Exploring the use of portfolio assessment in fostering students’ mathematical creativity and self-regulated learning in an era of uncertainty

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**Abstract**. Mathematical creativity and self-regulated learning (SRL) have been frequently explored in many previous studies in the mathematics education field because of their importance to be developed in the twenty-first-century era. Most of those studies were more stress­ing on learn­ing strategy or developing instructional media or material to support students in developing those two competencies. However, the use of portfolio assessment in supporting the develop­ment of students’ mathematical creativity and SRL has not been sufficiently explored so far. Accordingly, this study was intended to fill in that gap by provid­ing a concise description about it with an emphasis on the extent to which a portfolio assessment can be used in fostering students’ mathematical creativity and SRL and the challenges surrounding it. This literature review employed the Search, Appraisal, Synthesis, and Analysis (SALSA) method to achieve the objectives of this study. This study revealed that portfolio assess­ment can be used to promote students’ mathematical creativity through allowing students to involve in open-ended investigations and it can foster students’ SRL through allowing students to involve in self-assessment and self-reflection activities and improve their self-efficacy. The challenges surrounding of using portfolio assessment are related to task selection, time allocation, and validity and reliability issues.

1. Introduction

Creativity has attracted many researchers in the education field since a long time ago and getting more and more attention as it is considered to become one of four skills in the aspect of learning and innovation skills that need to be developed by students in the twenty-first-century education [1]. In line with this statement, Ritter and Mostert [2] argued that creativity can be viewed as an essential skill that should we have in this century because it can support us in thinking and acting flexibly to deal with the various problems. In the context of mathematics education, the term creativity is usually associated with the term mathematical creativity. Mathematical creativity deals with the ability of the student in providing something new in terms of process or result in the context of solving and posing mathematics problems [3]. Furthermore, Nadjafikhah and Yaftian [4] argued that mathematical creati­vity not only reflects student’s ability in providing something new but also providing something useful or meaningful. Even though mathematical creativity is a part of mathematical ability, students’ mathe­matical ability (e.g. spatial ability and quantitative ability) can be developed through facilitating students to promote their mathematical creativity [5]. Several previous studies [6,7] have suggested that students’ mathematical creativity can be promoted through providing students with the task that allows them to explore many ways or strategies to arrive at the solution of that task and even the solution of the task itself may vary. Such task then is referred to as an open-ended task.

Students’ mathematical creativity could be influenced by many factors. One of these factors is students’ SRL [8]. SRL, as a more specific term of self-regulation, associated with capability of students to control and monitor their own learning as well as to be proactive and motivated in constructing knowledge and dealing with the learning obstacles in order to achieve their set academic goals [9]. Accordingly, SRL of students can be promoted through learning environment that provides them with the opportunity to take control towards their own learning processes and strategies based on their own peace [10]. It is hoped that SRL can be owned and developed by students because SRL is required in lifelong learning [11], including creativity [12]. According to Ates and Alsal [13, p.4092], lifelong learning “…does not only enhance social inclusion, active citizenship and individual development, but also increases competitiveness and employability.” Therefore, it can be said that mathematical creativity and self-regulated learning are important to encourage students not only to achieve their learning success but also to achieve their life success in the future, even in an era of uncertainty. The era of uncertainty brings its own challenges for our lives in terms of predicting our future lives and setting up our realistic goals that encourage and lead us to move forward [14].

Because of the importance of mathematical creativity and SRL as aforementioned, many efforts have been put into supporting students in developing these two competencies. For promoting students’ mathematical creativity, many learning strategies and methods had been implemented in mathematics classroom, such as open-ended questioning, multiple solution tasks, and model eliciting activities [15]. In addition, many studies, e.g. [16], had also been conducted to produce learning media or material that effective to support the development of students’ mathematical creativity. The same thing also holds for SRL, in which a number of studies had been carried to implement learning strategies and methods, such as blended-learning [10], and produce mathematics learning material or media [17] in order to promote students’ SRL. Implementing a learning strategy or method and producing learning material or media are not the only ways to facilitate students in developing those two competencies. There is another way which is potential to do such a thing, i.e. utilising assessment.

