability. The reliability of the test is known based on external measures of consistency or internal. According to Retnawati (38), the internal analysis of the reliability of the description form test is known through the use of the Alpha Cronbanch formula as follows:

$$\alpha = \left(\frac{n}{n-1}\right)\left(1 - \frac{\sum \sigma^2}{\sigma^2}\right) \quad (3)$$

Where α = reliability coefficient, $\sum \sigma^2$ = number of score variances for each item, σ^2 = total variance and n = the number of questions

A high coefficient indicates high reliability. Conversely, if the coefficient of a test score is low, then the reliability of the test is low. To find out whether a test has high, medium, or low reliability, it can be seen from the reliability coefficient value in Table 2 [39].

Table 2. Reliability index criteria

Index	**Criterion**
$0,00 \leq r < 0{,}20$	Very low
$0,20 \leq r < 0{,}40$	Low
$0,40 \leq r < 0{,}60$	Enough
$0,60 \leq r < 0{,}80$	High
$0,80 \leq r < 1{,}00$	Very high

The results obtained were that the reliability coefficient of complex problem solving was at a high criterion with a value of 0.879. The data collection techniques consisted of observation, interviews, questionnaires (expert validation, response questionnaires), and the provision of tests of complex problem-solving skills. Interviews were conducted in the analysis process to capture the needs of students to learn geometry. Expert validation is carried out during the product design and development process. Observation is carried out when the application of the product is developed. tests and practicality questionnaires filled out by the subjects after learning using the developed products.

4. DATA ANALYSIS

This study data analysis method was used to examine data on the effectiveness of the created product as well as data on its validity and practicality.

1. The validation questionnaires and student response questionnaires were analyzed by the researchers descriptively. This was done so that the analysis of deficiencies and revisions can be carried out in more depth. Expert validation questionnaire and practicality using Likert scale with a range of 1-5. Validity data and practicality data were analyzed using the following formula [40].

$$Percentage = \frac{\sum subject\ response}{\sum highest\ score} \times 100\% \tag{4}$$

A product declared valid and practical must meet the minimum qualifications in percentage of 61% -80%. The percentage of the validity level of experts and the level of practicality obtained are then interpreted in the following categories, as shown in Table 3 [41, 42].

Table 3. Criteria for validity and practicality levels

Percentage	Validity category	Practicality Category	Description
81%-100%	Strongly Valid	Strongly practical.	No revisions needed
61%-80%	Valid	Practical	No revisions needed
41%-60%	Less valid	Less practical	Minor revisions
21%-40%	Invalid	Impractical	Major revisions
0%-20%	Strongly invalid	Strongly impractical	Total revisions

2. The effectiveness analysis was obtained by looking at the improvement of CPS skills. Analysis of improving complex problem-solving skills was carried out by stages:
   a) calculating pretest and posttest scores;
   b) testing with Paired Sample T-Test if the data are normally distributed and homogeneous;

The data normality test was carried out to find out whether the sample came from normally distributed data or not. The data testing in both the experimental class and the control class was carried out using the Microsoft Excel-assisted Liliefors test [43]. Decision-making criteria if the Lcount is ≤ Ltable, then H_0 accepted. The hypothesis for the data normality test is as follows.

H_0 : Samples from the normally distributed population

H_1: Sample not from a normally distributed population

The homogeneity test is used to determine whether several population variants are the same or not. The homogeneity test used in this study is the F test. The criteria for testing the hypothesis are If $F_{count} < F_{table}$, then H_0 accepted. The hypothesis for the data homogenity test is as follows.

$H_0: \sigma_1^2 = \sigma_2^2$ (Samples from homogeneous populations)

$H_1: \sigma_1^2 \neq \sigma_2^2$ (Samples from non-homogeneous populations)

The paired sample t-test was used to compare the achievement of students' complex problem-solving skills after and before learning using STEM-based e-module products in experimental classes. The statistical hypothesis of the paired sample t-test used is as follows.

