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Development of a model of creative thinking based on mathematical literacy

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ABSTRACT: This study aimed to design a model of creative thinking based on mathematical literacy (MCTBML) to deepen students' conceptual understanding of mathematics applied to other fields and real-life problems. This developmental research (R&D) was based on Plomp [1], and it refers to co-operative and problem-based learning (PBL) stages. The study involved 203 students from SMK Kartika XX-1 Makassar, Indonesia, in the odd semester of 2022/2023.The research data were obtained through observation, an open interview, followed by a test. The designed MCTBML is organised into the following phases: orientation, exploration, elaboration, presentation and evaluation. Creative thinking and mathematical literacy instruments have been assessed and declared valid. From the research findings, including the student tests, it can be concluded that the model's application facilitated students' ability to interact effectively with their peers in the learning process, and improved their mathematical literacy and creative thinking.

INTRODUCTION

The 21st-Century skillset includes literacy abilities, such as digital and technological literacy, creativity and problem-solving skills. Current approaches in mathematics education promote creative thinking so that students can develop a deep conceptual understanding of mathematics to be able to solve mathematical problems that occur in different contexts [2][3]. Creative thinking is a way to develop various ideas about mathematical concepts and apply them to better understand issues in other fields. Furthermore, the nature of mathematics provides a suitable platform for developing creativity. Solving problems can be obtained in different ways or through different strategies. Mathematics can be considered as a tool for solving problems, including problems in other disciplines [4]. The problem-solving technique can be defined as a method used to overcome hurdles or to find a suitable solution for problems through well-defined stages [5]. For example, Milner suggests that teachers should focus on the whole student community, not only on the achievement of academic outcomes [6]. Transferring knowledge from academics to society is essential in cultivating students' ability to think creatively [6].

It appears that a central focus in mathematics education research concerns the design of instructional environments, including factors like teaching and the curriculum, to increase students' chances of developing mathematical understanding [7]. Moreover, the more connections students develop between facts, ideas and procedures, the better their understanding of mathematics and the environments they live in [8]. Generally, school education is focused only on training convergent thinking processes limited to verbal and logical reasoning. However, there is a need to promote divergent thinking and foster creativity [9]. Furthermore, creative thinking is important in solving mathematical problems and understanding mathematics concepts [10]. This process involves identifying the current regular properties of objects and their transformation [11].

In this study, the authors of this article designed and applied a model of creative thinking based on mathematical literacy in view of stimulating creative thinking in students learning mathematics. It is a model designed to increase the students' fluency, flexibility and novelty. It emphiseses the ability to think creatively by students through an approach to objects, events, concepts and feelings, manifested in mathematical literacy. It is based on the assumption that students can learn techniques that stimulate their creativity. In applying this model, the classroom environment must be conducive, including social and emotional aspects, as well as approprate resources.

Learning design as a problem-solving process is structured to help students learn, where the learning process has immediate and long-term stages. Moreover, the learning design is a sequence of learning activities undertaken to attain learning objectives, including the resources and support mechanisms required to help learners complete these activities [12][13]. A good learning design must meet several criteria, and most importantly is has to be student-oriented, which is a key component in developing planning and learning. The learning process has to be designed in a way to make learning easier and at the same time effective for students. Thus, to come up with a successful model for learning, a preliminary study has to be conducted to determine students' needs, their abilities, learning resources available, and other factors.

RESEARCH METHOD

In this study, a model of creative thinking based on mathematical literacy (MCTBML) has been developed using the research and development (R&D) approach adopted from Plomp, which consists of the following stages: preliminary investigation; design; realisation or construction; test phase, evaluation and revision [1]. Within the model, the following products/resources were developed: a model book, lesson plans, teaching modules and student worksheets. Data were obtained using creative thinking and mathematical literacy instruments to determine the implementation and activities of students in the learning and teaching process. The model was implemented in SMK Kartika XX-1 Makassar, Indonesia, including 203 students from seven classes in the odd semester of 2022/2023.