Assessment plays a crucial role in the educational process, namely as a tool for measuring the achievement of students’ learning [18] and finding out what students’ needs in their learning and how they can be utilised by the teacher and students in order to enhance learning as well as figuring out the effectiveness of the learning process and curriculum [19]. In addition, Black and Wiliam [20] asserted that the assessment should be used as an opportunity for learning in which students should be pro­active in using the assessment and understanding the ways to get better. In line with this assertion, it can be argued that the assessment can be utilised in supporting the development and nourishment of students’ competencies. Portfolio assessment, in this case, is one of many types of assessment which potentially foster students’ mathematical creativity and SRL. Portfolio assessment can be understood as a type of assessment in which portfolio, an intentional collection of student’s work over period of time that reflects his process, improvement, and learning as well as his achieve­ment [21], is empowered to improve students’ learning itself.

Numerous existing studies have been carried out to describe the utilisation of portfolio assessment in edu­cation. However, there is relatively little study emphasising on the use of portfolio assessment to foster students’ mathematical creativity. Furthermore, several studies have also been focused on the use of that type of assessment in relation to the students’ SRL. But then, most of them are in the context of educational linguistic and the other contexts outside mathematics education, e.g. [22]. The present study, therefore, was intended to fill in such gap by providing an additional reference in the form of a concise description regarding the use of portfolio assessment as a tool for fostering students’ mathematical creativity and SRL in the context of mathematics education. The description is more centred on the two things, i.e. the extent to which a portfolio assessment can be used in fostering those two competencies of students and the challenges surrounding it.

1. Methods

A method commonly used in conducting a review, i.e. Search, Appraisal, Synthesis, and Analysis (SALSA) method was employed in this literature review. Through this method, searching for the literature in the form of journal article or proceedings paper in ScienceDirect, Taylor & Francis Online, Springer Link, and Education Resources Information Center (ERIC) became the initial step in this study. The literature that we included in the review was the literature which contains data about the definition and importance of mathematical creativity and SRL, the strategy that can be used by the teacher to foster students’ mathematical creativity and SRL, the definition and the use of portfolio assessment as well as its challenges to be used in the mathematics education and the use of portfolio assessment in relation to foster students’ mathematical creativity and SRL. The data, then, were assigned into four determined themes, namely mathematical creativity, SRL, the use of portfolio assessment in mathematics education, and the use of portfolio assessment in the context of mathe­matics education in relation to foster students’ mathematical creativity and SRL and its challenges. Data analysis was carried out through narra­tive analysis.

1. Results and Discussion

## Mathematical creativity

Because creativity, based on several studies, is considered as a domain-specific [5,15], in mathematics education the term creativity is well-known with the term mathematical creativity. Mathematical creativity, which is perceived as “the highest level of thinking in cognitive domain” [23, p.328], demonstrates student’s ability or process in performing and utilising creative work [24] in the form of original and practical ideas in mathematics [25], providing the unusual or new solutions to a given mathematics problem in which it does not depend on the complexity level of the problem [26] but depends on student’s mathematical background [27], or generating a new knowledge in mathematics and doing mathematical problem-solving flexibly [7]. Nadjafikhah and Yaftian [4] suggested that the creative work or product of mathematical creativity should be original and useful. That work or product is said to be useful if it is “valuable, relevant, adaptive, applicable, meaningful, high in quality, socially valuable” [4, p.345]. In contrast, Sriraman [26] asserted that, in the mathematician’s point of view, creative work or product of mathematical creativity does not always necessarily have to be applicable in the contemporary world. From the existing various ideas about mathematical creativity, it can be said that mathematical creativity is more emphasised on the abstract product such as the ideas rather than on the physical or tangible product.

