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Disability-Friendly Environment with Ramp: STEM Activity in Mathematics Classroom for Promoting Social Justice

[1]Russasmita Sri Padmi, [2]Titik Subarni, & [3]Farida Nurhasanah
[1]SEAMEO QITEP in Mathematics
[2]SMP Budi Mulia Dua
[3]Universitas Negeri Sebelas Maret
[1]r.sripadmi@staff.qitepinmath.org

Abstract

Mathematics is not only for educating functional members of society and producing a competent workforce but also for instilling social values and responsible citizenship. STEM is a potential learning approach to teaching social justice because it encourages students to integrate knowledge and skills from different subjects to solve real-life problems. This paper reports the first phase of design research to develop a STEM activity incorporating social justice issues for 8th-grade mathematics classrooms. The result of the first phase is a set of learning materials that integrates the subject content gradient in mathematics and simple machine in science in the context of designing an effective and efficient ramp for public use. The study confirmed that by designing in such a way that mathematics and science knowledge and skills are used in solving problems, social justice issues could be meaningful contexts for STEM lessons.

Keywords: STEM, social justice in mathematics education, problem-based learning

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Introduction

The purpose of mathematics education goes beyond educating functional members of society and producing a competent workforce; it can also be a tool to educate social values and responsible citizenship. Ernest (1993, p.151) identified "critical awareness and democratic citizenship via mathematics" as one of the five aims of mathematics education. Gutstein (2003) proposed "reading the world" and "writing the world" as two goals of teaching and learning mathematics for social justice. Respectively, they refer to using mathematics to understand current injustices in the world and using mathematics as a tool of social agency in making our society a better place.

Several studies have examined how social justice issues can be incorporated into the mathematics classroom. An effective lesson can be achieved by having a meaningful link between mathematics concepts and social justice issues and providing student-centered, collaborative and problem-solving activities (Wright, 2016). Tension can arise in balancing the goal of mathematics learning with understanding social justice issues (Bartell, 2013; Garii & Rule, 2009; Gutstein, 2006). Teachers tend to believe that mathematics learning should be the focus, and learning goals pertinent to social justice should complement, rather than replace, mathematics learning goals (Wright, 2016).

Existing lessons design usually feature data handling and mathematical modelling as mathematics concepts of choice, with social justice issues as the context (Bartell, 2013; Garii & Rule, 2009). The lesson begins with the students collecting, representing, and analyzing the data or building a mathematical model, followed by a discussion. The aim is for the students to shape their understanding of social justice issues around them through their interpretation of the data representation or mathematical model, or according to Gustein (2006), to "read the world". On the other hand, using mathematics as the solution to social justice issues or to "write the world" seems to be a potential largely left unexplored.

Mathematics has been demonstrated as a powerful tool to support students in better understanding social justice issues around them, either local or global (Wright, 2016). On the other hand, social justice issues also enhance mathematics learning to help the students build "mathematical power" (NCTM, 2000), namely knowing what and how far they can go with mathematics. Furthermore, the social justice issues in mathematics learning support the students' understanding of and belief in the role of mathematics in society and may influence their future actions in using mathematics as a tool of agency (Gutstein, 2006).

Going beyond mathematics, we propose incorporating social justice issues in a STEM lesson. STEM, which stands for Science, Technology, Engineering and Mathematics, was first mentioned as an acronym by the National Science Foundation (NSF) as a way to address the four disciplines simultaneously, mainly due to the significant importance gained over the last decade in different fields including immigration policy, national security, and education (Gonzalez & Kuenzi, 2012). While the term STEM initially refers to the teaching and learning of the four disciplines separately, the demand for Science and Mathematics curricula to be more relevant to the real world culminates in the concept of integrating the four subjects (English, 2016; White & Delaney, 2021). Therefore, the phrase STEM in this paper refers to integrative STEM, namely a learning experience where the students apply the knowledge and skills from the four disciplines to find solutions to real-world problems (English & Mousoulides, 2015; Hourigan & Leavy, 2020; Margot & Kettler, 2019; Shaughnessy, 2013).

Engineering is a characteristic of STEM that distinguishes it from other teaching and learning approaches. Engineering is "the application of knowledge to creatively design, build, and maintain technologies" (Cunningham, 2018, p.22). Engineers strive to optimize solutions to problems while considering goals and various constraints. In STEM lessons, engineering provides a meaningful context for the students to apply scientific knowledge and build connections, which promotes deeper understanding (Cunningham, 2018; Hefty, 2015). Therefore, it is no understatement that engineering can be said as the natural glue of integrative STEM lessons, without which it will just be another thematic or project-based lesson (Jolly, 2017). Furthermore, the integration of engineering is also beneficial to open the students' minds regarding the role of engineering in shaping our modern world, to spark their appreciation and excitement, and in turn to nurture future agents of change instead of simply a consumer of innovation in the developing worlds (Lachapelle & Cunningham, 2014).