RESULTS AND DISCUSSION

Preliminary Investigation Stage

At this preliminary investigation stage, theory, student, curriculum and course material analyses were carried out to examine core/basic competencies and indicators of competency achievement as outlined in the making of a lesson plan, reference book, student activity, evaluation and reflection sheets (Figure 1).

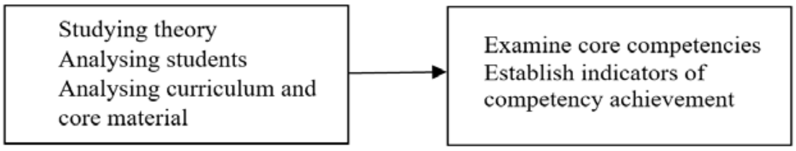

Figure 1: Research and development - preliminary investigation.

Design Stage

After completing the initial investigation, a model of creative thinking and mathematics learning sets were developed based on mathematical literacy (Figure 2).

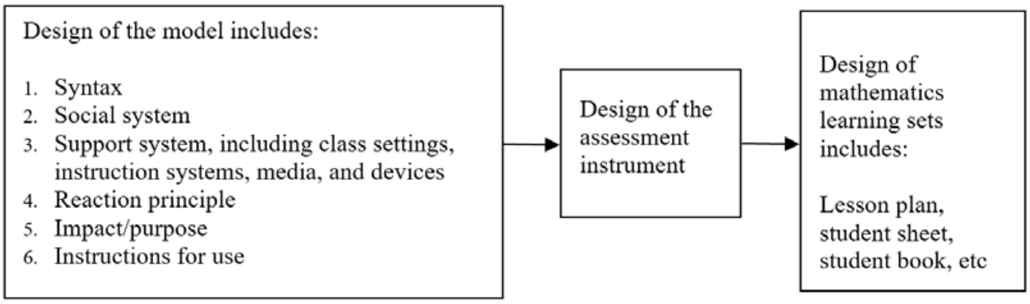

Figure 2: Research and development - design.

Table 1: Syntax of the MCTBML.

Teacher activities	Student activities
Phase 1: Orientation	
a. Pray to begin the teaching and learning process.* b. Check student attendance. c. Prepare students physicaly and psychologicaly to initiate learning activities. d. Associate the learning material/activities to be carried out with students' experience from previous materials/activities. e. Ask questions relevant to the learning process. f. Provide an overview of the benefits of the material to be studied in everyday life. g. Outline the learning objectives. h. Explain the learning stages that students will be engaged in. i. Organise students into study groups.	a. Pray to begin learning.* b. Respond to the teacher's roll call (checking for attendance). c. Prepare learning materials and resources. d. Listen to the teacher's explanation about the relationship between the previously studied material and the mathematics content to be studied. e. Answer the teacher's questions related to the learning to be carried out (*novelty/original thinking, fluent thinking*). f. Listen to and understand the benefits of the material to be learned in everyday life. g. Listen to and understand the learning objectives outlined by the teacher.

Phase 2: Exploration	
a. Introduce the core learning activity, explaining the material using various approaches or learning media. b. Ask questions about the material, encourage reading student books and engagement in other learning activities that comprise the preparation for solving mathematical problems (*literacy activities*). c. Give examples of contextual problems and ask learners to read and understand the problem. d. Allows learners to identify as many questions about the problem as possible (*exploration of creative ideas*).	a. Listen to the teacher's explanation of the material and try to understand the content. b. The stimulus in this phase provides opportunities for students to practice their ability to think creatively in mathematics-related problems through literacy activities. c. Observe, read, write, listen to the contextual problems presented by the teacher (*literacy activities).* d. Compile a list of questions on issues/prblems that could not be understood from the previous activities.
Phase 3: Elaboration	
a. Allow students to work on problems in the student worksheet (referred to as lembar kerja peserta didik – LKPD) that have been prepared individually. b. Guide/direct students who have difficulty completing the LKPD. c. Allow students to exchange work with other students - successful students who have been able to solve problems in the LKPD can help those that are still struggling.	a. Look for solutions to problems that are presented in the LKPD (*think fluently, be flexible and original*). b. Exchange work with other students, if problems in the LKPD are too difficult. c. Help your unsuccessful friends to solve problems in the LKPD, explaining each step leading to the solution.
Phase 4: Presentation	
a. Allow students to present their work and guide the presentation (one group consists of two pairs of students). b. Provide limited assistance to students, if they need help responding to other students' questions.	a. Present the work results in pairs and be prepared to respond to questions from other students. b. Pairs of students who have difficulty responding receive stimuli from the teacher that lead to problem solving.
Phase 5: Evaluation	
a. Evaluate the learning outcomes related to the learned material (review results and processes). b. Allocate project assignments to work on at home.	a. Prepare résumés about the material that has been learned (*fluently, flexibly, and be open to novelty*). b. Pay attention and record project assignments.

