Interactive e-Module on Exponential Material to Support Computational Thinking

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***Abstract*—An important aspect of 21st-century education is student-oriented teaching targeted at essential training skills that should be possessed, such as Computational Thinking (CT). All individuals need CT due to being helpful in solving various problems associated with computer science and mathematics, as well as daily life. However, most students still have low CT levels, leading to a need for teaching materials capable of enhancing the skills, such as a problem-based interactive e-module. Therefore, this study aimed to produce interactive e-module on valid and practical exponential material using Problem-Based Learning (PBL). The subjects used were high school students in grades 9 and 10, while the applied method included 3 stages, namely analysis, design, and development. The study data were collected and analyzed quantitatively using tables of validity and practicality criteria. The results showed that a very valid interactive e-module on exponential material was produced with an average validity percentage of 90.8%, as signified by the comments and suggestions from the validators. The practicality value of 82.7% was determined from a small group trial, denoting that the developed interactive e-module corresponded with the practical criteria. Because the developed interactive e-module is already very valid and practical, the product can be used in classroom learning to enhance students' computational thinking skills after using the interactive e-module.**

***Keywords*—computational thinking, interactive e-module, exponential, problem-based learning**

I. Introduction

Indonesia is preparing to compete with major global players by adopting the technological developments accompanying this rapidly changing era [1]. Considering this situation, the skills necessary to navigate the digital era need to be prepared immediately, even though the task might not be easy to achieve. Students will become victims of the modern era because of the inability to tolerate the rapid development of communication technology, as well as the increasingly difficult and complex future problems without the skills [2]. Therefore, students need to prepare with strong problem-solving skills to tackle the rapid advancement [3].

A type of problem-solving skills required in the 21st century is Computational Thinking (CT) [4], which includes breaking down each problem into several effective and efficient parts [5]. CT incorporates methods that train students to simplify problems and stimulate creativity [6, 7]. This is synonymous with computer science, but comprises broader benefits and can be integrated into other disciplines, including mathematics.

Moreover, the learning of mathematics that emphasizes critical and systematic thinking, such as algorithms, computation, problem-solving strategies, and a focus on processes, shows correspondence with CT principles [8, 9], signifying CT covers more than computer science and holds significant importance across diverse educational fields. Wing divided the indicators of CT into 4 categories, including decomposition, pattern recognition, abstraction, and algorithms [10]. Csizmadia et al. presented a different perspective, asserting the existence of 5 indicators, namely algorithms, abstraction, generalization, decomposition, and evaluation [11].

Based on previous analysis results and descriptions, this study used decomposition, pattern recognition, abstraction, and algorithm indicators, which correlate with classroom mathematics learning. Therefore, the aim was to develop interactive e-module serving as teaching material for students during the classroom learning process without applying the evaluation indicator.

CT skills of students are still relatively low in reality, as confirmed by the study of Mufidah that mathematics students currently experience challenges in solving problems through the integration of acquired information [12]. The factors affecting these low skills include the lack of creativity from teachers in innovating the learning process. Teachers often emphasize learning that requires memorizing the procedures used to solve mathematical problems, which leads to low CT levels among students [13, 14].

A suitable alternative to support CT is Problem-Based Learning (PBL) method which uses real-world problems as a context for learning and practicing problem-solving skills as well as developing individual learning strategies [15, 16]. By using this method, students develop CT skills that can be enhanced through problem-solving skills [17]. Therefore, PBL is among the alternative solutions that can support learning activities to achieve good results in both problem-solving and CT skills.

Exponential material is associated with CT, as it requires students to use existing CT stages to solve problems [18, 19], leading to being suitable for training CT skills related to thinking and problem-solving skills. However, students still face difficulty in calculations and a lack of precision in solving problems in this material [20]. Several factors that make exponential material difficult to learn include an inappropriate learning method and insufficient content in the provided teaching materials [21].

Inappropriate teaching materials are among the factors contributing to low CT skills and the difficulties experienced by students with exponential material. Therefore, teaching materials corresponding with the current era of Technology 4.0 need to be developed [22]. Teaching materials are systematically and attractively organized learning materials designed to promote interest in learning and independent study [23]. Interactive teaching materials combine two or more media, such as audio, text, graphics, images, and

animations [24].

In this study, teaching materials will be designed in the form of a module, which is a package of independent learning structured into several sub-chapters [25]. A module with a problem-based method helps students learn independently without teacher guidance [26]. The current conditions demand independent learning without direct guidance, hence, technology plays an important role in supporting the learning process [27].

Inadequate teaching materials are a contributing factor to low CT levels and difficulties encountered by students with exponential material. Considering the importance of CT, an innovation will be carried out by designing interactive e-module corresponding with CT indicators and using PBL.