In order to assess student’s mathematical creativity, in general, there are two version of indicators or criteria of mathematical creativity that can be used and commonly used by many researchers in their studies to develop instrument of that competency. The first version comprises of three indicators; namely fluency, flexibility, and originality or novelty (see [5,7]). In this case, the term originality and novelty can be used interchangeably [6]. The second version is the extended version of the first one by adding one indicator called elaboration (see [4,8]). These four indicators are provided as follows according to Leikin as cited in [5], Levenson, Swisa, and Tabach [6], and Singh [25]. Fluency is associated with the student’s ability in providing a number of correct or acceptable ideas or solutions; flexibility is associated with the student’s ability in producing different strategies, approaches, types, or categories of situations or problem-solving to arrive at the desired solutions; and originality or novelty is associated with the student’s ability in demonstrating unusual and new ideas or responses, in which it is relative to the involved and observed participants. Elaboration, based on Guilford as cited in [4], is associated with the student’s ability in presenting, extending, and developing his/her ideas or work in detail.

Considering the indicators of mathematical creativity, many researchers have recommended several strategies that can be implemented by the teachers in their mathematics classroom in order to create a learning environment that promotes mathematical creativity to their students. Most of those strategies, therefore, end up in the two things, i.e. problem-solving and problem posing. The teachers are strongly encouraged to present a non-routine problem [26], open-ended problem, ill-posed problem [28], or even mathematics quiz and give opportunity to their students to solve such problems by trying to use various unusual methods, by depending on their own decisions [24], as well as by empowering their motivation, perseverance, and considerable reflection [26]. Nadjafikhah, Yaftian, and Bakhshalizadeh [28] suggested that when students have difficulties in solving such problem, instead of telling the solution to the problem, teacher is more encouraged to give some important hints to the students so that they can engage on the challenging situation and obtain a new insight into the problem that they are facing based on the results of their own self-reflection. Moreover, they stated that the teacher should allow the students to take some risks and make mistakes such that they can learn from those things in order to find out the alternative ways or perspectives to solve the existing problem. To sum up, mathematics learning environment that can support the development of students’ mathematical creativity is not focusing too much on obtaining the right answers rather than it is more focusing on obtaining various ideas or perspectives.

## Self-regulated learning

There is no specific definition for SRL, but the SRL is typically focused on the two things, i.e. (1) how students choose, regulate, or create a learning situation that provides benefits for themselves and (2) how students plan and control their learning [9]. SRL not only deals with student’s cognitive and metacognitive regulation aspects, but it also deals with student’s motivational, affective, behavioural [29,30], and social-context regulation aspects [30]. These aspects are associated with four phases of regulation which are not necessarily to be hierarchically structured [30]. The structure of those phases, therefore, depends on how student approaches to the existing task or context. In the first phase, students set a plan and goal as well as activate their knowledge about the task or context that they are dealing with. In the second phase, students empower their metacognitive awareness in relation to monitor the process of dealing with the task or context. In the third phase, students determine a proper strategy to control and regulate their work on task or context. In the last phase, students involve in choosing behaviour and affective reactions as well as self-reflection on the task or context. Context including social-context, here, refers to learning environment or classroom setting [30]. Based on the aforementioned aspects and phases of regulation, SRL can be considered as a “complex and multidimensional construct” [31, p.1356] that reflects student’s ability in dealing with the aspects of SRL [32] adaptively and effectively to achieve learning goals [33].

Students who have a good SRL, called as self-regulated learners, are characterised by their willing­ness to analyse the problem for gaining an understanding towards that problem, make an effort to obtain the solution to the problem, and evaluate their performance [34]. Besides, Cho, Kim, and Choi [35] state that self-regulated learners are more focused on the intrinsic goal orientation or motivation rather than the external one, learn something with a high confidence, have a high control towards their learning beliefs, and perceive a task that they are facing with a high value. Marchis [34] suggests some skills that need to be mastered by students in order to be a self-regulated learners as well as succeed in solving problem. One of those skills is self-efficacy. Consequently, self-regulated learners can also be characterised by the high self-efficacy that they have. Students’ self-efficacy reflects students’ beliefs about their own capability compared to the required capability to deal with some challenges and situations [36]. In addition, in the context of mathematics learning, students who have a high self-efficacy tend to be persistent in dealing with challenges of learning mathematics and accomplishing the existing mathematics problem-solving task [36] so that it allows them to explore various strategies to achieve their intended goals flexibly [37]. Self-regulated learners, therefore, can be perceived as students, who not only have capability in planning strategies for dealing with the tasks, performing the planned strategies, and controlling, monitoring, and evaluating their works, but also have capability in regulating their beliefs and motivation.