*Note: Prayer at school is a long-standing tradition in Indonesian schools. Indonesia has no specific law mandating prayer in schools. Before religious education classes, students pray according to their religion.

The syntax of the MCTBML is expressed in steps, in a series of learning activities. The syntax will indicate the activities carried out by both the teachers and students. The syntax includes five phases; namely: 1) orientation phase; 2) exploration phase; 3) elaboration phase; 4) presentation phase; and 5) evaluation phase. The syntax of the model was obtained to facilitate teaching and learning activities, as presented in Table 1.

This learning model integrates problem-based learning (PBL) and the co-operative learning model by adding insight into the teachers' creativity to enable students to enhance their motivation and inventiveness. The design of mathematics learning sets in this study, including the student worksheets and activities, is geared to show students some real-life mathematics-related issues and *personalise* mathematics. Furthermore, the mathematical literacy required in the learning set is not just about understanding the mathematical topic, but more about provoking problem solving that requires reasoning and creativity.

Indicators of creative thinking can be seen in divergent thinking, including fluency, flexibility and novelty. The co-operative learning model adopts two syntaxes for teacher and student activities, with the latter organised in groups. In another model, the National Council of Teachers of Mathematics in the USA recognised that a basic model of mathematical literacy must represent the five processes through, which students achieve and use their mathematical knowledge: valuing mathematics knowledge, becoming confident in the ability to do mathematics, becoming problem solvers, communicating mathematically and reasoning mathematically [14].

Realisation or Construction Stage

The development of a prototype takes place in the realisation or construction phase and the evaluation of it is conducted by experts in the next stage (expert judgment). Actually, a sequence of prototypes may have to be developed that are tried out and revised on the basis of formative evaluation during the next stage [1].

Test, Evaluation and Revision Stage

Experts validated the developed learning model and instrument in the evaluation stage, including material, learning assessment, product design and research instrument assessment (Figure 3). The instrument's content validity was assessed according to the feedback of two experts/validators in mathematics education (a professor and a senior lecturer at the Mathematics Department of the State University of Makassar, and members of the Indonesian Educational Evaluation Association (Himpunan Evaluasi Pendidikan Indonesia - HEPI). Expert validity of the instrument was obtained to determine content and construct validity.