$H_0: \mu_2 \leq \mu_1$ (Complex problem-solving skills after learning using STEM-based e-modules is less than or equal to the ability to solve complex problems before learning using STEM-based e-modules)

$H_1: \mu_2 > \mu_1$ (Complex problem-solving skills after learning using STEM-based e-modules are more than complex problem-solving skills before learning using STEM-based e-modules)

The criteria for the test decision are $t_{count} > t_{table}$, then H_0 rejected. t_{count} is calculated using the following formula:

$$t_{count} = \frac{\bar{X}_1 + \bar{X}_2}{\sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2} - 2r\left(\frac{s_1}{\sqrt{n_1}}\right)\left(\frac{s_2}{\sqrt{n_2}}\right)}} \quad (5)$$

c) if the pretest and posttest differ significantly from one another, then proceed with computing the average normalized gain score (N-Gain) to assess how much a person can to solve complex problems has improved;
d) interpreting the improvement with criteria: high (N-Gain ≤ 0.7), medium (0.3 ≤ N-Gain < 0.7), or low (N-Gain < 0.3). The STEM-based Spatial Geometry e-module is said to be effective if complex problem-solving skills are at least increased in the medium category [44]. The results of N-Gain can be obtained using the following equation:

$$N - gain = \frac{posttest\ score - pretest\ score}{maximum\ score - pretest\ score} \quad (6)$$

IV. RESULTS

1. ANALYSIS OF PRODUCT VALIDITY

The validity test is conducted after going through several stages of development such as analysis, design, and development. At the analysis stage, a literature study was conducted on e-module, STEM, and complex problem-solving skills. In addition, the researchers observe the needs of teaching materials for the Spatial Geometry course. The result of needs analysis questionnaire showed that students need teaching materials in the form of STEM-based E-module as a media to facilitate Spatial Geometry learning. Module which designed systematically and based on learning objectives encourages students' academic performance, interest, and learning skills, with greater improvements for low-achieving students [45]. However, some students still misinterpret the STEM. Furthermore, at the design stage, the STEM-based spatial geometry e-module is designed by using these several steps: 1) identify the equipment used; 2) plan the design and layout; 3) design the material or subject and competency achievement. The topics on e-module are elements in geometry, perpendicularity, cube, cuboid, prism, pyramid, rotating objects, cone, and sphere.

Then, at this stage, research instruments were also prepared in the form of questionnaire for student responses questionnaires, validation from media and material experts, pre-test questions and post-test complex problem-solving skills. The results obtained at the design stage are then compiled and developed using the canva application. At the development stage, after compiling STEM-based e-module, the material and media experts are assessed the e-module. Proposed work (model) STEM-based spatial geometry e-module is disseminated through https://bit.ly/GeometriRuangSTEM. The assessment of content aspects is seen from the aspects of content feasibility, presentation feasibility, and STEM-based media development feasibility Based on the assessment of the two material validators, the validity score in the category is strongly valid, as shown in Table 4. Then, the assessment of media aspects is seen from the aspect of graphical feasibility and language feasibility of STEM-based spatial geometry e-module. Based on the assessment of the two content experts, the validity score in the category is strongly valid, as shown in Table 5. The overall validation results can be seen in Table 6.

Table 4. The content expert validation result

No	Experts	Total Score	Maximum score
1	1st Expert	114	135
2	2nd Expert	117	135
Total		231	270

Percentage	**85.55%** (**Strongly Valid)**

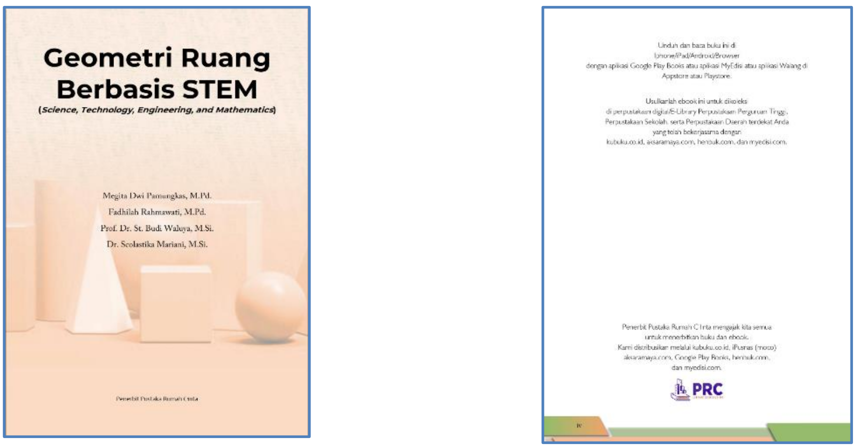
Table 5. The media expert validation result

