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THE EFFECTIVENESS OF MICROLEARNING-BASED E-MODULES IN IMPROVING CRITICAL THINKING ABILITIES OF VOCATIONAL HIGH SCHOOL STUDENTS

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Abstrak
Kurangnya sumber belajar dan inovasi pembelajaran matematika dengan pemanfaatan teknologi yang mampu memfasilitasi siswa untuk belajar mandiri menjadi penyebab rendahnya kemampuan berpikir kritis. Oleh sebab itu, diperlukan inovasi dalam pembelajaran matematika yang relevan dengan kebutuhan siswa dan mampu memfasilitasi kegiatan belajar mandiri seperti e-modul. Penelitian ini bertujuan untuk mengembangkan dan menguji validitas, kepraktisan, dan efektivitas e-modul berbasis microlearning dalam meningkatkan kemampuan berpikir kritis siswa SMK. Penelitian dan pengembangan model Four-D diterapkan dengan subjek para ahli media, ahli materi dan 36 siswa SMK Dwijendra Denpasar. Hasil penelitian menunjukkan E-Modul SIMPLE bernilai valid, praktism dan efektif dalam meningkatkan kemampuan berpikir kritis yang diukur meliputi kemampuan analisis, evaluasi, dan argumentasi lanjut. Penelitian ini menunjukkan pendekatan microlearning mampu mempengaruhi peningkatan kemampuan berpikir kritis. Penelitian berikutnya dapat mengembangkan media pembelajaran digital berbasis microlearning yang memfasilitasi perkembangan kemampuan menyusun argumentasi lanjut.

Kata Kunci: e-modul; *microlearning*; berpikir kritis; pembelajaran matematika

Abstract
The lack of learning resources and innovation in mathematics learning with the use of technology that can facilitate students to study by themselves is the cause of low critical thinking skills. Therefore, innovation in mathematics learning that is relevant to students' needs and can facilitate independent learning activities such as e-modules is needed. This study aims to develop and test the validity, practicality, and effectiveness of a microlearning-based e-module in improving the critical thinking skills of vocational school students. The Four-D model of research and development was applied with media experts, subject matter experts, and 36 students from Dwijendra Denpasar Vocational School as subjects. The results showed that the SIMPLE E-Module was valid, practical, and effective in improving critical thinking skills, which were measured in terms of analytical, evaluative, and advanced argumentation skills. This study shows that the microlearning approach can influence the improvement of critical thinking skills. Further studies can develop microlearning-based digital learning media that facilitate the improvement of further argumentation skills.

Keyword*: e-module; microlearning; critical thinking; mathematics learning.*

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INTRODUCTION

The discipline of educational technology continues to develop and is increasingly needed amidst advances in other fields of science that influence education and social life (Fania et al. 2021; Parwati, Suharta, and Sudatha 2021; Spector et al. 2014). In line with technological developments, critical thinking skills are crucial to develop in an effort to create high-quality human resources ready to face the challenges of the flow of information in the 21st century (Sholikhah and Arif 2024; Zakiah and Lestari 2019). Critical thinking skills can equip students to analyze all information obtained from various digital sources, draw conclusions, and produce sound arguments (Pramudita, Praherdhiono, and Adi 2021). Developing critical thinking provides students with the ability to evaluate information correctly, present convincing arguments, and think clearly, rationally, and systematically (Astawan et al. 2023). Critical thinking can be developed through mathematics learning (Kurniawan, Nurfahrudianto, and Yohanie 2023). This may be due to the abstract nature of the subject matter, which is characteristic of mathematics learning (Aryaningsyih and Silviana 2023). Mathematics is a fundamental science that plays a crucial role in problem-solving. However, mathematics is often considered difficult by some students (Alviana, Sukmawati, and Amalia 2024). On the one hand, the role of technology in the digital era can have a positive impact on mathematics learning activities. Technology can provide visualizations of abstract concepts in mathematics and serve as an innovative learning resource for students (Pagau and Mytra 2023). Furthermore, the use of technology in mathematics learning is also effective for students at various ability levels and educational levels (Ali, Yasmeen, and Munawar 2023).