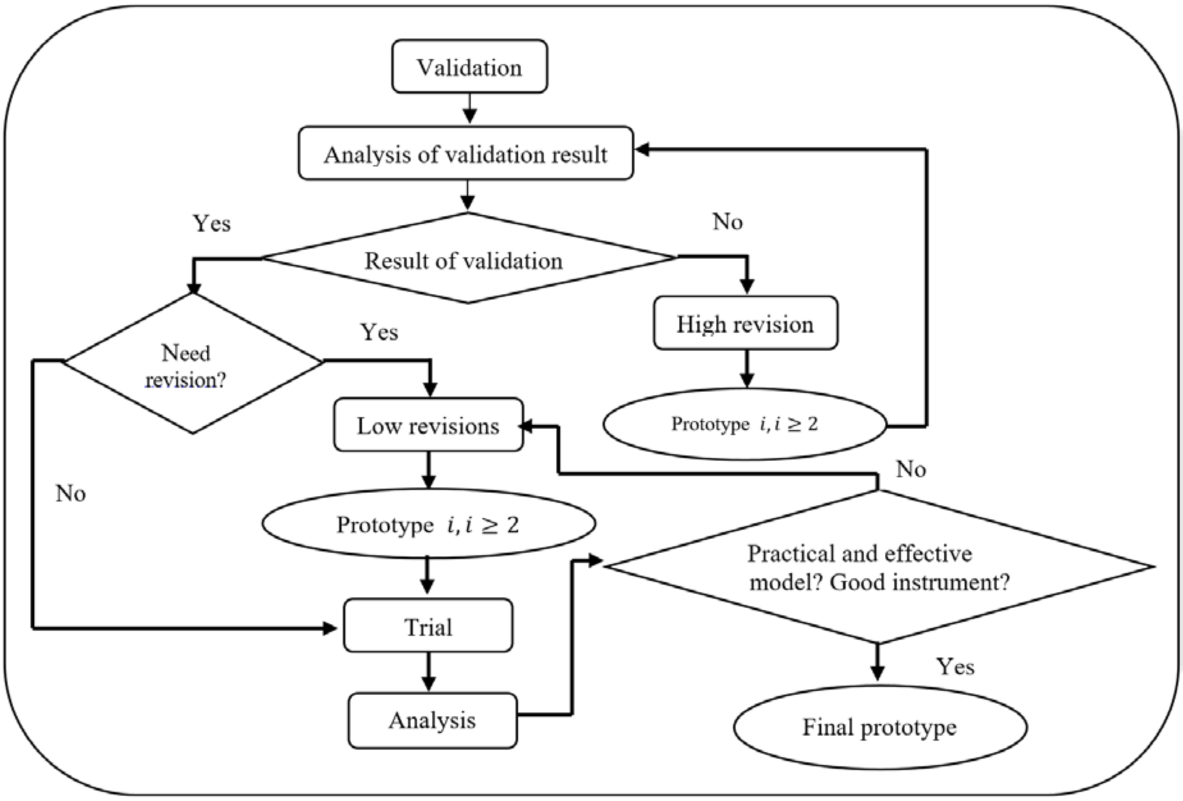

Figure 3: Validation and revision of the prototype.

The student sheets that were developed in this study consisted of assignments given to students that challenge them to solve problems, and thereby to identify creative individuals. Also, included tasks that required students to demonstrate their mathematical literacy abilities. Thus, the student sheets allowed students to practice their creativity and literacy. In addition, the heterogeneous group set-up of students in teaching and learning, as one of the components of this model, helped trained them to accept differences and to collaborate.

Validation Results

Based on the assessment of every aspect of the creative mathematics learning model, the research instruments developed are in the valid and very valid categories within the following ranges: $3.5 \leq M \leq 4.0$ = very valid, $2.5 \leq M < 3.5$ = valid, $1.5 \leq M < 2.5$ = low validity, $M < 1.5$ = very low validity, as shown in Table 2.

Table 2: Validation results of the meathematics learning model.

Products/resources	Indicators	Average rating	Category
Learning model			
Model book	Supporting theories	3.62	Very valid
	Syntax	3.40	Valid
	Social system	3.66	Very valid
	Reaction principle	3.83	Very valid
	Support system	3.62	Very valid
	Instructional impact and supplementary impact	3.33	Valid
Lesson plan	Content	3.50	Very valid
	Construct	3.67	Very valid
	Language	3.50	Very valid
Teaching modules	Content	3.37	Valid
	Construct	3.71	Very valid
	Language	3.60	Very valid
Student worksheet	Others	3.58	Very valid
	Construct	3.49	Valid
	Language	3.50	Very valid

