ISSN: 2320-5407 Int. J. Adv. Res. 12(03), 943-949

Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/18477
DOI URL: http://dx.doi.org/10.21474/IJAR01/18477

RESEARCH ARTICLE

A PROPOSAL FOR AN INNOVATIVE APPROACH TO EXTENDED MODELLING CYCLES INCORPORATING PROBLEM-POSING FROM A CREATIVITY PERSPECTIVE

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Manuscript Info

Manuscript History
Received: 25 January 2024
Final Accepted: 27 February 2024
Published: March 2024

Key words:-
Mathematical Modelling, Modelling Cycle, Problem-Posing, Creativity, Fluency, Extended Modelling Cycle

Abstract

Many studies have shown that mathematical modelling, creativity, and problem-posing activities are deeply related. However, there is a lack of research that poses mathematical modelling problems. Additionally,only few studies have conducted statistical analyses of the relationship between creativity in problem-posing and creativity in psychology. The purpose of this research is to conduct a survey to quantitatively evaluate creativity, and to propose a more effective modelling cycle based on the survey results. This study focuses on fluency; a creativity factor that is measured by the number of problems posed by students. The survey results showed a moderate positive correlation between fluency in posing mathematical modelling problems and creativity in psychology ($r = 0.44$, $p < 0.01$). Based on the results, an extended modelling cycle is proposed and discussed.

Introduction:-

The modelling cycle, which represents the stages of mathematical modelling-a two-way translation process between the real world and mathematics- has been studied from various perspectives (Blum and Borromeo Ferri 2009; PerrenetandZwaneveld2012). The modelling cycle has been used to visualise the thinking process, and its connection to technology has been discussed (Greefrath2011; Hartmann et al. 2019;Ärlebäck2009). Recently, research has been conducted to incorporate creativity into that modelling cycle (Lu and Kaiser 2021; Wessels 2014). However, while there have been studies on mathematical modelling and creativity, they are still only few (Lu and Kaiser 2021).

On the other hand, there are relatively many studies on the relationship between problem-posing and creativity.It has been suggested that there is a link between problem-posing activities and creativity (Bonottoand Santo 2015; Leikin and Elgrably 2020; Silver 1997; Shriki2013; Van Harpenand Sriraman 2013). These studies suggest that problem-posing could be used to develop and evaluate creativity. However, no consensus has been reached on the evaluation criteria (see Table 1 in section of Literature Review). Furthermore, relatively few studies have analysed the correlation between creativity as defined in those studies and creativity in psychology.

The link between problem-posing activities and mathematical modelling has been studied (Christou et al. 2005; Stillman 2015). In those studies, problem-posing is stated to be an important stage in the modelling activity. However, the statement is limited to suggestions, and few of them have been demonstrated by empirical studies. Moreover, the problems posed by students in research on problem-posing are often not mathematical modelling

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problems but rather general computational problems or non-open problems (Bonottoand Santo 2015; Leikin and Elgrably 2020).

Thus, there is a lack of research on posing mathematical modelling problems. Even in schools, when mathematical modelling is performed, in many cases, it is already created modelling problems that are considered as real problems to be solved. Ideally, students should be able to perceive the truly existing real-world problems themselves, create their own problems, and conduct modelling. In addition, a limited number of studies statistically analyse the relationship between creativity in problem-posing and creativity in other fields, such as creativity in psychology. It is suggested that these three major themes of problem-posing, creativity and mathematical modelling are related to each other. However, few studies discuss the relationship between the three themes at once.

We hypothesised that there might be a positive correlation between creativity in posing mathematical modelling problems and creativity itself.The analysis in this study used creativity as measured by creativity tests used mainly in psychology. Among the types of creativity, there is mathematical creativity, which is specific to the domain of mathematics (Leikin 2013). A study by Schoevers et al. (2020) showed that their mathematical creativity is influenced by mathematical ability, and creativity as measured by creativity tests used mainly in psychology. In this study, the participants only posed mathematical modelling problems and did not deal with the mathematical procedures of modelling. Thus, creativity, as measured by creativity tests used in psychology, was selected, which is less influenced by mathematical ability. We considered that if there is a positive correlation, it is more effective to incorporate the stage of posing a mathematical modelling problem into the modelling cycle of Lu and Kaiser (2021) which includes the creativity aspect. We surveyed German middle school studentsto discuss our hypotheses and ideas. This chapter proposes a modelling cycle with an extended problem-posing phase based on the experimental survey.