Previous investigations developed e-module to improve CT skills in early childhood coding education [28] using PBL on data presentation materials [29], fractions [30], flat shapes [31], and linear programming [32]. There are no studies that have used PBL to develop interactive e-module on exponential material capable of providing interactive and engaging learning experience for students as well as enhancing CT skills. Therefore, this study aimed to produce interactive e-module on valid and practical exponential material using PBL.

Interactive e-module will offer interactive and captivating learning experience, leading to the enhancement of CT skills. This incorporates a video showing how to solve exponential material problems using CT, as well as learning activities that students can access and engage with.

Conducting this study is necessary because there are currently no teaching materials in the form of interactive e-module for the mathematics subject, which can help improve CT skills used in schools during classroom learning. Supposing a designed e-module on exponential material is effective in improving CT skills, it can be further developed into interactive e-module for connecting CT skills of students with all mathematical materials. Meanwhile, the method applied in this study to measure validity of the developed product includes 3 stages, namely analysis, design, and development.

II. Material and Method

A. Study Design

This study is a development study that produces an interactive e-module on exponential material that is valid and practical using PBL and through three stages that will be explained in the subheading "Procedure for Developing Interactive e-module," namely analysis, design, and development. Furthermore, only 3 validators were included in the expert review stage, namely 2 professors and 1 teacher, which became a limitation. Validator 1 assessed the correspondence of interactive e-module with CT and PBL indicators. Validator 2 confirmed the correspondence of the constructs and interactivity in the developed e-module.

Validator 3 confirmed the correspondence of language and content in interactive e-module. The subjects of this study were grade 10 students from a high school, consisting of 3 and 6 students for one-to-one and small-group validation phases, respectively.

The study instruments used included validity and practicality questionnaires, where the validation process applied validity questionnaire. Validators added comments and suggestions on the provided sheet, while students received the practicality questionnaire to offer comments and suggestions. Validity and practicality questionnaires were supplied in the form of a Likert scale with four answer categories. The analytic method was divided into several stages:

B. Stage of Validity Analysis

This stage included calculating the average of the validation sheet consisting of content, construct, and language aspects carried out by the validators. Validity categories are presented in Table 1.

Table 1. Criteria for validity of e-module [33]

Validity Level	Validity Criteria
85.1%–100%	Very Valid
70.1%–85%	Fairly Valid
50.1%–70%	Less Valid
0.1%–50%	Not Valid

Interactive e-module was considered valid when the average score from each validator met the criteria of being sufficiently valid. A revision was conducted in case there were deficiencies in the obtained scores.

C. Practicality Analysis Stage

The criteria for the practicality questionnaire are presented in Table 2.

Table 2. Practicality criteria [34]

Practicality Level	Practicality Criteria
$84\% \leq Na \leq 100\%$	very practical
$68\% \leq Na < 84\%$	practical
$52\% \leq Na < 68\%$	less practical
$36\% \leq Na < 52\%$	not practical
$20\% \leq Na < 36\%$	very impractical

Interactive e-module was considered practical when the average response of students fell in the practical category.

D. Procedure for Developing Interactive e-Module

This study was conducted to measure validity of the developed product through three stages, including analysis, design, and development. Each stage is explained as follows:

1) Analysis stage

Analysis stage included examining the independent curriculum, reviewing the literature on learning materials such as exponential and problem-based learning, identifying the need for developing interactive e-module, and conducting a design study.

2) Design stage

Design stage included developing interactive e-module comprising elements such as the front cover, main menu, preface, table of contents, Learning Outcomes (LO), learning objectives flow, usage instructions, concept map, materials, exercises, evaluation, bibliography, and author biography. Furthermore, wizer.me was used to design the exercises and evaluations, and the initial design was referred to as prototype I. The designed e-module was developed into an Android application using Flip PDF Corporate, Web 2 APK Builder, and Google Play Console.

3) Development stage

During development stage, experts in the fields of content, media, and language assessed interactive e-module to determine validity. Subsequently, interactive e-module results were revised based on the feedback and suggestions received. This was followed by a product trial stage, which comprised one-to-one and small-group phases. The one-to-one trial was revised based on feedback, and a small group trial was conducted to assess the practicality of interactive e-module.

III. Result and Discussion

A. Analysis Stage

This stage generated results from a study conducted on the independent curriculum by mapping LO as a basis for developing learning objectives of exponential material, particularly regarding the concepts, properties, and exponential equations. The use of interactive e-module as supplementary teaching material was supported by a program at one high school that implemented technology in all learning processes and during exams. The analysis results were applied as a guideline in developing interactive e-module on exponential material, namely the concepts, properties, and equations of exponential.

B. Design Stage

Canva was used to design interactive e-module comprising a cover page, main menu, preface, table of contents, learning outcomes, learning objectives flow, usage instructions, concept map, materials, exercises, evaluation, bibliography, and author biography. The exercise and evaluation pages, including front display, identity, problems, and CT-based questions, were designed with wizer.me. Table 3 presents interactive e-module as well as the exercise and evaluation pages.

