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Development of the 4C Teaching Model to Improve Students' Mathematical Critical Thinking Skills

Irham* 

Postgraduate of Universitas Negeri
Makassar, INDONESIA

Ismail Tolla 

Postgraduate of Universitas Negeri
Makassar, INDONESIA

Baso Jabu 

Postgraduate of Universitas Negeri
Makassar, INDONESIA

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Abstract: This study aims to develop a learning model based on 4C skills to improve high school students' mathematical critical thinking skills. Research & development is the design used in this research by applying Plomp's development theory which consists of three phases, namely needs analysis, design and implementation, and evaluation. This research was conducted at Madrasah Aliyah Negeri 2 Parepare, South Sulawesi, Indonesia involving five experts, four teachers, and 20 students. Data collection and analysis were carried out qualitatively and quantitatively. Analysis of interviews' data and observations qualitatively with the thematic analysis technique. We also analyse data from validation sheets, questionnaires, and mathematical essay tests with the help of SPSS 20.00. The results show that students and lecturers need a learning model to improve mathematical critical thinking skills. In addition, other findings stated that the learning model developed was proven to be valid, practical, and effective to be used in general. Developing your learning model can further improve students' learning outcomes and mathematical critical thinking skills because they are designed based on the actual needs and problems. For this reason, a teacher must be able to design his learning model.

Keywords: *Mathematical critical thinking skill, teaching model, the 4C skills.*

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Introduction

Every individual entering the era of the industrial revolution 4.0 is expected to master various skills. In general, the essential skills that must be learned in the 21st century include thinking critically, identifying problems, and creating the best solutions for these problems (Aizikovitsh-Udi & Cheng, 2015; Arisoy & Aybek, 2021; Kuntze et al., 2017). In addition, related to the increasingly rapid development of digital technology, students are also expected to have good literacy in technology to adapt to today's globalization (Chusni et al., 2021). These various skills absolutely must be mastered by students in addition to their general knowledge.

As one of the four skills (4C), critical thinking has become the primary goal of education that has played an essential role for approximately the last two decades (Stupple et al., 2017). Critical thinking skills are part of high order thinking skills (HOTS) and creative thinking skills, problem-solving or problem solving, and reflective thinking (Hidayah et al., 2017; Phan, 2010). Critical thinking can be conceptualized as a form of cognitive skill or social and emotional disposition. Some of the abilities in the disposition section referred to in this context include truth-seeking skills, open-mindedness, systematic analysis, maturity, curiosity, and self-confidence (Facione, 2011).

There are many benefits for students who have these critical thinking skills. By mastering this skill, students are assisted in paying attention to the context of the actions and ideas they generate (Brunning et al., 2004). In addition, critical thinking can also influence students to be skeptical of quick-fix solutions and single answers to problems and universal truth claims (Ebadi & Rahimi, 2017; Halpern, 2001). On the contrary, they become individuals who are open to looking for other ways of looking at and behaving towards things.

In practice, students' mastery of critical thinking skills in Southeast Asian countries is still considered very low. A study states that Indonesia and countries in Southeast Asia are considered at a minimal level of critical thinking skills (Devi et

* **Corresponding author:**

Irham, Postgraduate of Universitas Negeri Makassar, Makassar, South Sulawesi, Indonesia. ✉ irhamman2pare@gmail.com



al., 2016). Four world-leading institutions also presented similar research results: The Conference Board, Cooperate Voice for Working Families, The Partnership for 21st Century Skills, and The Society for Human Resource Management. The four institutions examined 400 employers who stated that there are more than 50% of their employees are less skilled in the aspects of: (1) oral and written communication, (2) professionalism or work ethic, and (3) critical thinking (Levin-Goldberg, 2012; Radulovic & Stancic, 2017). This condition, of course, requires more attention from various groups in the field of education so that school/university graduates have much better skills.

Integrating critical thinking skills into certain subjects is one way to train students' critical thinking. Mathematics is a subject that can promote students' critical thinking skills because this subject involves reasoning, decision making, and problem-solving (Cresswell & Speelman, 2020; Firdaus et al., 2015; Su et al., 2015). Students' critical thinking skills are still relatively low due to the large number of teachers who apply teacher-centred learning in the classroom (Artuz & Roble, 2021; Irwanto et al., 2018). Currently, students tend to only be trained to respond to problems with the memorization method, which impacts students' performance in critical thinking skills.