Literature Review:-

Mathematical Modelling and Modelling Cycle

Mathematical modelling is the process of translating between the real world and mathematics in both directions (Blum and Borromeo Ferri 2009). The stages of the mathematical modelling activity are shown in the modelling cycle (see Fig. 1). The modelling cycle has been used to visualise the thinking process, and its connection to technology has been discussed (Greefrath2011; Hartmann et al. 2019;Ärlebäck2009) Thus, the concept of the modelling cycle has been extended. In this context, recent research has been conducted to incorporate creativity into that modelling cycle (Lu and Kaiser 2021; Wessels 2014). For example, Lu and Kaiser (2021) illustrated a modelling cycle incorporating a creativity perspective (see Fig. 2).

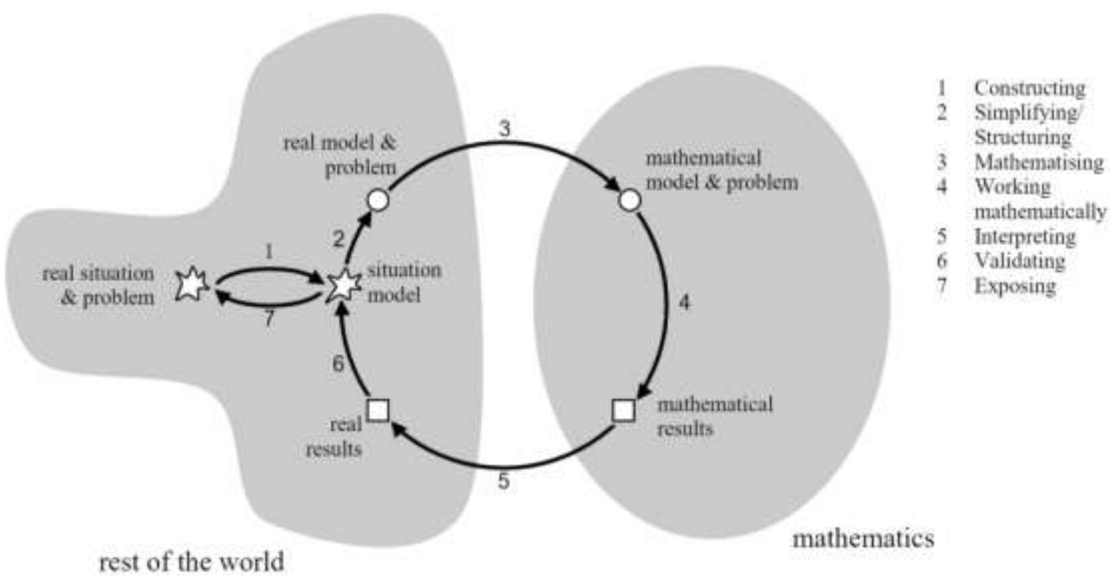

Fig.1:- An example of a modelling cycle (Blum and Borromeo Ferri 2009, p. 46).