Table 3. Interactive e-module of exponential material designed

Information	Display	Information	Display
Cover	(Translate note: *untuk mendukung computational thinking* implies to support computational thinking, *mulai* implies start).	Exercise/Evaluation	(Translate note: *silahkan isi data seperti nama, kelas, dan hari/tanggal* translates to Please fill in the data such as name, class, and day/date, *nama* means name, l*atihan/evaluasi* implies exercise/evaluation).

Exercises that would be used in interactive e-module were developed, along with practice and evaluation problems based on the concepts, properties, and equations of exponentials. Additionally, several questions were designed in correspondence with CT skills, aiming to guide students in solving provided problems, training, and enhancing CT skills. Each problem applied the same form to meet the indicators of decomposition, pattern recognition, and abstraction but used a different form to meet the algorithm indicator.

Questions a and b were designed to ensure students meet the decomposition indicator, while c was to meet the pattern recognition indicator. Subsequently, question d was developed to meet the abstraction indicator. The last indicator, namely algorithm, was applied to questions e and more. Table 4 presents the format of the questions for each problem.

Table 4. Form of problems and questions on the practice and evaluation pages

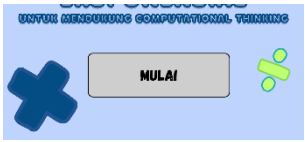
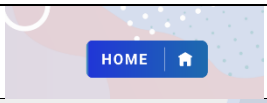
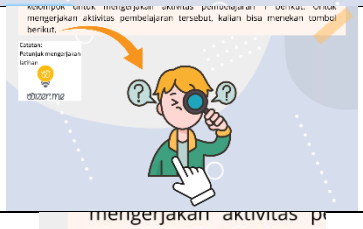
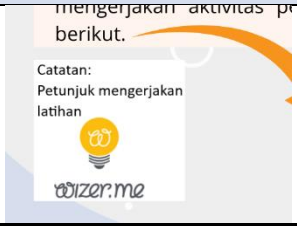
Problems and Questions	Information
A building contractor has built two hotels side by side, which will be named Hotel Amalia and Hotel Waru. Hotel Amalia is planned to have 4 floors, with each floor comprising 4 blocks. In each block, there are 4 classes of rooms, and each consists of 4 rooms. Meanwhile, Hotel Waru is planned to have 5 floors, each containing 5 blocks, and there are 5 rooms in each block. Which hotel has more rooms? Which steps must be taken before solving the problem? What is asked of the problem?	The exercise page comprises problems that could be solved by students using the following exponential concept. $a^n = \underbrace{a \times a \times a \times \ldots \times a}_{As\ many\ as\ n}$ There are 6 questions that lead students to solve these problems, as well as

Problems and Questions	Information
Which ways can you use to solve these parts? Which important information can be identified from the problem? What are the steps to find the number of rooms at Hotel Amalia and Hotel Waru? Write down your steps to find which hotel has more rooms and what is the difference in rooms?	practice and develop CT skills.
The chain length of a bacterium is known to be 8×10^{-6} meter. When the length of one bacterium is $0{,}4 \times 10^{-8}$ meter. The number of bacteria in the chain ... Write down what steps must be taken before solving the problem Write down what is asked of these problems Write down what ways you can solve these parts of the problem Write down what important information can be identified from the problem Write down your steps to find the number of bacteria in the bacterial chain	The exercise page comprises a problem that could be solved by students using an exponential property, namely the operation of dividing exponential. $$\frac{a^m}{a^n} = a^{m-n}$$ There are 5 questions that lead students to solve these problems, as well as practice and develop CT skills.
When a right triangle has an oblique side length of 2^{x+2} cm and the length of the other side is 4 cm and 2^{2x+1} cm, what is the area of the triangle ... cm^2. Write down what steps must be taken before solving the problem Write down what is asked of these problems Write down what ways you can solve these parts of the problem Write down what important information can be identified from the problem Write down your steps to find the number of bacteria in the bacterial chain Write down your steps to find the area of the triangle	The exercise page comprises a problem that could be solved by students using the following exponential equation. $$a^{f(x)} = a^c$$ There are 6 questions that lead students to solve these problems, as well as practice and develop CT skills.
A plant expert examined 3 samples of mango trees. After observation, each tree has 3 branches, each branch has 3 branches, and each branch has 3 branches. Also, each twig has 3 leaves, each leaf has 3 leaf bones, and each leaf bone has 3 leaf fibers. What is the total number of leaf fibers in the three mango tree samples… Write down what steps must be taken before solving the problem Write down what is asked of these problems Write down what ways you can solve these parts of the problem Write down what important information can be identified from the problem Write down your steps to find the total leaf fibers found in each mango tree sample Write down your steps to find the total leaf fibers contained in the three mango tree samples	The evaluation page comprises problems that can be solved by students using the following exponential concepts. $$a^n = \underbrace{a \times a \times a \times \ldots \times a}_{As\ many\ as\ n}$$ There are 6 questions that lead students to solve these problems, as well as practice and develop CT skills.
Siska has a vacant land with an area of 243 m^2. Siska wants to use $\frac{1}{9}$ the vacant land for gardening. Supposing Siska wants to plant pumpkins, carrots, and potatoes with each type of plant having 3 different seeds, what is the area for each plant seed from each type of plant... Write down what steps must be taken before solving the problem Write down what is asked of these problems Write down what ways you can solve these parts of the problem Write down what important information can be identified from the problem Write down your steps to find the area to be used... m^2 Write down your steps to find many seedlings that you want to plant... seeds Write down your steps to find the area for each plant seedling of each type of plant ... m^2	The evaluation page comprises a problem that can be solved by students using an exponential property, namely multiplication operations and division of exponential. $$\frac{a^m}{a^n} = a^{m-n}$$ and $$a^m \times a^n = a^{m+n}$$ There are 7 questions that lead students to solve these problems, as well as practice and develop CT skills.
Mr. Ibra prepared a puzzle out of wood in the shape of a right triangle. The length of the beveled side of the puzzle is 2^{2x+3} cm. The length of the other two sides is 8 cm and 2^{4x+2} cm. The value of x that fills the length of the puzzle sides… Write down what steps must be taken before solving the problem Write down what is asked of these problems Write down what ways you can solve these parts of the problem Write down what important information can be identified from the problem Write down your steps to find the value of x that fills the length of the puzzle sides Write down your steps to find the area of the puzzle	The evaluation page comprises problems that can be solved by students using one form of exponential equation, namely $$a^{f(x)} = a^c$$ There are 6 questions that lead students to solve these problems, as well as practice and develop CT skills.