To overcome these problems, one way that teachers must do is the use of appropriate teaching models. In efforts to improve critical thinking skills, one of the proper teaching models is learning based on 4C skills, namely critical thinking, creativity, collaboration, and communication (Partnership for 21st Century Learning, 2016; Partnership for 21st Century Skills, 2010). The 4C simplifies 21st-century skills defined by The Partnership for the 21st Century. The institute states that 18 types of skills must be mastered by students whose grades are too complicated by experts (Erdoğan, 2019; Van-Laar et al., 2020). Thus, 4C skills must be the primary goal in the education process worldwide in equipping students to face the changing times like today.

This learning model integrates the four primary skills into the learning process. This model is expected to impact student profiles, create learning experiences, and improve skills and knowledge both online and face-to-face (Ismail et al., 2016). In other words, this learning model is identical to hybrid learning, where learning must be combined face-to-face and online-based (Jarvis, 2005). Hybrid learning has become a necessity in today's learning system since covid-19 hit the world and the effects of the increasingly rapid development of communication technology.

Researchers have conducted several studies about learning by integrating the 4C skills. Research with class action research (CAR) design in improving the four basic 4C skills has been carried out by several researchers using the creative problem solving model (CPSM), cooperative learning with the Student Teams Achievement Divisions (STAD) type, and learning to write English (Adrianto, 2019; Angkowiati, 2020; Yu & Wan Mohammad, 2019). In addition, Purwasih et al. (2021) found these four skills can also be improved by using a blended learning model during the COVID-19 pandemic.

Research with a research & development design has also been carried out by Hamdu et al. (2020) who developed a rubric for assessing the performance of students' 4C skills in STEM learning in elementary schools. Furthermore, the research and development (R&D) design was also carried out by Rahmi and Suparman (2019), who had developed a mathematics learning module in promoting 4C skills. Another similar study was also conducted by Hamida and Desnita (2021), who found that contextual-based learning videos in improving students' 4C skills were declared valid after being tested for validity by involving educational experts and practitioners.

From these several studies, there are no researchers who design learning models that aim to improve critical thinking skills specifically. So far, researchers and teachers have focused more on developing one of several learning tools. The development of a learning model is significant for all teachers. Learning objectives can be achieved based on an analysis of the needs of product users. For this reason, researchers are interested in conducting research by developing a mathematical learning model based on 4C skill elements to improve mathematical critical thinking skills for students. Specifically, there are three problem formulations in this research: (1) how is the description of the need to develop a 4C skills learning model to improve mathematical critical thinking skills? (2) how to design a 4C skills learning model to improve mathematical critical thinking skills? and (3) what is the level of validity, practicality, and effectiveness of the learning model that has been developed?

Methodology

Research Design

To answer some of the research questions above, the researchers used a research & development (R & D) design regarding the theory developed by Plomp (2013). There are three main stages in this development theory, namely: (1) conducting needs analysis and problem identification, (2) designing and implementing products, and (3) evaluating. These three phases to obtain a valid, practical, and effective 4C skill-based learning model.

Participants

This research was conducted at Madrasah Aliyah Negeri (MAN) 2 Parepare, South Sulawesi, Indonesia. From the user aspect of the developed product, two groups of participants are involved, namely a group of 20 students (1 study group) and four mathematics teachers. On the other hand, to test the level of product validity, five experts were involved in

assessing the product. Participants in this study were selected using a purposive sampling technique which emphasizes several considerations in determining the research sample.

Data Collection

Semi-structured Interview

The main instrument used is the semi-structured interview type in the needs analysis and problem identification phase. This instrument is used to collect and explore the perspectives and needs of teachers in learning mathematics. The use of semi-structured interviews is based on the consideration that this instrument can explore more deeply to participants in a more relaxed atmosphere and does not seem formal or rigid (Bokiev & Ismail, 2021; Guthrie, 2019; Islamiyah & Fajri, 2020; Wilkinson & Birmingham, 2003). In general, the theme of the questions in this interview relates to the current learning conditions, challenges and problems faced the importance of learning 4C skills, and the need to develop new learning models.