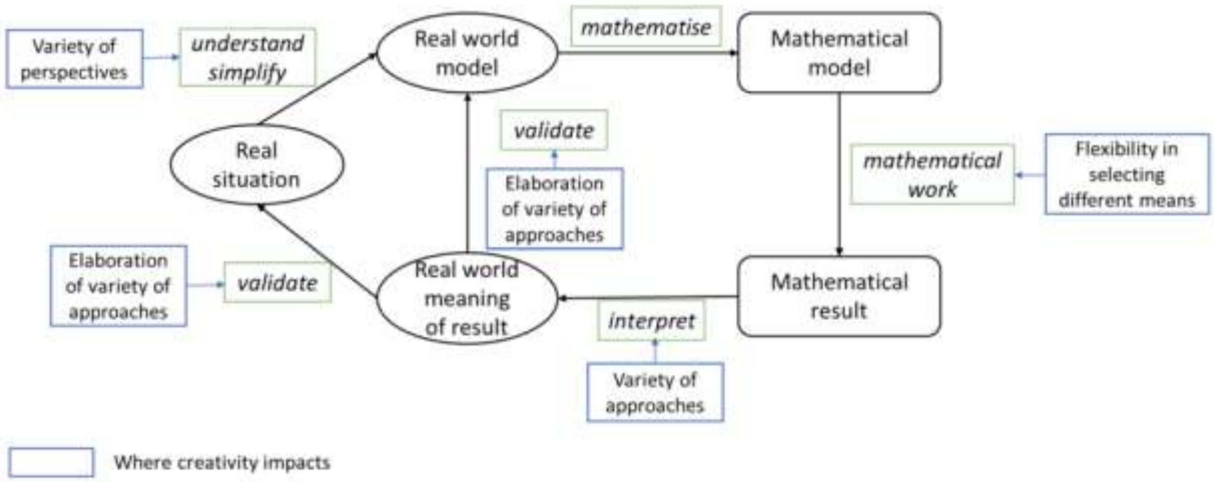

Fig. 2:- A modelling cycle enriched by aspects of creativity (Lu and Kaiser 2021, p.6)

As shown in Fig.2, they showed how creativity is affected at each stage of mathematical modelling. In addition,Wessels' (2014) study attempts to define the creativity factors in mathematical modelling and also showed that creativity could be enhanced by resolving mathematical modelling. However, the number of mathematical modelling studies incorporating a perspective of creativity is still limited (Lu and Kaiser 2021).

Creativity

Definitions of creativity are varied and not defined in a single one. In support of this, Treffinger (2011) collected and organised the literature on definitions of creativity up to 2011 and found that more than 100 definitions exist. This chapter considers creativity based on the work of Wilson et al.(1954) and Guilford (1973), who are considered pioneers in the study of creativity. Wilson (1954) et al. hypothesised that creativity consists of several factors. The factors hypothesised were Sensitivity to Problem, Fluency, Flexibility, Originality, Penetration, Analysis, Synthesis, and Redefinition. Furthermore, Guilford (1973) summarised the characteristic factors of creativity based on those hypotheses. Sensitivity is a common factor discussed in those studies. Guilford (1973) described Sensitivity as "The ability to sense problems, to see deficiencies and needs in life, the challenge to find solutions and fill these needs" (p. 3).It has been suggested from psychological and cognitive-neural perspectives that Sensitivity has a significant impact on creativity by several empirical research, and several frameworks have been proposed (Bridges andSchendan2019).

Sensitivity is assumed to play an important role in problem-posing activities (Bonottoand Santo 2015). Moreover, Bonotto and Santo (2015) suggested that problem-posing activities stimulate students' Sensitivity and encourage creative thinking. Therefore, we hypothesise that it could be beneficial tofocus on problem-posing activities that can be creative and explicitly incorporate a problem-posing phase in the modelling cycle.

Problem-Posing

Problem-posing in mathematics education has received attention since the 1980s, and some of these studies have shown that problem-posing could have a positive effect on the cultivation of creativity (Bonottoand Santo 2015;Shriki 2013; Silver1997; Van Harpenand Sriraman 2013). Additionally, several studies attempted to measure the creativity factor in problem-posing (Kontorovich et al. 2011; Leikin 2013; Leikin and Elgrably 2020; Leikin et al. 2009; Shriki 2013; Silver and Cai 2005; Van Harpenand Sriraman 2013).

	Fluency	Flexbility	Originality	Others
Silver & Cai, 2005	Quantity: the number of response generated		another feature of responses that was evaluated. (It is given by comparison with a typical problem, not by the rate of occurrence.)	complexity
Leikin et al., 2009	the total number of the problems	availability and the number of different strategies and of different problems	availability and the number of unconventional problems (not by the rate of occurrence)	
Kontorovich et al., 2011	the number of posed mathematical problems	by the number of types of problems and by the number of problem posing strategies.	number of posed problems generated by very few or no other people. (not by the rate of occurrence)	
Shriki, 2013	the number of problems he or she posed	the number of categories his or her posed problems	the number of problems posed that were indicated by 33% or less were counted	Organization Overall creativity
Van Harpen & Sriraman, 2013	the total number of viable problems	The total number of categories	each of the responses was then determined according to their rareness(under 10% is original)	
Leikin, 2013; Leikin & Elgrably, 2020	the number of posed problems	categories of previously discovered property	number of discovered properties (%) (frequency) $(p < 10\%) \rightarrow 10$pt, $10\% \leqq p < 40\% \rightarrow 1$pt, $40\% \leqq p \rightarrow 0.1$pt,	Total creativity

Fig. 3:-Summarising factors of creativity in problem-posing.