After gathering all the components, interactive e-module was developed in accordance with the previously prepared

design by converting Canva-designed interactive e-module into an Android application using Flip PDF Corporate, Web 2 APK Builder, and Google Play Console. Interactive e-module comprising materials and problems related to the concepts, properties, and equations of exponentials was produced on Google Play Store. Table 5 provides representations of interactive elements of the developed e-module.

Table 5. Representations of interactivity elements of interactive e-module

Elements in e-module	Explanation of Element Interactivity
	If students click the 'Start' button, the application will immediately switch to the first page.
	If students click the 'back' button, the application will immediately switch to the previous page. If students click the 'next' button, the application will immediately switch to the next page.
	If students click the 'introduction' button, the application will immediately switch to the page containing the introduction. If students click the 'learning outcomes and objectives' button, the application will immediately switch to the page containing the learning outcomes and objectives. If students click the 'concept map' button, the application will immediately switch to the page containing the concept map. If students click the 'material' button, the application will immediately switch to the page containing the material. If students click the 'evaluation' button, the application will immediately switch to the page containing the evaluation. If students click the 'bibliography' button, the application will immediately switch to the page containing the bibliography. If students click the 'developer biography' button, the application will immediately switch to the page containing the developer's biography.
	If students click the 'home' button, the application will immediately switch to the main menu page.
	If students click the 'exponential concept' button, the application will immediately switch to the page containing the exponential concept material. If students click the 'exponential properties' button, the application will immediately switch to the page containing the material on exponential properties. If students click the 'exponential equations' button, the application will immediately switch to the page containing the exponential equations material.
	If students click the button on the material page, the application will immediately switch to the YouTube view and display the learning video.
	If students click the button on the learning activity or evaluation page, the application will immediately switch to the wizer.me interface and display the learning or evaluation activities that students can work on.
	If students click the 'exercise instructions' button on the learning activity or evaluation page, the application will immediately switch to a page containing instructions for accessing wizer.me and completing the learning activity or evaluation.

C. Development Stage

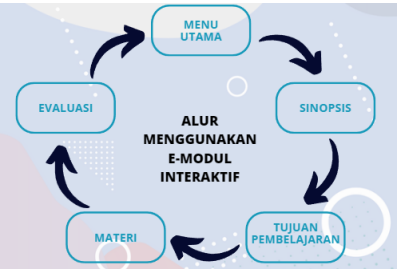
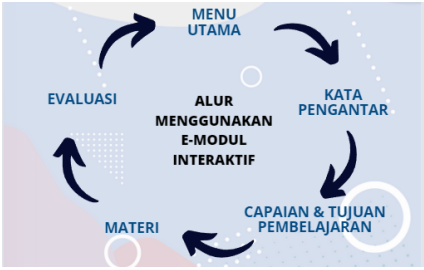
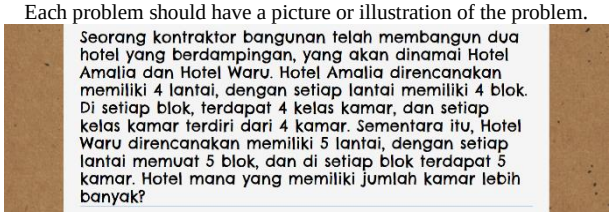
At this stage, the validation process was conducted by three validators, including two mathematics education professors and one mathematics teacher. The validators conducted the validation process twice, followed by a revision based on comments and suggestions. The purpose of this stage was to assess validity of the developed interactive e-module. Table 6 shows the calculation results of the validators.