Observation

In the initial phase, the researcher also used observation to collect data in addition to semi-structured interviews. Observation is a technique used to observe a subject or thing using the five human senses. This technique keeps the research focus directly by recording events naturally, not artificially, and spontaneously within a certain period (Adler & Adler, 1994; Smit & Onwuegbuzie, 2018). The aspects observed in this initial phase relate to the activities of teachers and students during the learning process before using the 4C learning model.

Learning Product Validation Sheet

In addition, data collection in this study was also carried out using a product validation sheet. This sheet is an instrument for collecting data on product validity from experts' assessments. There are five types of product validation sheets, namely: (1) model book validation sheets, (2) Semester Lesson Plan validation sheets, (3) student books, (4) teacher books, and (5) student worksheets. Several aspects assessed on this validation sheet include (1) presentation aspect, (2) language use, (3) attractiveness aspect, (4) suitability for student development, and others (Helaluddin et al., 2021; Supartini et al., 2020).

Teacher and Student Response Questionnaire

Regarding the practicality of the learning model, the researcher used a teacher and student response questionnaire to collect their responses as users to the learning model that had been developed. This questionnaire was designed by providing an assessment range from 1 to 4. Several aspects were responded to by the teachers and students, including parts of language, elements of presentation, aspects of ease of use, aspects of benefits, and others.

Math Ability Essay Test

The effectiveness of the learning model was measured with the mathematical ability test was used to see the development of students' mathematical thinking skills by comparing the pretest and posttest scores. This instrument consists of 5 essay questions designed to measure students' mathematical critical thinking skills covering four main aspects, namely: (1) identification and justification of concepts, (2) generalization, (3) algorithm analysis, and (4) problem solving (Buhaerah, 2015). Before being used, this mathematical test instrument was tested explicitly with a reliability score of .90.

Data Analysis

In research and development, two approaches are used in analyzing data, namely qualitative and quantitative approaches. Data from the needs analysis phase (interview results) were analyzed using a qualitative approach. The data collected from this phase is described descriptively without involving numbers. This data analysis uses the thematic analysis technique, which aims to determine the most prominent themes by analyzing the similarities and differences in the participants' perceptions so that they can bring up new, unexpected insights (Braun & Clarke, 2006; Nowell et al., 2017).

Data analysis also uses a quantitative approach, particularly in validity, practicality, and effectiveness tests. In the validity and practicality test, the data that has been collected is analyzed quantitatively by determining the average score. Furthermore, the score is compared with the category of score ranges to assess the level of validity and practicality. The type of the score range can be seen in Table 1.

Table 1. Category Scoring Validity and Practicality

No.	Score Range	Category
1.	$3.6 \leq M \leq 4.0$	Very Valid/Very Practical
2.	$2.6 \leq M \leq 3.5$	Valid/Practical
3.	$1.6 \leq M \leq 2.5$	Less Valid/Less Practical
4.	< 1.5	Invalid

In addition to the validity and practicality data, other data analyzed in this study is the analysis of the effectiveness of the learning model. The data collected through the mathematical essay test were analyzed using the help of SPSS 20.00. The learning model's effectiveness is determined by looking at the difference in scores between the pretest and posttest. The difference between the two test results is made by running the t-test. The effect of learning models on mathematical critical thinking skills can be measured through the difference in scores between pretest and posttest with t-test.

In addition to conducting the t-test, the researcher also analysed the data to determine the effect size of the influence of the learning model on mathematical critical thinking skills. The analysis was carried out using Cohen's (1988) formula as follows:

$$D = \frac{d}{sd}$$

Description:

D = effect size

d = difference between the average pretest and posttest

SD = standard deviation

After the effect size score is determined, it is then interpreted to determine how strong the influence of the learning model is. There are four categories of effective measures that have been defined in this study, namely weak, moderate, strong, and very strong. The criteria for measuring the effectiveness are presented in Table 2.