Fig. 3 summarises the creativity factors used as assessment criteria in measuring the creativity of problem-posing in several studies. In this area, Leikin and her co-researchers have focused on mathematical creativity and studied its relationship to creativity used in problem-posing (Leikin 2013; Leikin and Elgrably 2020;Leikin et al. 2009). Over the course of their research, the way creativity factors are assessed has changed, and other researchers' assessment criteria differ. In this way, there is no consensus on measuring creativity in problem-posing (see Fig. 3). Furthermore, only few empirical studies have investigated whether creativity in problem-posing correlates with creativity.

The connection between problem-posing and mathematical modelling has also been studied (Christou et al. 2005; Stillman 2015). In those studies, problem-posing is considered an essential stage in the modelling activity. However, the statements are only suggestive, and few have been demonstrated by statistical analysis. Moreover, problem-posing studies often have the researcher create a general mathematical problem rather than mathematical modelling problems (Bonottoand Santo 2015; Leikin and Elgrably 2020). For example, Leikin and Elgrably (2020) have students posing proof problems for geometric figures. Naturally, some studies have reported instances of posing mathematical modelling problems (Bonottoand Santo 2015). However, the number of studies on the creativity required in posing mathematical modelling problems remains limited.Increasing quantitative studies would strengthen the link between problem-posing and creativityfrom the perspective of mathematical modelling. Furthermore, we focused on the possibility that one component of creativity,namely Sensitivity, is exhibited by problem posing.

The purpose of this research is to conduct a survey to quantitatively evaluate creativity, and to propose a more effective modelling cycle based on the survey results. As seen in Fig. 3, the creativity factors in problem-posing are often evaluated by fluency,flexibility, and originality. However, there is no consensus on measuring creativity in problem-posing (see Fig. 3). In particular, flexibility and originality are different evaluation criteria across studies. For this reason, this chapter focuses on fluency, which has relatively well-defined measurement methods.

Method:-

The survey included a test of creativity in psychology and a test of posing mathematical modelling problems. The survey problem consisted of three parts. The first part was an explanation of the concept of mathematical modelling, after solving the mathematical modelling problem. The reason for this was to consider the possibility that the participants might not be familiar with the concept of mathematical modelling. Subsequently, participants had 10 minutes to pose the mathematical modelling problem. Finally, participants were given the Test for Creative Thinking-Drawing Production, a test to measure creativity. Based on the results, a correlational analysis was conducted.

Sample
The 111 students who participated in the study came from two schools in Karlsruhe, Baden-Württemberg, Germany. Their grades rangedfrom 8th to 9th, and their age ranged from 13 to 15. The participants‘ teachers reported that the participants had little experience with mathematical modelling.

Instrument
1. Mathematical modelling problems

Three mathematical modelling problems were used in this survey. It is designed to help students understand what mathematical modelling problems are.

2. Test of posing mathematical modelling problems

After the students solved the mathematical modelling problems, thetest of posing mathematical modelling problems was given with the following text:

> Now it's your turn. Find as many interesting problems as you can and create your own tasks.

We conducted a preliminary survey and confirmed that the above text was suitable.The assessment method of this test is described below. Fluency in posing mathematical modelling problems in this study is assessed by the number of posed problems. For example, if a student produced two problems;How many eyes are there in Germany? and How much CO_2 does one German produce in one year?,the score is 2 points.Even if a problem was posed, those whose sentences could not be read or whose meaning could not be understood were not counted.

3. Test for Creative Thinking-Drawing Production (TCT-DP)

This creativity test was created by Urban and Jellen (2010). In this test, participants made additional drawings on an incomplete picture and gave it a title. The drawing is rated on 14 items. The sum of the scores on these items is used as the creativity score. TCT-DP shows good inter-rater reliability, with $\alpha = .81–.99$ for the total score and $\alpha \geq .89$ for the test criteria. The survey was scored according to the TCT-DP manual (Urban and Jellen 2010).