Tabel 6. Expert validation analysis

Aspects	Average	Category
Content	88%	Very Valid
Construct	92%	Very Valid
Language	97%	Very Valid
Total	**90.8%**	**Very Valid**

Based on the results, the average percentage of validity is 90.8%, signifying that interactive e-module on exponential material is very valid [35]. E-Module is declared valid when it meets validity standards for the specified aspects and is considered suitable for use in the learning process [36]. Despite the high validity, the suggestions of the validators require several revisions. Table 7 presents the results of the revisions to interactive e-module based on comments and suggestions of the validators.

Table 7. Results of e-module revision at the validation stage

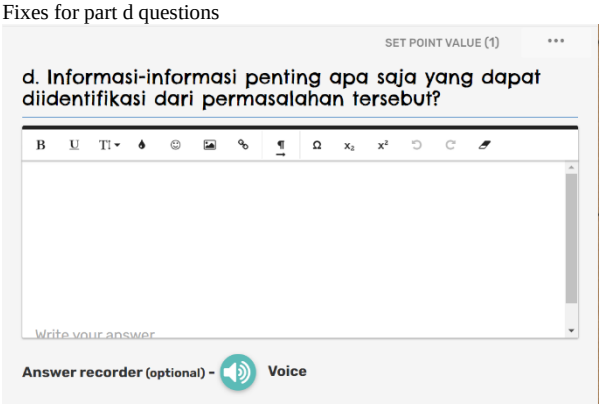
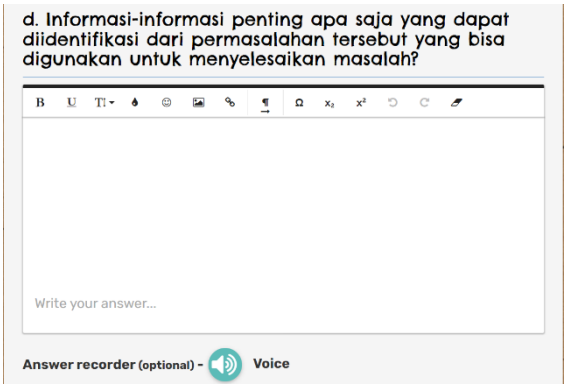
Initial Design	Revision Results
The instructions for use were modified to avoid multiple interpretations.  (Translate notes*: alur menggunakan* means flow using, *menu utama* means main menu, *sinopsis* means synopsis, *tujuan pembelajaran* means learning objectives, *materi* means material, *evaluasi* means evaluation).	Changed to a form that does not give rise to multiple interpretations 
Each problem should have a picture or illustration of the problem.  Seorang kontraktor bangunan telah membangun dua hotel yang berdampingan, yang akan dinamai Hotel Amalia dan Hotel Waru. Hotel Amalia direncanakan memiliki 4 lantai, dengan setiap lantai memiliki 4 blok. Di setiap blok, terdapat 4 kelas kamar, dan setiap kelas kamar terdiri dari 4 kamar. Sementara itu, Hotel Waru direncanakan memiliki 5 lantai, dengan setiap lantai memuat 5 blok, dan di setiap blok terdapat 5 kamar. Hotel mana yang memiliki jumlah kamar lebih banyak? (Translate notes*: Seorang kontraktor bangunan telah membangun dua hotel yang berdampingan, yang akan dinamai Hotel Amalia dan Hotel Waru. Hotel Amalia direncanakan memiliki 4 lantai, dengan setiap lantai memiliki 4 blok. Di setiap blok, terdapat 4 kelas kamar, dan setiap kelas kamar terdiri dari 4 kamar. Sementara itu, Hotel Waru direncanakan memiliki 5 lantai, dengan setiap lantai memuat 5 blok, dan di setiap blok terdapat 5 kamar. Hotel mana yang memiliki jumlah kamar lebih banyak...* means A building contractor has built two hotels adjacently, which will be named Hotel Amalia and Hotel Waru. The Amalia Hotel is planned to have 4 floors, with each floor comprising 4 blocks. In each block, there are 4 classes of rooms, and each consists of 4 rooms. Meanwhile, Hotel Waru is planned to have 5 floors, with each containing 5 blocks, and in each block there are 5 rooms. Which hotel has more rooms?).	Each problem has a picture added to describe the problem.
Exercise page should be changed to adjust to the problem-based learning model selected.	Exercise page is changed to Learning Activities