Research instruments/activities			
Instrument validation sheet	Instructions Content Language	3.65 3.55 3.73	Very valid Very valid Very valid
Model implementation	Content Construction	3.37 3.73	Valid Very valid
Learning management	Content Construction	3.74 3.92	Very valid Very valid
Student activities	Content Construction	3.75 3.83	Very valid Very valid
Students' responses	Content Construction	4.00 3.72	Very valid Very valid
Teacher's responses	Content Construction	3.75 3.57	Very valid Very valid
Learning outcomes tests	Content Construction	3.62 3.14	Very valid Valid

A summary of the results of validation analysis by the expert/validators of each instrument is provided below (Table 3).

Table 3: Validity category of the instrument.

Product	Average	Validity category
Learning model		
Model book	3.58	Very valid
Lesson plan	3.56	Very valid
Teaching modules	3.56	Very valid
Student worksheet	3.52	Very valid
Research instrument		
Instrument validation sheet	3.64	Very valid
Applicability of the model	3.55	Very valid
Learning management	3.83	Very valid
Student activities	3.79	Very valid
Students' responses	3.86	Very valid
Teacher's responses	3.66	Very valid
Learning outcomes test	3.38	Valid
Average total assessment	3.63	Very valid

Table 3 shows that the average validity of the model's instruments is 3.63, which indicates a very valid category. In addition, after a thorough examination, the expert/validator team declared that the research instrument met the content validity criteria. Figure 4 demonstrates the cover of the model book and student worksheets used in this study.

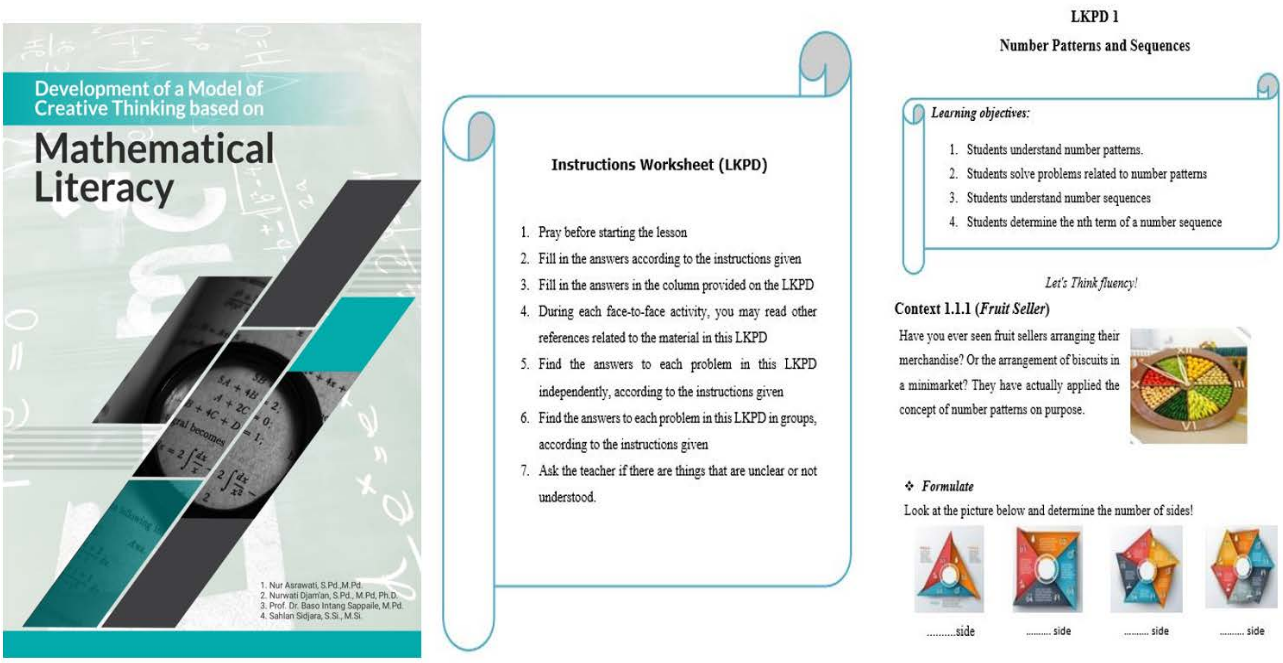

Figure 4: Book cover of the model book and student sheets.