Problems related to critical thinking skills still occur in education and learning in various regions, especially at the high school/vocational high school level. Students' critical thinking skills in vocational education are categorized as low due to various factors such as the quality and support in learning and the students' initial ability level (Lestari, Haryani, and Sumarti 2020). Furthermore, based on the many indicators of critical thinking skills that are not achieved, it is concluded that the average critical thinking skills of vocational high school students, especially in the mathematics of probability, are very low (Rammadan and Budiman 2022). A similar finding was also conveyed by Baidowi et al. (2021) who stated that more than half of the study subjects showed that the critical thinking skills of students at the vocational high school level were still relatively low. Research by Fatmawati et al. (2022) stated that students at the vocational high school level, especially in the Accounting department, still need to improve their critical thinking skills. In line with this, the results of researchers' observations at Dwijendra Vocational High School in Denpasar indicate the urgency of improving students' critical thinking skills, especially in mathematics. Low mathematics learning achievement, lack of motivation and independence in learning, and low student engagement in mathematics can influence students' learning difficulties and low critical thinking skills. Furthermore, mathematics learning is dominated by monotonous teacher roles and a lack of activities to train students' critical thinking skills (Mahayani, Agustini, and Sudatha 2023; Widiastuti et al. 2023). This is supported by a study in vocational schools by (Fajjriah, Atiqoh, and Hartono 2023) which found that student engagement and interest in learning in vocational schools are still low. Furthermore, educators have not been able to create digital teaching materials that can facilitate student independent learning. This results in students having difficulty understanding the learning material and has an impact on low student achievement (Dari and Sudatha 2022). Researchers also found that there is still a lack of adequate learning resources, both in the form of print and digital media, for use in teaching mathematics. Meanwhile, each student has been provided with a smartphone capable of being used as a source of information and communication (Sudarma and Sukmana 2022). Therefore, strategic efforts are needed to address

challenges in mathematics learning at the vocational high school level, particularly to improve students' critical thinking skills. This is because vocational high school education requires critical thinking skills, which are essential for preparing for the demands of the workforce (Sari and Listiadi 2023).

Several problems that contribute to low critical thinking skills, such as monotonous learning resources, low interaction, lack of student interest and focus, and difficulty achieving learning objectives, can serve as a reference for finding innovative solutions that make learning more engaging (Suartama et al. 2024). One learning tool that can be developed by integrating technology is the e-module. One characteristic of an e-module is self-instruction, meaning it can be used independently without relying on a teacher or other person, thereby increasing learning independence and maximizing self-potential (Ginting, Susanti, and Chotimah 2022). Providing learning content enriched with appropriate pedagogical elements, strategies, or structured steps has a significant impact on student success, intentions, and behavior in learning in the digital era (Simamora et al. 2024). Therefore, the e-module product developed integrates a microlearning approach. This approach can be an innovation in reducing the cognitive load felt by students, allowing them to be more focused and fully engaged in learning (Marti et al. 2024). In line with this, Carter & Youssef-Morgan (2022) explain that microlearning presents information in the way people learn best, making it suitable as an approach to information delivery in today's digital age. On the one hand, the effective implementation of a microlearning approach can improve students' critical thinking skills (Adilah and Rosyida 2024). This is also supported by a study by Nowak et al. (2023), which found that student performance on exams and final grades were positively correlated with successful completion of microlearning units. Students who successfully completed more microlearning units performed significantly better on all exams compared to those who completed fewer units. Furthermore, the integration of artificial intelligence and microlearning significantly increased students' motivation and higher-order thinking skills (Silitonga et al. 2024).

Considering the implementation of technology in the learning process in the digital age and the importance of improving students' critical thinking skills, researchers are interested in developing learning tools in the form of microlearning-based e-modules. Furthermore, the development of microlearning-based e-modules has yet to be found in mathematics subjects, particularly at the vocational high school level, which are oriented toward improving critical thinking skills using microlearning-based e-modules. Therefore, this study aims to test the validity, practicality, and effectiveness of microlearning-based e-modules in improving critical thinking skills in vocational high school students.

METHOD

The research conducted was research and development, a scientific process involving a series of activities: identifying needs, developing products, and validating them to meet those needs (Kuras 2023). The 4D research and development model by Silvasalam Thiagarajan was used by the researchers because it is specifically designed for developing learning tools (Farida et al. 2020). The stages in this model are shown in Figure 1 (Thiagarajan, Semmel, and Semmel 1974).