Initial Design	Revision Results
(Translate note: *latihan* means excersice, *setelah kalian memahami dan mempelajari materi tentang persamaan eksponensial. Silahkan kalian mengerjakan latihan 3 berikut. untuk mengerjakan latihan tersebut, kalian bisa mengklik tombol berikut* means After you understand and learn the material about exponential equations. Please do the following exercise 3. To do the exercise, you can click the following button, *catatan: petunjuk mengerjakan latihan* means note: instructions for doing exercises, *selamat mengerjakan* means good luck, *tidak ada yang tidak mungkin jika kamu berusaha* means nothing is impossible if you try).	(Translate note: *aktivitas pembelajaran* means learning activities, *setelah kalian memahami dan mempelajari materi tentang sifat eksponensial. silahkan kalian berdiskusi dengan masing-masing anggota kelompok untuk mengerjakan aktivitas pembelajaran 2 berikut. untuk mengerjakan aktivitas pembelajaran tersebut, kalian bisa menekan tombol berikut* means After you understand and study the material about exponential properties. Please discuss with each group member to do the following 2 learning activities. To do these learning activities, you can press the following button).

Product trials were conducted on one-to-one and small-group subjects. Students can download interactive e-module from Google Play Store on smartphones and use it for learning activities by logging in with the preferred full name and password. One-to-one trials were performed with 3 grade 10 students from one high school using interactive e-module focused on exponential material.

The purpose of this trial was to observe the thinking process and responses of students toward the use of interactive e-module. During the observation process, students were found to struggle with understanding the question in part d of each problem. This serves as feedback for the revision of the questions, which will be tested in a small group. Table 8 presents the results of the interactive e-module revision at the one-to-one stage.

Table 8. Results of the revision of interactive e-module at the one-to-one stage

Before the Revision	After the Revision
Fixes for part d questions	
	
(Translate note: *d. Informasi-informasi penting apa saja yang dapat diidentifikasi dari permasalahan tersebut?* means d. What important information can be identified from the problem?).	(Translate note: *d. What important information can be identified from the problem that can be used to solve the problem?* Implies d. What important information can be identified from the problem?).

IV. Discussion

Six different students from the same school participated in a small group trial to observe the learning process and responses to the practicality of using interactive e-module. There were no revisions or comments found during the observation process. All students used interactive e-module smoothly without any obstacles. Following the small group implementation phase, a practicality questionnaire was provided for interactive e-module. After calculating 13 statements, the practicality questionnaire produced an average percentage result of 82.7%, showing that the developed interactive e-module met the practical criteria [37].

Students generally provided positive feedback on the interactive e-module developed by stating that the design was attractive and simple to understand, leading to increased interest in learning. Teaching materials in the form of practical modules can be meaningful, engaging, enjoyable, and beneficial, as well as able to foster creativity in students [38]. There is still some confusion with one question in interactive e-module.

Therefore, the wording used was reconsidered and the necessary information was added to promote easier understanding. The choice of words and the use of sentences in e-module should be carefully considered to avoid confusing students [39]. Several previous studies, including the one by Setiabudi, Octaria, & Fuadiah a study in 2022 on "Problem-Based Learning-Based e-module Design on Linear Program Material for 11th Grade High School Students," provided valuable insights. Additionally, Anggreni and Agustika conducted a study in 2022 titled "Development of Problem-Based Learning-Based e-module on Fraction Material for 4th Grade at SD No. 2 Sembung".

There are several fundamental differences between the investigations of Anggreni and Agustika. These are evidenced by the manufactured product, e-module that has not yet evolved into an Android application. Additionally, in the subjects section, some investigations used XI-grade high school and IV-grade elementary school students, but the subjects in this study were X-grade high school students. In the methods section, some investigations applied the Ken Peffers design stages and development study with ADDIE model.

However, this study used a method comprising analysis, design, and development stages. Another significant difference from the two previous investigations is the absence of CT indicators in the developed e-module. This study was limited to one school but generated valid and practical results.

The developed interactive e-module covered material on exponential concepts, exponential properties, and exponential equations, with only one problem featured in each subtopic.

V. Conclusion

In conclusion, the results showed that interactive e-module developed for CT skills was highly valid and practical. The advantage of interactive e-module was that students could independently access the application at all times from any location, and repeatedly watch the videos contained. However, some features required an internet connection for access.

The factors supporting the success of this study included the proficiency of students in using technological devices, such as smartphones, and the availability of accessible internet networks in the study area. However, obstacles were encountered due to the limited devices owned by students, leading to errors, slow loading, or navigation difficulties when trying to access interactive e-module.

Future studies should conduct trials with a larger number of students to observe the effectiveness of the developed interactive e-module during classroom learning. Additionally, interactive e-module should be developed on other mathematics topics, incorporating relevant problems capable of enhancing CT skills. The development of a similar interactive e-module as an application, accessible without an internet connection, could be considered.