No	Experts	Total Score	Maximum score
1	1st Expert	146	165
2	2nd Expert	150	165
Total		296	330
Percentage		**89.69%** (**Strongly Valid)**	

Table 6. Overall validation results

No	Expert	Total Score	Maximum score
1	Content Expert	231	270
2	Media Expert	296	330
Total		527	600
Percentage		**87.83%** (**Strongly Valid)**	

These outcomes reflect a collaborative effort to incorporate expertise and improve the project. By integrating expert feedback, we have refined and enhanced various aspects of the work, ensuring its quality and effectiveness. These results stand as a testament to the value of collaboration and continuous improvement in achieving our goals. After carefully considering the input and suggestions from experts, the development and revision process has yielded the following results, as shown in Figure 2-5 below. Figure 2 shows the front-page display of the e-module. Figure 3 is a table of contents, chapter page and basic competencies page. Figure 4 shows part of each chapter in the e-module. Finally, Figure 5 shows the final part of each chapter e module consisting of exercises, summaries and questions.



(a) (b)

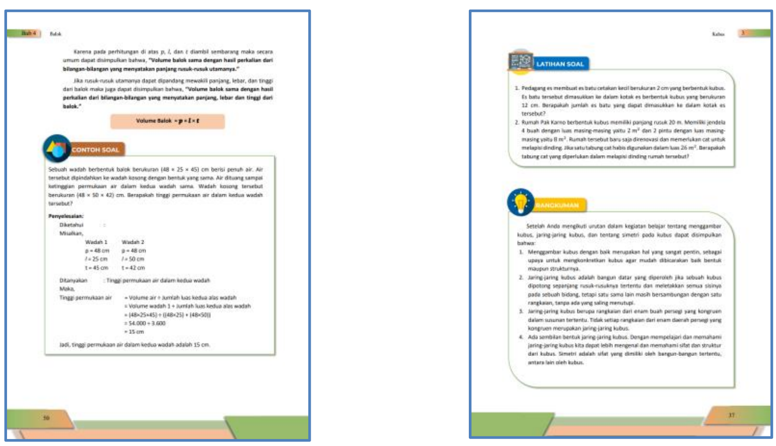
FIGURE 2. The display of (a) cover page and (b) dissemination address

(a) (b) (c)

FIGURE 3. General view (a) table of contents (b) chapter page and (c) basic competency page

(a) (b) (c)

FIGURE 4. Part of each chapter e-module: (a) realistic problem (b) topic explanation (c) problem illustration



(a) (b)

FIGURE 5. End of chapter page (a) part of questions (b) exercises and summaries

2. PRODUCT PRACTICALITY ANALYSIS

The practicality test results were obtained after the process of implementing and evaluating the e-module. The practicality test was carried out through the analysis of student response questionnaire. Nieveen [46] explained that the practicality of a product can be seen from the ease of using learning product developed. From the Table 6, it is found that STEM-based spatial geometry e-module get a practicality percentage of 83% based on assessing aspects of display, content presentation, operation, and benefits. All aspects described received a positive response from students, therefore, STEM-based e-module to enhance students' complex problem-solving skills is very practical to be used as learning media in spatial geometry class.The results of the product practicality test applied in the experimental class, as shown in Table 7.