Considering the validation results, the prototype was declared valid. The application of the model was carried out next with 203 school students to examine their mathematical literacy and creative thinking ability.

Mathematical Literacy and Creative Thinking Ability Analysis

The creativity test developed and used in this study to identify students' creative abilities in solving mathematics problems encompasses three creative aspects: flexibility, fluency and novelty. Fluency is the ability to produce several response ideas to a mathematical question; flexibility is the ability to generate various methods to solve mathematical problems; and novelty is the ability to produce distinct, personal ideas and solutions to problems.

An open-ended test was used to test creativity. The mathematical literacy framework has a multidimensional structure composed of three main attributes: content, processes and context. The instruments were validated by the two experts/ validators in mathematics education. The results of the descriptive statistical analysis are demonstrated in Table 4.

Table 4: Results of descriptive statistical analysis.

		Mathematical literacy skills	Mathematical creative thinking ability
N	Valid	203	203
	Missing	0	0
Mean/average		67.42	71.33
Standard error of mean		1.362	1.086
Median		70.00	75.00
Mode		85	75
Standard deviation		19.407	15.466
Variance		376.622	239.204
Skewness		-0.783	-1.163
Standard error of skewness		0.171	0.171
Kurtosis		-0.489	0.610
Standard error of kurtosis		0.340	0.340
Range		70	65
Minimum		20	25
Maximum		90	90
Sum		13,687	14,481

Based on Table 4, the highest score obtained by students in the mathematical literacy ability test was 90, the lowest score was 20, the average - 67.42, and the median - 70, with a standard deviation of 19.407 and a variance of 376.622.

In regard to the test of students' mathematical creative thinking skills, the highest score obtained was 90, the lowest score was 25, the average - 71.33, the median or middle value - 75; with a standard deviation of 15.466, which means that the mathematical literacy skills and creative thinking ability of the students are in the high category.

Furthermore, the frequency distribution interval of the mathematical literacy test results indicate that 73.4% of the students are in the high category in regard to mathematical literacy skills.

The percentage of students who are in the high category in regard to mathematical creative thinking ability amounts to 78.8%. Thus, the model improves students' mathematical literacy and creative thinking skills. This is in accordance with Cortright et al who state that co-operative models promote critical thinking, problem solving and decision-making skills that enable students to solve problems and master the concepts [15]. This also aligns with Tan et al pointing out that co-operative learning strategies have been developed to improve academic performance and motivation, leading to more positive social behaviour [16].

The attentiveness aspect of behavioural engagement is also seen through classroom observations. The data about the perseverance aspect also came from students' activities when they were involved in the exploration, elaboration and presentation phase. Also other activities undertaken by students were observed: understanding the topic, solving the problem and communicating. This is in accordance with Egbert who states that the interaction between problem solving and other instructional goals is also a central component of problem solving because students must ask questions and investigate the answers to solve the problem; students apply critical and creative thinking skills to prior knowledge during the problem-solving process and communicate [17].

CONCLUSIONS

This study aimed to design a model of creative thinking based on mathematical literacy to deepen school students' conceptual understanding of mathematics applied to other fields and real-life problems. The model is organised into the following phases: orientation, exploration, elaboration, presentation and evaluation. After the model and the learning sets were declared valid, then the dissemination stage of the model was conducted. There were 203 students involved from SMK Kartika XX-1 Makassar, Indonesia, in the odd semester of 2022/2023. Findings, including the test outcomes, indicate that the model can facilitate student activities in the teaching and learning of mathematics, and creates opportunities for students to solve mathematical problems in class-wide or peer-group discussions. Further, it can improve mathematical literacy skills and creative thinking ability.

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