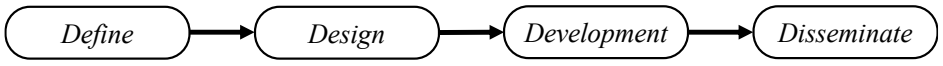

Figure 1. 4D Research and Development Model

The microlearning-based e-module was developed using Exelearning software. This software is capable of providing adequate display quality and navigation of online modules. This is in line with the advantages of Exelearning software, namely easy to apply, effective, and efficient as an e-module (Norsalam and Rani 2024). The subjects involved in this study were two material experts and two media experts. The experts came from Ganesha University of Education and were selected based on their fields of expertise. This study also involved students of Dwijendra Vocational High School, Denpasar, to test the practicality and effectiveness of the developed e-module product. The research instrument used to measure product quality is based on the product quality framework in formative evaluation according to Niveen (1999) which includes validity, practicality, and effectiveness (Van Den Akker et al. 1999). The validity testing instrument was developed with the learning media feasibility criteria according to (Surjono 2017). The microlearning-based e-module media is declared valid if the percentage of the material expert test score or the media expert test score reaches >80%. The practicality test of the e-module was conducted using the UEQ (User Experience Questionnaire) questionnaire with six aspects and categories as shown in Table 1 (Laugwitz, Held, and Schrepp 2008). The e-module developed in this study must achieve at least a score in each aspect that meets the minimum criteria above average to be declared practical.

Table 1. UEQ Six Aspect Category Intervals

Aspect	Category				
	Excellent	*Good*	*Above Average*	*Below Average*	*Bad*
Attractiveness	>1,75	>1,52	>,17	>0,7	≤ 0,7
Clarity	>1,9	>1,56	>1,08	>0,64	≤ 0,64
Efficiency	>1,78	>1,47	>0,98	>0,45	≤ 0,54
Accuracy	>1,65	>1,48	>1,14	>0,78	≤ 0,78
Stimulation	>1,55	>1,31	>0,99	>0,5	≤ 0,3
Novelty	>1,4	>1,05	>0,71	>0,3	≤ 0,3

Testing of the product's effectiveness was conducted by measuring student learning outcomes through pre-tests and post-tests. Students' critical thinking skills were measured using indicators of critical thinking activity according to Butterworth & Thwaites (2016:7), as presented in Table 2.

Table 2. Critical Thinking Ability Indicators

Indicator	Desciption
Analysis	Students' ability to find the core of a problem by considering ideas, arguments and concepts that are relevant to formulating conclusions.
Evaluation	Students' ability to measure and assess concepts relevant to problems through implementing problem-solving procedures and concluding final answers based on the problems given..
Further Argumentation	Students' ability to provide arguments for problems, stages of resolution and final answers as a reflection of the claims of the answers obtained..

The improvement in critical thinking skills is indicated by the n-gain score calculated using the formula proposed by Hake (1998). The obtained Gain score is classified using the gain level classifier in Table 3.

Table 3. Gain Score Indicator

Kriteria	Skor Gain
High	g≥0,7
Middle	0,3≤g<0,7
Low	g<0,3

In this study, the results of the development of a microlearning-based e-module were tested procedurally, starting from the validation step to the user, namely vocational high school students. The microlearning-based e-module can be declared effective in learning when ≥75% of students obtain a minimum moderate gain score criterion.

RESULT

This research resulted in a microlearning-based e-module product called SIMPLE, an acronym for Smart & Innovative Mathematics Practically Learning Environment, meaning a practical and innovative mathematics learning environment. This learning media contains Statistics and Probability Theory materials broken down into 40 learning units for high school/vocational school students (Phase E of the Independent Curriculum / Grade X) according to the Head of Agency Decree No. 32 of 2024 BSKAP. The structure of the SIMPLE E-Module can be seen in Figure 2.