Previous study [38] suggested some strategies that can be used by teacher to promote SRL via self-efficacy, for instance provide an opportunity for students to recognise successful learning efforts that can lead them to arrive at the desired learning goals and provide an appropriate feedback on the students’ efforts. Another possible strategy that may be used to develop students SRL is by asking students to explain the strategy and reasoning that they use to solve a problem to the teacher or even to their friends [34]. Moreover, Hoops, Yu, Wang, and Hollyer [39] provide some strategy to help students in promoting their SRL in more detail based on the regulation aspects of SRL as follows: (1) in the cognitive and metacognitive regulation aspects, students should be encouraged to use specific strategies in learning something or solving existing problem and monitor their understanding level as well as prepare students to learn something new; (2) in the motivational and affective regulation aspects, students should be encouraged to be well-informed about the usefulness of learning materials that they are going to lean or learning task that they are going to deal with so that they are interested to engage with the learning process or activities; (3) in the behavioural regulation aspect, students should be encouraged to engage in an active learning and be allowed to seek for help when they are struggling with some difficulties or challenging tasks; and (4) in the social-context regulation aspect, students should be provided with a proper instructional scaffolding to help them in controlling their learning environments.

## The use of portfolio assessment in mathematics education

Portfolio assessment, in a simply understanding, is related to utilise a portfolio that reflects students’ meaningful works [40] for assessing students’ achievements and tracing students’ performance. Birgin and Baki [41, p.78] describe portfolio as “a systematic and purposeful collection of the evidence which reflect the success, performance, and efforts of the students in one or more areas over a period of time.” According to McDonald [42], portfolio is usually comprised of the evidence of students’ best works which reflect their growth in mastering what they are learning and also reflect the growth of their positive moral, ethic, attitudes, and habits. Portfolio also demonstrates students’ capability in collaborating with others and reflecting their own learning [43]. From these definitions of portfolio, a portfolio can be described as the collection of students’ process and product of their works which not only reflect students’ growth in the cognitive and psychomotor domain of competency, but also reflect students’ growth in the affective domain of competency.

In the context of mathematics education, Stenmark, as cited in [44], stated that a mathematics portfolio can be understood as a collection of students’ works in which these works can be in the form of assignments, projects, reports, and writings. Through this collection of students’ works, teachers have an opportunity to see comprehensively on progress and understanding in learning what should be learned in mathematics learning as well as attitude towards mathematics of their students. In addition, Crowley and Dunn [45] suggested that a mathematics portfolio should be consisted of a collection of students’ best work in mathematics, in which this work can be in the form of journal writings, presentations, computer-based explorations, and open-ended investigations. The utilisation of portfolio assessment provide a number of promise potentials and benefits in a learning process, including in mathematics learning, not only for teacher and students, but also for parents. Through portfolio assess­ment, teacher can evaluate students’ higher-order competency [46,47], teacher and students can work together in the evaluation process of students’ work [40], and parents are allowed to observe and provide a useful comment for improvement on the work of their children as well [42]. Cicmanec and Viechnicki [44] argued that the use of portfolio assessment can facilitate mathematics learning and accelerate communication among teachers, students, and parents. Furthermore, through utilising port­folio assessment, the teachers can obtain additional information about the progress and needs of their students in mathematics learning [43,48]. Using portfolio assessment in mathematics learning is basically intended to encourage students in developing their mathematical flexibility and capability in communicating mathematically [45].

Portfolio assessment is considered as a part of assessment as learning (AaL) and as a consequence, it also becomes part of assessment for learning (AfL) [49]. Accordingly, portfolio assessment can be used by teacher to support students to regulate their process of learning, evaluate their knowledge construction with or without guidance from their teacher, and do self-reflection. The existence of self-reflection in portfolio assessment is a crucial matter. Without self-reflection, the collection of students’ meaningful and purposeful works is no longer referred to as a portfolio [40].