Table 2. Effect Size

No.	Interval Score	Criteria
1.	$0 < d \leq 0.2$	Low
2.	$0.2 < d \leq 0.5$	Moderate
3.	$0.5 < d \leq 0.8$	High
4.	$d > 0.8$	Very High

Before we conducted the inferential statistical test, the researcher ran a normality test on the pretest. And posttest data before the inferential statistical test. A normality test was conducted to determine whether the data obtained were normally distributed. The normality test on the pretest data obtained the value of $\text{sig} = .477 > .05$, while the posttest value of $\text{sig} = .804 > .05$ was obtained. This shows that the data from the mathematical ability test results are normally distributed.

Furthermore, to ensure the reliability of the qualitative data, the member checking technique was carried out. The researcher drafted a written interview and then asked the participants to review it. Participants can cross out several points of the interview draft that are deemed inappropriate or may even add topics that are considered essential (Carlson, 2010; Creswell, 2007; Morse et al., 2002).

Results

Needs Analysis Results

In the needs analysis and problem identification phase, the researcher attempted to explore the teachers' views and perspectives on learning mathematics related to 4C skills. The research results obtained information that there are still many students who have difficulty understanding mathematical concepts. In addition, mathematics learning has not been rigid, and students are not active in class. This is caused by students who still think that mathematics is a challenging and uninteresting lesson. This is following the following interview excerpt from a teacher:

"Students still think that mathematics is a difficult, abstract, and uninteresting subject. This assumption makes them passive in class and tends not to develop their abilities," (Teacher-1).

The interview results also stated that there is no mathematical learning model that integrates 4C skills explicitly. The majority of mathematics learning models only refer to mathematical abilities. This means that very few mathematical learning models still encourage other skills as the output of their learning.

“The learning model used by the teacher is more focused on improving math skills. Some teachers still think that the mathematics learning model must be associated with efforts to develop students’ cognitive abilities. That is, many other aspects and skills are not considered,” (Teacher-3).

The teachers also think that it is necessary to develop a more contemporary learning model that does not only focus on mathematical abilities. They also emphasized that learning mathematics must also be linked to life skills or 21st-century skills, including critical thinking, creativity, collaboration, and communication skills. This is following the following statement of one teacher:

“It seems that the mathematics learning model must be redesigned to suit the changing times. I think basic math skills alone are not enough to be able to compete in the global market as it is today. I think designing a learning model by integrating 4C components is very important to be done immediately,” (Teacher-1).

The results of observations in the needs analysis phase also showed results that were not much different from the results of the interviews. In learning mathematics, there are still many students who tend to be passive and only accept explanations from their teachers. They are not motivated to ask questions, discuss with colleagues, or take the initiative to do feedback activities during learning. The majority of students are still unable to develop their capacity to collaborate and work together in solving mathematical problems. This is allegedly a factor that causes students to be passive and only “accept” what the teacher gives.

In addition, teachers also do not take the initiative to develop or integrate subjects with components of students' thinking skills. They tend to deliver subject matter based on handbooks that have been provided by the government (directories from the Indonesian Ministry of Education & Culture). This is not entirely wrong, but on the other hand, a teacher must be able to design his learning model so that students are motivated to learn more actively. One thing that should be said is that the guidebooks provided by the central government cannot fully address the problems faced by students. In other words, every student has their problems, and there are very open opportunities for teachers to detect these problems to provide the best solution.

Learning Model Design

After the needs analysis has been identified, the next step is how to design the learning model. The first step is to design a model book that serves as the basis and benchmark in carrying out the learning model. The learning model is adapted to the provisions and classifications suitable for 21st-century skills learning. This learning model was developed by modifying the three previous learning models: inquiry, problem-based, and project-based learning. Another thing considered necessary in a model is the syntax or stages of learning. In this 4C-based learning model, there are five stages, namely: (1) orientation, (2) organizing learning with a hybrid learning model, (3) exploration, (4) solving problems in learning, and (5) presentation and feedback. In addition to model books, several types of learning tools are developed, namely student books, teacher handbooks, Semester Learning Plans (SLP), and Student Worksheets (SW).

About learning content, some Mathematics subject matter was developed by researchers based on the applicable curriculum, namely the 2013 Curriculum. This learning content was developed specifically for the Mathematics subject of class X High School. The researcher designed the learning into six meetings with different materials, namely: (1) finding the concept of function, (2) the types of functions, (3) algebraic operations of functions, (4) the concept of compositional functions, (5) properties composition function, and (6) the concept of the inverse function.