The Result of the Survey and Discussion:-

The survey results showed a moderate positive correlation between fluency in posing mathematical modelling problems and creativity in psychology ($r = 0.44$, $p<0.01$). The cut-off points for the correlation coefficients were determined using Döring and Bortz (2016).Bridges and Schendan (2019) showed that Sensitivity influences divergent thinking related to fluency.We believe thatSensitivity was the source and was expressed in the form of fluency, which has shown a moderate correlation in the present experimental survey.

Therefore, we propose the following extended modelling cycle with problem-posing in terms of creativity (see Fig. 4).

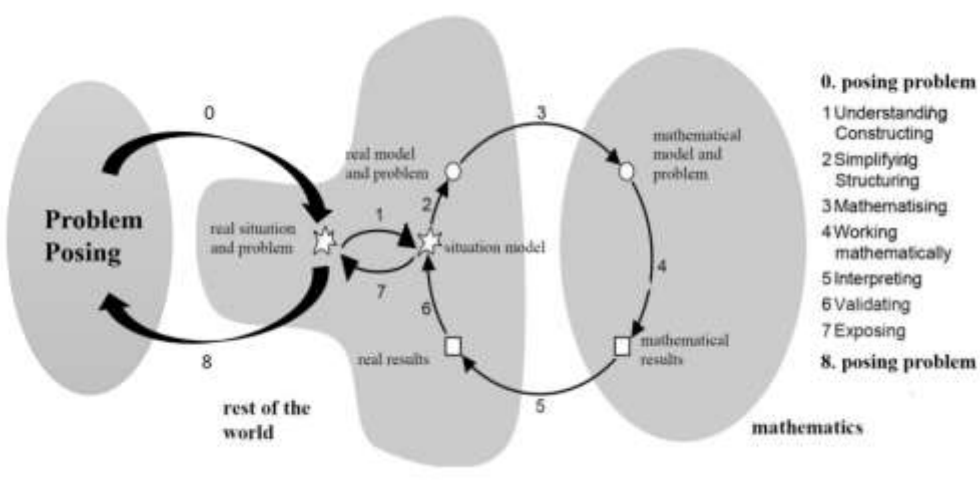

Fig.4:-An Extended Modelling Cycle with Problem-Posing from Creativity Perspective.

Fig.4 adds a problem-posing phase to the traditional modelling cycle shown in Fig.1. Wepresume that a problem-posing phase will increase the opportunities for creativity, because students apply creativity to come up with their mathematical modelling problems. Furthermore, we assume that it will also accelerate the rotation of the modelling cycle. For example, it is expected to increase motivation to solve problems, as students will be able to solve problems posing themselves.

Moreover, even if the modelling cycle ends with one problem, it is possible to return to the modelling cycle by posing a similar problem based on the mathematical modelling problem that has been solved. Since it is not always possible to cycle through a single problem multiple times, it can be assumed that the problem-posing phase increases the possibility of recycling of the modelling cycle. Thus, we consider that there could be value in explicitly positioning the problem-posing phase within the modelling cycle.

On the other hand, limitations and difficulties exist. This study focused only on fluency, which is the creativity factor. Flexibility and originality, which have been dealt with in previous studies, are not considered. In addition,this survey is experimental and the sample of students is relatively small.There is also the difficulty of conducting modelling activities using student-posed mathematical modelling problems. The modelling problem created may be beyond the student's ability and not suitable. They may also pose problems that do not require the use of mathematical skills.

The value of this research is that it tried to analyse and integrate three themes at once, although modelling, creativity, and problem-posing have been analysed separately so far. However, this research is still in the experimental stage, and our thoughts remain as proposals. Within this survey, several problems posed by studentswhich the authors did not predict were discovered,which creates the possibility of evaluating them as originality. Therefore, future research should consider the creativity factors of flexibility and originality, which were not addressed in this chapter. The link with mathematical creativity, which has been studied in mathematics education, was not investigated in this study. The link between mathematical modelling and mathematical creativity is expected to be strong and will be investigated further. Furthermore, we will examine whether there is a different impact on creativity and mathematical modelling ability when the problem-posing stage is positioned in the modelling cycle and when it is not.

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