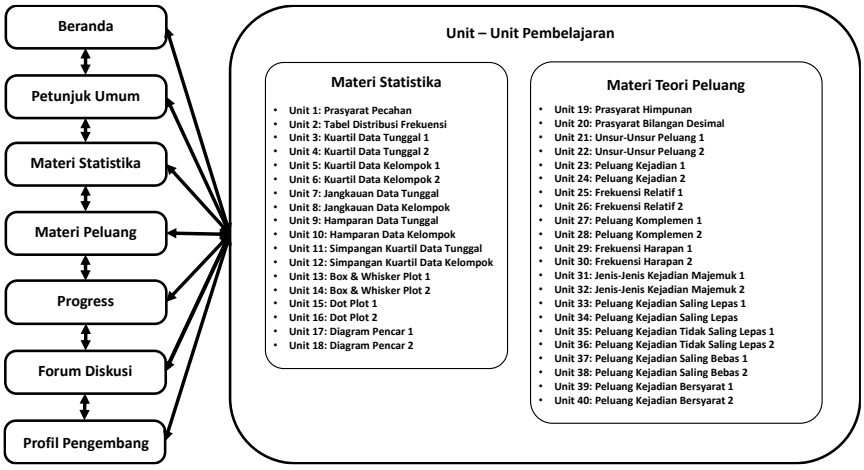

Figure 2. SIMPLE E-Module Structure

The homepage displays a greeting and a description of the e-module, and is the first screen users see when opening the SIMPLE E-Module. The general instructions display contains procedures or directions that apply generally to users. The material display consists of Statistics and Probability Theory. Each material display contains a flipbook unit that provides an overview of the material being studied. Learning units contain learning activities structured on a microlearning basis. There are two units for each subtopic of a material. The first unit of a subtopic is an introduction, while the second unit is a more in-depth unit. Each unit contains learning unit instructions, interactive learning videos, interactive complete-the-word activities, quizzes, and a feedback feature. Each learning unit is expected to be completed within 10–15 minutes. The Progress display displays student learning progress for each completed unit. The discussion forum menu display contains links and QR codes that direct users to join the WhatsApp group. The developer profile display contains the identity of the SIMPLE E-Module media developer.

The development stage involved testing the feasibility or validity of the e-module. This testing was conducted in collaboration with two media experts and a material expert. The media experts involved were lecturers and experts in the field of learning technology, while the material experts involved were lecturers and experts in the fields of Mathematics Education and Computer Science. The instrument developed used a Likert scale with 5 score gradations. There were a total of 22 statement items in the media/display validity test instrument and 44 statement items in the content/material validity test instrument. The following are the results of the media and material

validity tests. The table 4 are the results of the media and material validity tests for the SIMPLE E-Module.

Table 4. Media Validity Test Results

Aspects	Score	Percentage
Layout	27	90%
Use of Color	38	95%
Text Quality	30	100%
Image Quality	40	100%
Audio/Video Quality	38	95%
Navigation Functions	39	98%
Total	212	96%

The results in Table 4 show that the text and images have good display quality for use in learning. The highest percentages were achieved by the text quality and image quality aspects (100%), while the lowest percentages were achieved by the color use and audio/video quality aspects (95). However, the total score achieved was 96%, categorized as very valid, so the microlearning-based e-module product called SIMPLE that was developed was declared valid based on the quality of the display or learning media.

Table 5. Material Validity Test Results

Aspects	Score	Percentage
Appropriateness of material to learning objectives	44	88%
Correctness of material structure	31	78%
Accuracy of material content	36	90%
Correctness of terminology	28	93%
Correctness of spelling	24	80%
Accuracy of theme	28	93%
Quality of questions	24	80%
Quality of feedback	35	88%
User control	33	83%
Total	364	83%

The content validity test data in Table 5 shows that the highest percentage score was for the theme accuracy and terminology accuracy aspects (93%), while the lowest percentage score was for the grammatical correctness and learning strategies aspects (75%). The total score percentage of 83% indicates that the SIMPLE microlearning-based E-Module learning media obtained the very valid criteria based on the content contained therein.

Table 6. Expert comments and suggestions

No	Expert comments and suggestions
1	In the instructions, explain that the material elements, videos, exercises, and quizzes are located under the "Material Unit" bar/button.
2	On the cover/homepage, add the subject and program objectives.
3	Ensure there's not too much white space; the white space is proportional and balanced.
4	It's best to explain how to view each subject in relation to the others in the general instructions.
5	Illustrations can be added to the activity elements.
6	Feedback needs to be more varied.
7	Enhance hyperlinks; connecting one material to another should be done with links.
8	Learner control is optimized with links.
9	Feedback provided in learning using microlearning-based e-modules is very useful, and if necessary, cross-fertilization between students is encouraged.

Testing by media and subject matter experts yielded various comments that could be followed up or not, depending on the researcher's capacity and rationality. Table 6 presents the various comments the experts provided for product development. Nevertheless, the product received positive feedback from the experts and can be continued to the next steps.

Table 7. Media Practicality Results

	UEQ Scales (Mean and Variance)			
Aspect/Indicator	**Standar Mean Minimum (*Above Average*)**	**Mean**	**Varian**	**Kriteria**
Attractiveness	1.18	2.43	0.27	Excellent
Clarity	1.2	2.48	0.40	
Efficiency	1.05	2.38	0.13	
Accuracy	1.14	2.27	0.73	
Stimulation	1	2.25	0.75	
Novelty	0.7	2.27	0.39	

The results of the product's practicality testing were obtained through individual and small group trials with students. Data from the UEQ questionnaires from both trials were summarized and analyzed. The descriptive analysis results are presented in Table 7.