Test of Validity, Practicality, and Effectiveness

The validity test was carried out by involving five experts in mathematics education. They are tasked with assessing the learning products that researchers have developed. From the validity test results, information was obtained that the models and learning tools were declared valid by the experts with an average total score of 3.67. Overall, the validation results are presented in Table 3.

Table 3. Product Validation Results from Experts

No	Development of Product	Expert Score Average	Category
1.	Model Book	3.8	Very valid
2.	Semester Learning Plan (SLP)	3.6	Very valid
3.	Student Worksheet (SW)	3.8	Very valid
4.	Student Book	4.0	Very valid
5.	Teacher's Guide	3.6	Very valid
Total score		3.76	Very valid

In addition to the validity test, the learning product resulting from this development was also tested for its practicality. The practicality of this learning model is determined by the results of the teacher's response questionnaire and student responses after they use the product. The results of the practicality test are presented in Table 4.

Table 4. Results of Teacher Response Questionnaire Analysis

No	Assessment Aspect	Expert Score Average	Category
1.	Response to learning models and tools	3.58	Very Practical
2.	Presentation	3.4	Practical
3.	Language usage	3.0	Practical
4.	Level of compatibility with student development	3.25	Practical
5.	Practicality in use	3.6	Very Practical
6.	The role of learning models in improving mathematical critical thinking skills	4.0	Very Practical
Total Score		3.54	Very Practical

Table 5. Results of Student Response Questionnaire Analysis

No.	Student Code	Total Score	Student Response	Percentage (%)
1.	P-01	141		90
2.	P-02	138		88
3.	P-03	138		88
4.	P-04	139		89
5.	P-05	142		91
6.	P-06	137		88
7.	P-07	137		88
8.	P-08	136		87
9.	P-09	139		89
10.	P-10	141		90
11.	P-11	140		90
12.	P-12	142		91
13.	P-13	143		92
14.	P-14	143		92
15.	P-15	143		92
16.	P-16	144		92
17.	P-17	145		93
18.	P-18	147		94
19.	P-19	146		94
20.	P-20	146		94
Mean		141.4		90.61

The level of practicality of the learning model is also carried out by using students' responses to the model after they use it during the learning process. Several aspects are contained in the response questionnaire, including aspects of language, ease of using learning tools, aspects of graphics or attractiveness in learning tools, and others. The analysis results obtained information that this learning model was declared practical based on students' positive responses. The percentage of positive responses from these students is 90.61%.

The purpose of the practicality test and effectiveness test is to determine the level of quality of the learning model developed. Mathematics tests were given to students twice, namely in the pretest and posttest sessions. The data collected in the two sessions were analysed using paired sample t-test to determine whether there was a difference between the pretest and post-test scores. The results of the paired samples test are presented in Table 6.

Table 6. Paired Samples Test

	Paired Differences					t	df	Sig. (2 tailed)
	Mean	Std. Deviation	Std. Error Deviation	95% confidence interval of the difference				
				Lower	Upper			
Pair-1 pre-test post-test	-11.600	3.085	.690	-13.044	-10.156	-16.817	19	.000

From Table 5, it is known that the value of Sig. (2-tailed) of .000. That is, according to the provisions that if the score Sig. (2-tailed) < .05, it can be stated that there is a significant difference between the average score of mathematical critical thinking skills between the pretest and posttest sessions. From the analysis results, it can be concluded that the 4C learning model can improve students' mathematical critical thinking skills. Therefore, this 4C-based learning model has proven effective, so it is feasible to use it widely.

Furthermore, the results of data analysis to determine the size of the effect size obtained a score of 3.75847. After being interpreted with the criteria table in the method section, it can be concluded that this learning model has a very high category of effectiveness measures. This is based on the criteria table, which states that if $D > 0.80$. Then the measurement of the effectiveness of this learning model is categorized as very strong.

Table 7. Effect Size

Pretest-posttest mean difference	Standard deviation	D
11.65	3.09	3.7584

Discussion

Developing a learning model begins with the stages of needs analysis and problem identification. This phase is carried out to seek personal and objective information from participants, which is used as the basis for developing the product. In this study, the method used in identifying needs is to conduct interviews with teachers about learning mathematics. With this method, various information and actual conditions can be identified comprehensively. This is in line with several previous studies that mainly used the interview method in the needs analysis process and observation methods, document analysis, questionnaires, and others (Ariyana, 2020; Gupta et al., 2007; McCawley, 2009).