Engineering is not traditionally included in school curricula like Mathematics or Science. Therefore, its integration into STEM lessons must focus on engineering practices – what engineers do as they engage in their work (Cunningham & Carlsen, 2014). Generally, the integration of engineering in STEM activity is achieved through Engineering Design Process (EDP). EDP is the systematically iterative process that guides real engineers in solving problems in various fields and embodies many principles that constitute engineering, such as problem-solving, knowledge application, and constant improvement of a solution against specific criteria. For the students to become familiar with engineering practices, instructional activities need to be structured around EDP (Cunningham, 2018). There are different versions of EDP, but generally, they involve starting with a problem, creating the solution, and testing and improving them. The EDP cycle we use in this paper consists of five phases: Ask, Imagine, Plan, Create, and Improve (Cunningham, 2018).

STEM subjects are an important way to prepare a globally competent and competitive workforce. However, studies have found that students majoring in STEM tend to place far less importance on social agency than non-STEM majors (Garibay, 2015; Sondel, Koch, Carrier, & Walkowiak, 2017). This is exacerbated by the fact that Science and Mathematics are usually given more importance than Social Science subjects, where social justice issues are often discussed in national or international assessments. As a learning approach that encourages students to integrate knowledge and skills from different subjects to solve real-life problems, STEM activities are potential platforms to teach social justice. Deliberate efforts need to be made to emphasize the importance of social justice in STEM lessons and highlight the connection between the two (Garibay, 2015; Sondel, Koch, Carrier, & Walkowiak, 2017). NGSS (2013) corroborates the importance of connecting social justice and STEM by mentioning the necessity of "engaging students in defining problems and designing solutions of community projects in their neighborhoods" (p. 3).

Several studies have attempted to design STEM lessons with social justice emphasis; however, mathematics tends to be overlooked (Nicol et al., 2019) on the cost of strengthening the science, technology, or social justice parts. As an example, a lesson developed by Jungck and Manon (2019) where learners discuss sensitive issues, namely the one-child policy and slavey involving the analysis of real data, and an interdisciplinary STEM unit developed by (Mildenhall, Cowie, & Sherriff, 2019) where science and technology are employed to design shoes appropriate for refugees. Through STEM for social justice, not only do the students learn about the role of each subject in society, but these disciplines are connected, and the ability to understand the connection can help them devise solutions to real-life problems around them (Hefty, 2015).

This paper reports one of these projects, which attempts to develop STEM learning materials for 8th-grade mathematics classrooms with social justice goals. The research question we aim to answer is *how to develop STEM learning materials to promote social justice in the mathematics classroom.*

Methods

To answer the research question, the method employed in this project is design research. Design research is an approach whose purpose is to develop theories about learning and designing the means that support that learning (Gravemeijer & Cobb, 2006), which we consider suitable for the aim of this study.

Design research consists of three phases: preparation and design, teaching experiment, and retrospective analysis (van Eerde, 2013), as depicted in Figure 1.

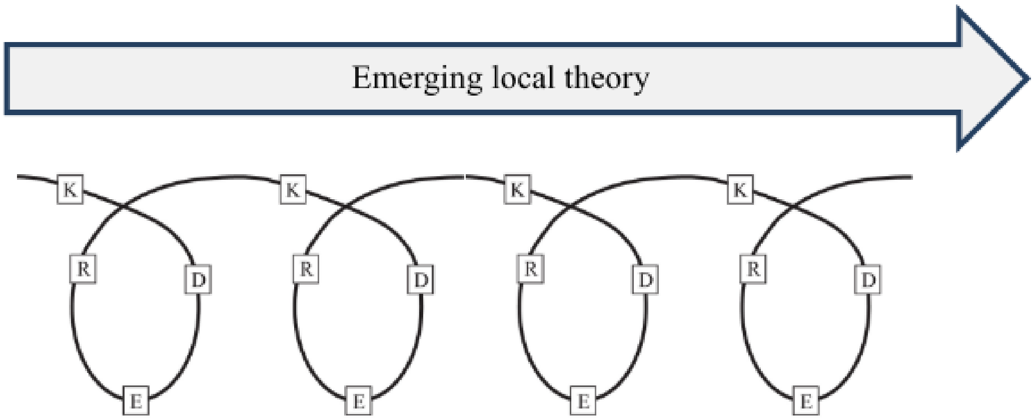

Figure 1. Phases of Design Research.