Table 8. Gain Score Analysis

Level category	**Number of**	**Percentage**
Low	0	0%
Middle	26	72%
High	10	28%
Mean Gain Score	0,62	
Mean Pre-test	51	
Mean Post-test	81	

Based on the total number of subjects involved in this test, namely 3 students for the individual trial and 9 students for the small group trial, these combined results indicate that the SIMPLE microlearning-based E-Module media is practical for application in learning. The data shows that the minimum score achievement criteria formed based on the number and responses of the subjects, namely the above average criteria, have been achieved. In addition, the results of data analysis on the UEQ aspect of the SIMPLE e-module have met the excellent criteria. Thus, the SIMPLE E-Module is said to be practical.

Table 9. Critical Thinking Ability Test Results

Aspects	**Pre-test**		**Post-test**	
	Score	**%**	**Score**	**%**
Analysis	146	51%	247	86%
Evaluation	151	52%	242	84%
Further Argumentation	143	50%	210	73%

The effectiveness of the SIMPLE E-Module product was tested by involving 36 students of class X Hospitality at SMK Dwijendra Denpasar in the even semester of the 2024/2025 academic year. The effectiveness test data was obtained through the administration of pre-tests and post-tests offline in the classroom. Based on the effectiveness test data in the table, it was found that 72% of students obtained gain scores with medium criteria and 28% of students obtained high criteria with no students obtaining low gain score criteria. In addition, 83% of students were in the complete category for the post-test score. The average pre-test score of 36 students of class X Hospitality was 51 while the post-test was 81. In addition, the average gain score was 0.62 with a medium average category. This can indicate a difference or increase in student scores after participating in learning using the SIMPLE E-Module. The results of the pre-test and post-test using the critical

thinking ability test instrument provide an overview of the scores of each aspect of students' critical thinking abilities as a whole. The following are the scores and percentages of students' critical thinking abilities according to the pre-test and post-test results.

The pre-test results showed that critical thinking skills reached 50–52% in each measured aspect. After the learning intervention with the SIMPLE microlearning-based e-module, all aspects experienced an increase in percentage. The analysis aspect experienced the highest increase, from 51% to 86%, indicating that students were better able to identify and analyze information. The evaluation aspect increased from 52% to 84%, indicating a strengthening in the ability to assess arguments objectively. Meanwhile, the advanced argumentation aspect, although experiencing a lower increase from 50% to 73%, still showed an improvement in critical thinking skills. The development of technology-based microlearning e-modules in this study is relevant to the use of technology-based learning that can strengthen higher-order thinking skills (Prasasti and Anas 2023; Rahayu and Al Hadi 2023; Salsabila et al. 2025).

DISCUSSION

The development of e-modules using Exe-learning software as the primary tool provides valid and practical e-modules. This aligns with the advantages of Exe-learning software, which is easy to apply, effective, and efficient as an e-module (Norsalam and Rani 2024). This study then evaluated the effectiveness of a microlearning-based e-module called SIMPLE in improving critical thinking skills for vocational high school students. The results of the gain score analysis demonstrated a positive impact of the SIMPLE e-module implementation on mathematics learning. Seventy-two percent of students achieved a gain score in the medium category, while 28% achieved a high category, and no students fell into the low category. These data indicate a significant increase in critical thinking skills, despite the varying initial abilities of students in the pre-test.

The effectiveness of the e-module in improving critical thinking skills is reflected in significant improvements in the measured critical thinking aspects. Improvements in post-test scores were seen across all measured critical thinking aspects. Specifically, significant improvements occurred in the analysis and evaluation aspects. Although improvements in advanced argumentation were lower, this suggests that microlearning-based e-modules have the potential to enhance students' reasoning and problem-solving abilities. The findings of this study support previous research examining the effectiveness of microlearning in improving learning quality and higher-order thinking skills (Adilah and Rosyida, 2024; Nowak et al., 2023). Studies have shown that microlearning has a positive impact on learning outcomes (Aritonang, Parmiti, and Sudarma, 2023). The identified key learning outcomes, categorized according to Bloom's Taxonomy, include cognitive aspects: knowledge acquisition, retention, enhancement, recall, transfer, and application; as well as critical thinking, problem-solving, feedback, and self-regulation skills (Monib et al., 2025). Furthermore, the results obtained in this study are also relevant to the finding that rigorous microlearning, taking into account students' needs and context, can foster not only knowledge and skills but also critical thinking and reasoning abilities (Santi, Situmorang, and Iriani, 2024). Thus, microlearning-based e-modules are a learning medium capable of influencing improvements in students' critical thinking skills.