Because the developed interactive e-module is already very valid and practical, the product can be used in classroom learning to enhance students' computational thinking skills after using the interactive e-module.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The contributions of each author are as follows: Hapizah was responsible for conceptualization, writing the original draft, editing and visualization, investigation, methodology, and project administration. Muhammad Aidil Fitrisyah contributed to validation, formal analysis, and writing-review and editing. Budi Mulyono contributed to validation and formal analysis. All authors had approved the final version

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References

[1] H. Haqqi and H. Wijayati, "The industrial revolution 4.0 in the midst of society 5.0: A spatial integration, technological breakthrough, and life transformation in a disruptive era," *Great Children of Indonesia*, 2019.

[2] M. Ansori, "Computational thinking in problem solving," *Dirasah: Journal of Islamic Education Science and Management Studies*, vol. 3, no. 1, pp. 111–126, 2020.

[3] M. G. Supiarmo, "Transformation of computational thinking process of high school students on mathematical problem solving through reflection [in Bahasa]," *UIN Maulana Malik Ibrahim Malang*, 2021.

[4] R. A. Cahdriyana and R. Richardo, "Computational thinking in mathematics learning [in Language]," *Literacy: Journal of Educational Sciences*, vol. 11, no. 1, pp. 50–56, 2020.

[5] S. Inganah, R. Darmayanti, and N. Rizki, "Problems, solutions, and expectations: 6C integration of 21 st century education into learning mathematics," *JEMS: Jurnal Edukasi Matematika Dan Sains*, vol. 11, no. 1, pp. 220–238, 2023.

[6] M. R. K. Brennan, "New frameworks for studying and assessing the development of computational thinking," *Studies in Computational Intelligence*, vol. 727, pp. 135–160, 2012.

[7] M. Román-González, J. Moreno-León, and G. Robles, "Complementary tools for computational thinking assessment," in *Proc. International Conference on Computational Thinking Education (CTE 2017)*, pp. 154–159, 2017.

[8] M. Safik, "Integration computational thinking in mathematics learning at Madrasah Ibtidaiyah [in Bahasa]," *IBTIDA'*, vol. 3, no. 2, pp. 241–248, 2022. (in Indonesian)

[9] X. P. Voon, S. L. Wong, L. H. Wong, M. N. M. Khambari, and S. I. S. S. Abdullah, "Developing computational thinking competencies through constructivist argumentation learning: A problem-solving perspective," *International Journal of Information and Education Technology*, 2022.

[10] A. Csizmadia, P. Curzon, M. Dorling, S. Humphreys, T. Ng, C. Selbu, and J. Woollard, *Computational Thinking (A Guide for Teachers)*, The Educational Divison of Hachettte, 2020.

[11] J. M. "Wing, computational thinking," *Communication of the ACM*, vol. 49, no. 3, pp. 33–35, 2006.

[12] I. Mufidah. (2018). Computational thinking profile in solving Bebras Tasks reviewed from students' mathematical logical intelligence [in Bahasa]. *Thesis, Dept. Mathematics and Science Edu., Sunan Ampel Islamic Univ., Surabaya*. [Online]. Avalailable: http://digilib.uinsa.ac.id/id/eprint/28697

[13] C. Angeli and M. Giannakos, "Computational thinking education: Issues and challenges," *Computers in Human Behavior*, vol. 105, 2020.

[14] G. Gadanidis, R. Cendros, L. Floyd, and I. Namukasa, "Computational thinking in mathematics teacher education," *Contemporary Issues in Technology & Teacher Education*, vol. 17, no. 4, pp. 458–477, 2017.

[15] R. Ardianti, E. Sujarwanto, and E. Surahman, "Problem-based learning: Apa dan Bagaimana," *DIFFRACTION: Journal for Physics Education and Applied Physics*, vol. 3, no. 1, pp. 27–35, 2021.

[16] N. Hidayati, S. Zubaidah, E. Suarsini, and H. Praherdhiono, "Cognitive learning outcomes: Its relationship with communication skills and collaboration skills through digital mind maps-integrated PBL," *International Journal of Information and Education Technology*, vol. 10, no. 6, pp. 433–448, 2020.

[17] A. N. Dewi, E. Juliyanto, and R. Rahayu, "The effect of science learning with scratch-assisted computational thinking approach on problem-solving ability," *Indonesian Journal of Natural Science Education*, vol. 4, no. 2, pp. 492–497, 2021.

[18] M. Lestari, "Implementation of intuitive-based learning model on student creativity [in Language]," *Journal of Mathematics Education (Kudus)*, vol. 2, no. 1, pp. 13–22, 2019.

[19] T. Salwadila and H. Hapizah, "Computational thinking ability in mathematics learning of exponents in grade IX," *Infinity Journal*, vol. 13, no. 2, pp. 441–456, 2024.