## The use of portfolio assessment in relation to foster students’ mathematical creativity and self-regulated learning and its challenges

The results of review on mathematical creativity suggest that this competency is associated with the ability of students to look at and think something from various perspectives so that they can produce numerous acceptable and unique ideas and explain in detail the product of their thoughts as well. To support the developing of students’ mathematical creativity, engaging students in open-ended tasks has been suggested by many researchers as one of learning strategies that can be implemented by teacher in mathematics classroom. This strategy, therefore, is in line with the use of portfolio assess­ment in mathematics learning, in which mathematical work in the form of the product of open-ended investigations is considered to be component of portfolio [45] and students are facilitated to produce that kind of mathematical work. McDonald [42] affirms that divergent thinking skills, which is commonly associated with creative thinking skills, of students becomes possible to be fostered through utilising portfolio assessment. In addition, when students are engaging in portfolio assessment, they are allowed to involve in determining portfolio content and criteria for evaluating portfolio [40,45,50] as well as assessing their own and friends’ mathematical work contained in portfolio [50]. Through this involvement, students are facilitated to gain multiple insights, ideas, strategies, and perspectives about how other students organise and accomplish their mathematical work so that it can stimulate students’ mathematical creativity.

The results of review on SRL show that in order to facilitate the development of students’ SRL, mathematics learning environment should be designed such that it allows students to set a learning goal and a plan to achieve that goal; perform, monitor, and evaluate their learning; get a proper scaffolding and feedback on their learning progress and product; and know the usefulness of what they are going to learn and do. By bringing portfolio assessment into mathematics learning, students become more intrinsically motivated and committed to devote their best efforts in accomplishing the existing tasks as a consequence of the existence of sense of belonging towards the tasks that they are handling [42]. Students are also encouraged to review the mathematics concepts behind their portfolio, take control over their understanding and grades, see the usefulness of mathematics in students’ daily lives, and enjoy the mathematics class when portfolio assessment is employed in mathematics learning [50]. Such activities, therefore, reflect that portfolio assessment can improve students’ self-efficacy [50]. Furthermore, portfolio also allows students to have an opportunity in expressing their self-reflection on their learning to the teacher [43] so that they know their strengths and weaknesses as well as strategies to minimise or overcome those weaknesses. Portfolio assessment, therefore, offers an advantage in terms of fostering students’ SRL.

Along with the positive influence of using portfolio assessment on the development of students’ mathematical creativity and SRL, the implementation of that assessment brings its own challenges for teacher and students. The first one is about task or content selection issue. Both teacher and students need to select what kind of content that should be included in portfolio without ignoring the learning objectives and mathematics competency that should be developed by students through that portfolio. The second one is about time allocation issue [41,42,51]. This issue is related to the fact that portfolio assessment needs an on-going assessment and evaluation over period of time. Consequently, teacher and students require allocating more time in working on the portfolio. Teacher need to allocate more time to learn more about portfolio assessment and its implementation in learning [41] and explain to students about the purpose, structure, materials, and scoring criteria of portfolio assessment [51]. The third one is about validity and low of score reliability issue [41,42]. To deal with this challenge, Birgin and Baki [41] suggest teacher to follow the developed rubrics to assess students’ work. In line this, McDonald [42] suggest teacher to triangulate on the objective of portfolio and the appropriateness of that objectives for the target students.

1. Conclusion

The theoretical contribution of this study is to provide a concise description on the extent to which portfolio assessment can support the development of students’ mathematical creativity and SRL in mathematics education. The use of that type of assessment can be considered to be one of alternative strategies to foster students’ mathematical creativity and SRL. The rationale behind this assertion is that through portfolio assessment, students are allowed to participate in deciding the content that are going to be included in portfolio, deal with the open-ended investigations, assess and evaluate their own and friends work, control their motivation such that they feel motivated in dealing with the task. The use of portfolio assessment, however, brings some challenges, such as task or content selection, time allocation for preparing and implementing portfolio assessment, as well as validity and low of score reliability. For teachers who are going to implement portfolio assessment in learning, it is better for them to collaborate with the other teachers who have experienced in implementing that type of assessment and developing rubrics to assess students work as suggested by Wolfe and Miller [51].

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