The needs analysis results in this study stated that it was essential for teachers to develop learning models, especially learning mathematics, based on the 4C skill component. Teachers consider critical thinking skills to have a crucial role in forming competent students in the current era of the industrial revolution 4.0. The same thing was also stated by Howard et al. (2015), which noted that critical thinking skills are essential to be mastered by students at all levels of education. Some researchers also support this by providing their perspective that the process of developing a learning model must place crucial things as a top priority in educational programs (Abdel-Maksoud & Saknidy, 2016; Golpour, 2014). In other words, needs analysis to develop learning models must be adapted to the existing context, such as curriculum, textbooks, problems faced, and others (Tzotzou, 2014).

Raising the issue of 4C skills, especially critical thinking skills in mathematics learning, is considered by teachers as the best step in the 21st century. Based on the interviews, learning mathematics has been less attractive to students because it has not shown the contextuality of mathematics in everyday life. In other words, mathematical concepts are still presented abstractly by the teacher in class. By developing their learning model, teachers can design more precise learning instructions and more explicit strategies and provide a variety of learning activities (Kumaravadivelu, 2007; Nunnez et al., 2012).

After the needs analysis phase is complete and various identification problems are found, the next step is to design learning products. The product developed must follow the needs and be the best solution step for students to improve their mathematical critical thinking skills. In designing a product, many aspects must be a priority for developers, including language and the depth of material adapted to student development. The use of simple and unambiguous language contributes significantly to accelerating students' understanding. Likewise, the depth of material adapted to their development can more easily encourage the improvement of learning outcomes and critical thinking abilities (Angelina, 2018; Wahyudi & Winanto, 2018).

After the learning model has been designed, the next step is to determine the level of product quality. The quality of the learning model can be known by testing its validity, practicality, and effectiveness (Nieveen, 1999). Based on the three tests, the 4C learning model is valid, practical, and effective. In the validity test, the experts assess the learning product from various aspects, such as aspects of material, language, presentation, and others. Holguin and Morales (2014) claim that the existence of a validation process aims to avoid the deficiency of the first-person view of the teachers who act as material developers. In the linguistic aspect, correcting the language used in learning products can allow the material to provide a better level of language according to student development (Helaluddin et al., 2020; Wyatt, 2011).

In addition to validity testing, learning products are also tested for their practicality from users' points of view, namely teachers and students. The practicality test is based on several aspects of user ratings related to interest in the product (Mustami et al., 2019). In addition, the practical element can also be seen in how much the user tends to respond positively to the learning model. In other words, a learning product is said to be practical if the teacher and students as users state that the product can be used and is easy to understand.

The quality of the learning model is also viewed from its effectiveness. The results of this study prove that the 4C skill-based learning model is effective in improving students' mathematical critical thinking skills. There is a significant

difference between the pretest and posttest scores in terms of students' necessary thinking skills. In line with these findings, a study states that the mathematics learning module with the 4C skills approach can also increase their level of critical thinking skills (Rahmi & Suparman, 2019). For subjects outside of mathematics, the development of contextual-based Physics learning videos and 4C skills was also declared valid, practical, and effective in improving students' thinking skills (Hamida & Desnita, 2021). In addition to critical thinking skills, the 4C-based learning model will also influence student learning outcomes and academic capabilities (Supena et al., 2021). This indicates that students need appropriate models or learning tools in developing their mathematical critical thinking skills.

This model is proven to improve students' mathematical critical thinking skills. This is due to several activities in the learning stage that can improve mathematical critical thinking skills, such as providing feedback, hybrid learning, and problem-solving activities (Agbi & Yuangsoi, 2022; Rahmawati et al., 2022). Learning mathematics associated with problem-solving activities is considered to improve students' critical thinking skills. Students who have problem-solving skills tend to have mathematical critical thinking skills.