Several interrelated factors can explain the improvement in students' critical thinking skills. The microlearning format is designed to focus on a specific sub-topic relevant to the cognitive load theory of Chandler & Sweller (1991), which states that learning becomes more effective when instructional design reduces unnecessary cognitive load and optimizes the learning process (Ngu et al. 2023). The reliance on memory and greater exploration and discussion activities indicate that microlearning can reduce students' cognitive load and foster critical thinking and in-depth learning

(Susilana et al. 2022). The learning design in the SIMPLE e-Module is designed to guide students in practicing critical thinking skills. One sub-topic is discussed in two learning units, one involving a general presentation of the material and the second unit providing in-depth study. This aligns with previous research showing that appropriate design and content of learning media can stimulate improvements in critical thinking skills (Apriadi, Agustini, and Parwati 2024). Careful microlearning design that takes into account students' needs and context has the potential to foster not only knowledge and skills, but also critical thinking and reasoning abilities (Santi et al. 2024).

Improved analytical skills can be achieved through the systematic design of the SIMPLE e-Module. The e-module structure packages learning into learning units, allowing students to freely explore, repeat, and satisfy their curiosity within an innovative learning medium. This not only increases engagement in learning but also supports the development of higher-order thinking skills (Sosilo, Estriyanto, and Utomo 2025). Improved evaluation skills can be enabled by the learning activities contained within the SIMPLE e-Module. Providing discussion space and feedback that adapts to student problems can also support the development of students' evaluative skills as part of critical thinking (Cui and Teo 2021). The capacity of the SIMPLE e-Module media to facilitate the development of advanced argumentation skills is supported by studies that suggest microlearning has the potential to improve students' soft skills, such as communication skills, through chunked learning units and in-depth discussions (Luo and Li 2025). This improvement in aspects can be attributed to the e-module's ability to provide students with opportunities to explore concepts and engage in discussions, enabling them to clarify their understanding of complex concepts (Hasan, Andayani, and Susilawati 2025). Furthermore, the flexibility and adaptability of microlearning content implementation allows students to organize their own learning and reflection schedules, leading to improved critical thinking skills (Utama, Mashfufah, and Thohir 2024).

This research contributes to addressing the research gap regarding the application of microlearning in mathematics learning at the vocational high school level. The introductory and in-depth unit learning approach represents a systematic model resulting from this research that can be adopted in other subjects. A practical implication of this research is the need to develop supporting tools, such as argumentation rubrics or structured digital discussion forums, integrated into e-modules. Considering the lowest improvement in the advanced argumentation aspect, the results of this study support the importance of learning innovation in utilizing an argumentative-based microlearning approach to develop 21st-century competencies. The limitations of this study lie in the limited interactive features in the e-module that have not optimally facilitated two-way communication or cross-fertilization between students as input from experts and collaborative activities. In addition, the sample size is limited to one vocational school in Denpasar City, so the generalization of the findings can be further expanded to other subjects. Future developments are expected to be able to accommodate more innovative interactive activities, feedback, and reflective activities in a microlearning learning unit to provide an efficient learning experience and better improve students' 21st-century skills.

CONCLUSION

The microlearning-based e-module named SIMPLE that was developed obtained very valid criteria from the media/display perspective with a total score percentage of 96% and from the content/material perspective with a total score percentage of 83%. The practicality of this learning media is demonstrated by the average score that exceeds the above average category in every aspect of the UEQ. The average score is in the score interval from 2.25 to 2.48 which is generally included in the very good category so that the SIMPLE E-module is declared practical as one of

the mathematics learning media. The effectiveness of this microlearning-based e-module developed is demonstrated through the gain scores obtained in the pre-test and post-test results. A total of 72% of students obtained gain scores with medium criteria and 28% of students obtained high criteria with no students obtaining low gain scores criteria. Therefore, the SIMPLE E-module media is declared effective in improving the critical thinking skills of vocational high school students. Considering input from experts and the results of product effectiveness tests, the development of microlearning-based learning media is suggested to be able to provide elements to support the improvement of students' argumentation skills.

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