[20] A. F. Rahma and S. Khabibah, "Analysis of high school students' mistakes in solving exponential problems [in Language]," *MATHEdunesa*, vol. 11, no. 2, pp. 446–457, 2022.

[21] M. S. Gunawan and D. Fitra, "Students' difficulties in doing exponential and logarithmic problems [in Bahasa]," *Mosharafa: Journal of Mathematics Education*, vol. 10, no. 2, pp. 257–268, 2021.

[22] R. M. Sari and H. Hapizah, "Development of Android-based linear program teaching materials for problem-based learning [in Bahasa]," *Kreano, Journal of Creative-Innovative Mathematics*, vol. 11, no. 2, pp. 161–172, 2020.

[23] M. Mardeti, S. Supriadi, A. Arifmiboy, and S. Wati, "Development of teaching materials in the form of moral beliefs module assisted by crossword puzzles Class X science at MAN 2 Agam [in Bahasa]," *Journal of Education and Counseling (JPDK)*, vol. 5, no. 1, pp. 3773–3782, 2023.

[24] M. Frilia, E. S. Hapizah, and S. Scristia, "Development of android-based prism material teaching materials for problem-based learning in

grade VIII [in Bahasa]," *Gantang Journal*, vol. 5, no. 2, pp. 191–201, 2020.

[25] I. A. Khasanah and I. Nurmawati, "Development of digital modules as biology teaching materials for grade XI Science students [in Bahasa]," *Indonesian Journal of Mathematics and Natural Science Education*, vol. 2, no. 1, pp. 34–44, 2021.

[26] S. Suprihatiningsih and P. Annurwanda, "Development of a problem-based mathematics module on the material of a two-variable linear equation system [in Bahasa]," *Journal of Mathematics Education Works*, vol. 6, no. 1, pp. 57–63, 2019.

[27] K. Khotimah, G. Giyanti, and Y. Fajriani, "Development of e-modules based on the core learning model to facilitate students' mathematical communication skills [in Bahasa]," *Journal of Lebesgue: Scientific Journal of Mathematics, Mathematics and Statistics Education*, vol. 3, no. 3, pp. 584–593, 2022.

[28] M. Harahap and D. Eliza, "E-module of coding learning based on introduction to Indonesia culture to improve computational thinking [in Bahasa]," *Journal of Obsession: Journal of Early Childhood Education*, vol. 6, no. 4, pp. 3063–3077, 2022.

[29] F. Ramadanti, A. Mutaqin, and A. Hendrayana, "Development of PBL (Problem Based Learning) based mathematics e-module on data presentation materials for junior high school students [in Language]," *Journal of Scholars: Journal of Mathematics Education*, vol. 5, no. 3, pp. 2733–2745, 2021.

[30] N. N. D. Anggreni and G. N. S. Agustika, "Development of problem-based learning e-module for class iv fractional materials at SD No. 2 Sembung [in Bahasa]," *Journal on Teacher Education*, vol. 3, no. 3, pp. 35–43, 2022.

[31] A. S. Ningtyas, D. Triwahyuningtyas, and S. Rahayu, "Development of a simple flat building E-module based on Problem Based Learning (PBL) using the Kvsoft flipbook maker application for Grade III students [in Bahasa]," in *Proc. the National Seminar of PGSD UNIKAMA*, vol. 4, no. 1, 2020, pp. 10–19.

[32] A. A. Setiabudi, D. Octaria, and N. F. Fuadiah, Design of problem-based learning based e-module on linear program materials for grade XI high school students [in Bahasa]," *Mathema: Journal of Mathematics Education*, vol. 4, no. 1, pp. 27–38, 2022.

[33] S. Akbar, *Learning Tool Instruments [in Language]*, Bandung: Rosdakarya, 2013.

[34] Sugiyono, *Educational Research Methods*, Bandung: Alfabeta, 2013

[35] S. Akbar, *Learning Tool Instruments [in Language]*, Bandung: Rosdakarya, 2013.

[36] N. Isnaini, A. Listiadi, and W. T. Subroto, "Validity and practicality of contextual based e-module OTK subjects facilities and infrastructure for students of the office governance automation expertise program [in Language]," *Journal of Office Administration Education (JPAP)*, vol. 10, no. 2, pp. 157–166, 2022.

[37] Sugiyono, *Educational Research Methods*, Bandung: Alfabeta, 2013

[38] S. Eka, "Development of teaching materials for modules based on language literacy and numeracy in grade IV of SD [in Bahasa]," Doctoral dissertation, Uin Raden Intan Lampung, 2022.

[39] P. M. Nikita, A. D. Lesmono, and A. Harijanto, "Development of dynamic fluid material E-module to improve critical thinking skills of high school students in grade XI [in Bahasa]," *Journal of Physics Learning*, vol. 7, no. 2, pp. 175–180, 2018.

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