The 4C learning model is considered suitable and appropriate for developing students' critical thinking skills. This is because the 4C learning model combines constructivism and collaboration (Supena et al., 2021; Zivkovil, 2016). Not much different from this statement, Guo (2017) stated that the 4C learning model, which contains schemata, assimilation, accommodation, cognitive imbalance, and scaffolding, also impacts critical thinking skills. In addition, critical thinking skills can also have an impact on increasing intellectual skills, arguing, understanding concepts, overcoming problems, and being able to explore their thinking abilities naturally, objectively, and logically (Biasi et al., 2018; Demiral & Cepni, 2018; Siew & Mapeala, 2016; Yee et al., 2016; Zhdanto, 2019). Thus, it can be concluded that the development of critical thinking skills is focused on developing higher-order thinking skills capacity and increasing the identity of someone who has a good attitude and authority.

Critical thinking is increasingly being used in education because its presence is significant for every student. These skills are widely used in the application of curricula worldwide in various creative ways in learning to achieve higher goals (Erdem & Adiguzel, 2019). Critical thinking has become the primary reference of current education in developing a skilled and quality workforce and school graduates (Cansoy et al., 2018; Janssen et al., 2019). This skill must still be applied in learning at school because not all students can realize this ability naturally (Mahanal et al., 2019). Thus, it is understandable that the majority of current learning is focused on the methods of teachers and students in developing critical thinking skills.

Conclusion

This study aims to develop a 4C-based learning model to improve mathematical critical thinking skills. The research resulted in two types of products, namely model books and learning tools consisting of teacher books, student books, lesson plans, and student worksheets. The learning model was developed based on the findings and needs of users (teachers & students) at the needs analysis stage. The learning model was developed while still based on the applicable curriculum and focused on efforts to improve students' mathematical critical thinking skills.

Given the importance of the role of critical thinking, the researchers developed this learning model so that it can be used as a reference in implementing these skills. Specifically, the conclusions of this study are as follows:

- 1) Based on the needs analysis, teachers and students need a mathematics learning model linked to the 4C component as a 21st-century skill. Users indicated that a learning model should be able to facilitate long-term math skills and other skills, namely critical thinking skills
- 2) Based on the results of the needs analysis, the researchers designed books and learning tools based on the 4C skills. In addition to model books, this research also produces several learning tools, such as teacher books, student books, lesson plans, and student worksheets. In this learning model, the researcher designs several stages of learning or syntax as a characteristic of this learning model. The syntax in this learning model consists of orientation, hybrid learning, exploration, problem-solving, and presentation/feedback
- 3) The test results on the quality of the learning model show that the learning model is valid, practical, and effective. Validity is determined by assessing experts on several aspects of the learning model, while practicality is obtained from the responses of teachers and students through questionnaires. Furthermore, the effectiveness of this learning model was determined by a t-test using the help of SPSS 20.00 from the pretest and posttest of students' mathematics learning outcomes.

Recommendations

The results showed that teachers and students in schools need the 4C skill-based learning model to improve their critical thinking skills. In addition, other results show that this learning model is proven to be valid, practical, and effective so that it can be used more widely. With the 4C skill-based mathematics learning model, it is hoped that it can be a reference for teachers to implement students' critical thinking skills in the classroom, especially at the general high school level. Furthermore, this research is also expected to spur teachers to develop their learning models to suit the needs of each

school. By designing their learning model, teachers can minimize student failures in achieving their learning goals because the model was developed based on identifying the problems these students face.

Furthermore, studying critical thinking skills is indeed very interesting. This skill is one of the four 21st-century skills that students must master. We recommend further research to broaden its scope to the other three skills, namely collaboration, communication, and creative thinking skills. In addition, the subsequent analysis should be able to design a more exciting and attractive mathematics learning model using the current generations' Z and A characteristics.

Limitations

One of the limitations of this study is that the intended achievement is only focused on one skill, namely critical thinking skills. As we know that the 4C model is a collection of four complementary skills, and each has an important role. Future research hopes teachers can broaden the scope of all these skills, namely critical thinking, creativity, collaboration, and communication.

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Authorship Contribution Statement

Irham: Conceptualization and data acquisition and analysis, drafting the manuscript. Ismail Tolla and Baso Jabu: Editing/reviewing, supervision, and critical revision manuscript.

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