Table 7. Results of practicality

No	Aspects of Practicality Assessment	Percentage
1	Display Aspect	86%
2	Content Presentation Aspect	81%
3	Operating Aspect	89%
4	Benefit Aspect	79%
	Percentage	**83%**

3. PRODUCT EFFECTIVENESS ANALYSIS

Before testing the effectiveness of the product, prerequisite tests were conducted. The prerequisite test mentioned is the normality and homogeneity test. The results of the normality test of pre-test and post-test are presented in the Table 8 and Table 9. Based on the calculations in Table 8 and Table 9, the data from the pretest results in the experimental and control class obtained a value $L_{value} < L_{table}$ while the data from the posttest obtained a value $L_{value} > L_{table}$. Consequently, it may be said that the pre-test data is normally distributed data, while the post-test data is not normally distributed. After the normality test, a comparison test of two paired samples was carried out. Because the appearance of not normally distributed data, the comparison test of the two samples used the wilcoxon test. According to the test results, there were significant variations in complex problem-solving skills before and after using STEM-based spatial geometry e-module. The the normality and homogeneity test results can be seen in Table 8-10 below.

Table 8. Normality test result of experimental class

Results	L_{count}	L_{table}	Conclusion
Pre-test	0.1376	0.1421	Data is normally distributed
Post-test	0.1443	0.1421	Not normally distributed

Table 9. Normality test result of control class

Results	L_{count}	L_{table}	Conclusion
Pre-test	0.0875	0.1386	Data is normally distributed
Post-test	0.1565	0.1386	Not normally distributed

Table 10. Homogeneity test results

Class	F_{count}	F_{table}	Conclusion
Experiment	-4.982	1.96	There are differences.
Control	-5.249	1.96	There are differences.

After knowing the differences between before and after the use of e-modules, the paired sample t-test and the N-Gain test were carried out to measure the improvement of complex problem-solving skills in the experimental class. The results of the paired sample t-test and N-Gain score in experimental class, as shown in Table 11 and Table 12.

Table 11. Results of paired samples t-test in the experimental class

Class	t_{count}	$t_{tabel(0,05;78)}$	Decision
Experiment	15,318	1,668	H_0 rejected

Table 12. Experimental class N-gain test

	Score		N	Category
	Pre-test	Post-test		
Mean	44.66	64.58	0.36	Moderate

Based on Table 11, it can be seen that the $t_{count} > t_{table}$ is 15,318 > 1,668 so it rejected, which means that the complex problem-solving skill after learning using stem-based e-modules is better than the complex problem-solving skill before learning using stem-based e-modules. The results of the test with N-Gain obtained an average of 0.36, which is included in the moderate improvement category. Hence, it can be concluded that a STEM-based e-module can effectively enhance the ability of prospective math teachers to develop complex problem-solving skills.

V. DISCUSSION

Instructional technology is used to learn mathematics [47]. This product-oriented research developed STEM-based Spatial Geometry e-module to enhance complex problem-solving skill for prospective mathematics teachers. This e-module is compiled and developed based on student needs and validated by material experts and media experts in mathematics learning. Based on the assessment of the two material validators, the validity score in the category is strongly valid. However, the e-module still needs to be improved by concentrating on the input of material validators and media validators. According to the validators, the material and concepts presented in the module are complete. However, STEM development elements need to be more prominently displayed. Learning using STEM has widely applied in higher education [48]. Moreover, STEM has been used with other learning models such as Project Based Learning (STEM-PJBL). STEM-PJBL is very different from knowledge-centered learning instruction in that it requires educators to fully understand their pedagogical orientation for successful teaching practice [49].

There are also some inputs from media experts including the size of the letters on the table of contents and the layout of the captions and images. The size should be enlarged and the layout should be rearranged to be more proportionate. Overall, the module size is standardized, content design, and language feasibility are good as well. Based on these data, it can be concluded that the STEM-based Spatial Geometry e-module can be used for learning. STEM activities in this e-module can directly and actively involve students in learning [50, 51]. The STEM components that have been provided in the teaching materials ensure that the content is not monotonous [52].

STEM-based e-modules to enhance students' complex problem-solving skills is said to be very practical to use as a learning medium for spatial geometry. Audie [53] mentioned that students tend to like visual learning media because it could improve students' motivation to learn and eliminate boredom. Learning can be done in various ways. A person can use a mobile device to access educational resources, connect with others, or create content inside and outside the classroom [54]. According to Balakrishman, Liew, & Pourghdaminejad [55], through technological advances, new opportunities for learning strategies are diverted to the use of media to create a "knowledge-based society" by improving student learning experiences. The application of technology can be one of the innovative ways to engage students with mathematics [56]. Therefore, using technology in the classroom can help students' prospective mathematics teacher become more proficient [57], especially complex problem-solving skills in mathematics.

This STEM-based spatial geometry e-module also met the effective criteria due to the difference in the average of the post-test and pre-test results in the experimental and control classes. The improved complex problem-solving skills in the experimental class showed an N-Gain value of 0.36 which was included in the moderate category. From theN-Gain measurement results, it can be seen that 4 students experienced an increase with high criteria, 18 students with a moderate increase category, and 16 students with a low increase category.

E-modules can help someone understand abstract concepts from an early age [58]. The developed e-module is integrated with STEM. STEM learning is able to reduce the burden of students in dealing with various problems in real life based on their knowledge [30]. The STEM-based electronic module includes specific learning activities that help students better visualize geometry concepts. With the use of experiments, projects, and challenges, this method enables students to apply theoretical concepts in real-world contexts in addition to being presented with them [59, 60]. For example, involving students in group projects and the creation of geometric models improves their comprehension and proficiency of the material.

Additionally, students find that the STEM activities in the e-module are memorable [61]. Throughout the learning process, interesting experiments and interactive games create memorable moments that make learning lively and enjoyable. Hyper content, or digitally based information sources, are used to enhance the content design of this digital module. Notably, students' positive responses to the digital module show their adaptability and excitement for this cutting-edge method of instruction [62]. The digital technology included in the module gives lecturers the ability to create self-directed learning materials, increasing the range of high-quality resources that are controlled in terms of both design and use. As a result, learning geometry becomes more than just a required academic subject thanks to the STEM-based e-module; it becomes an adventure that develops profound understanding and produces engaging learning opportunities.

Based on the results of the effectiveness test, students' complex problem-solving skills have increased. Complex problem-solving skills as a cognitive aspect measured in this research are presented in example questions and practice questions on the e-module. The indicators of complex problem-solving skills from the results of students' answers are the conceptualization aspect (finding existing information on the problem, connecting the information obtained) and implementing the strategy (using effective and efficient ways to solve problems). This research has limitations, namely it is only developed in limited classes in universities. In the future, it can be done in a larger scope and can be developed for other courses besides spatial geometry.

VI. CONCLUSION

This study demonstrates that the STEM-based spatial geometry e-module is highly effective in enhancing complex problem-solving skills among prospective mathematics teachers. The module's validity, practicality, and effectiveness were confirmed through expert validation and student feedback. These findings suggest that integrating STEM approaches in e-modules can significantly improve learning outcomes in abstract mathematical subjects. Future research should explore the long-term impact of such e-modules and their applicability in different educational contexts. It is clear from the outcomes of the practicality, effectiveness, and validity evaluations that the STEM-based e-module has been properly created. The STEM-based e-module is effective in enhancing complex problem-solving skills. It is suitable for use in higher education settings. The thorough evaluation indicates that the module is not only functional but also beneficial in improving students' analytical and problem-solving abilities, aligning with the educational goals of integrating STEM into the curriculum. This module serves as a valuable resource for college-level learning, providing a practical tool for educators to facilitate advanced learning experiences.

Funding statement

This research received funding from the DRTPM, Directorate General of Higher Education, Ministry of Education, Culture, Research, and Technology, Republic of Indonesia.

Author contribution

All authors made an equal contribution to the development and planning of the study.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data are available from the authors upon request.

Acknowledgements

We would like to thank the Indonesian Government, Universitas Tidar, and Universitas Negeri Semarang for supporting the implementation of this research. The authors would also like to acknowledge assistance of the Editor and Reviewers in the preparation of the article for publication.

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