Based on the current knowledge (K), which comprises a literature review, curriculum documents, and exemplary STEM activities, the researcher designs (D) learning activities. In the Teaching Experiment phase, the activities are practised in the classroom (E). In the Retrospective Analysis phase (R), the researcher reflects on the result of the teaching experiment, which contributes to new knowledge. The repeating cycles result in local instruction theory (LIT) comprising research-based instructional activities and a theory that explains how the students' thinking and understanding might evolve when the activities are implemented in the classroom (Gravemeijer & Cobb, 2006). This paper will report on the first phase (Design), which results in the initial designs of the learning materials.

Design Consideration

Based on the literature review, curriculum documents, exemplary STEM activities, and interviews with several teachers, we consider several aspects for the design of the learning materials, as described in Table 1, which is adopted from Li et al. (2022).

Table 1
Instructional Design Decision for STEM for Social Justice Learning Materials

Dimension	Design Decision	Description	Supporting literature
Task Design	Disciplinary integration	Integrating the four subjects by having the students apply their knowledge and skills to find solutions to real-world problems	(English & Mousoulides, 2015; Hourigan & Leavy, 2020; Margot & Kettler, 2019; Shaughnessy, 2013).
	Social justice issue as problem context	Relevant social justice issues as problem context, for which the students will employ STEM to find the solution.	(Gutstein, 2006)
	Inquiry-based learning	Engaging the students in an investigation and exploration aimed at formulating hypotheses or constructing a solution to real-life problems.	(Leung, 2018)

Dimension	Design Decision	Description	Supporting literature
Strategy Design	Engineering design process	An iterative process consisting of five stages (Ask, Imagine, Plan, Create, Improve) in applying STEM knowledge and skills to devise a solution for real-life problems.	(Cunningham, 2018).
	Group work	Students are divided into mixed-ability groups during the task.	
Process Design	Designed according to the national curriculum	The task is designed using the national curriculum as a reference.	

Result and Discussion

Based on the design consideration in Table 1, we designed the initial learning material entitled Disability-friendly Environment with Ramp. It comprises a lesson plan, assessment guide, and hypothetical learning trajectory.

Problem Context

The context used in this learning material is wheelchair ramps. The context was chosen because ramps are essential features of public facilities that ensure equal access for people with physical disabilities. A discussion starts the lesson on the difficulty people with wheelchairs face in daily life, such as when entering and exiting a building, followed by brainstorming the solution to that problem. Referring to the concept of mathematics for social justice by Gutstein (2006), the students start the lesson by "reading the world" and then spend the rest of the lesson devising a solution for wheelchair users using mathematics or "writing the world".

The problem to be solved by the students is the following.

> "Your school will build a new hall. Previously, the hall had only stairs at its entrance. This time, they want to build a building that provides equal access to everyone, including wheelchair users, by building a ramp.
>
> How can we use science and mathematics to build an effective and efficient ramp?"

However, since it is impossible to build an actual ramp, the students will design and build a miniature ramp using cardboard paper and a box. The miniature ramp is then tested using a toy car pulled by strings tied to a paper cup filled with marbles.

The lesson was designed using low-cost and easy-to-get materials, without the involvement of expensive and difficult technology, such as cardboard paper, cardboard boxes, marbles, and toy cars. This ensures teachers can replicate the activities in every socio-economic situation.

Science and Mathematics

Prior to designing the learning materials, we matched the mathematics and science standards of the national curriculum of Indonesia, the 2013 curriculum, to come up with the pairs of science and mathematics standards which appear in the same semesters and can be implemented in the same problem context. One of the pairs is the standard for a linear function involving gradient (mathematics) and force and inclined plane (science), which appears in grade 8 (Table 2).

Table 2
Mathematics and Science Standards Appearing in the Lesson

Science	Mathematics
4.3 Presenting the results of investigations or problem solving about the benefits of using simple machines in everyday life.	4.4 Solving contextual problems involving linear functions as equations of straight lines.

In this lesson, the students will use the knowledge and skills they learned during the topic of the gradient and force and inclined plane to devise the solution for the ramp problem.

Engineering and Technology

The engineering aspect of STEM is manifested in this lesson through the concepts of effectiveness and efficiency, namely, using the least resources to achieve intended results. The concept of effectiveness and efficiency is apparent in the success criteria and design constraints (Table 3). The success criteria and design constraints will guide the students throughout the process of finding the solution to the ramp problem to ensure that all students are moving in the same direction.

Table 3
Success Criteria and Design Constraints

Success Criteria	Constraints
● The toy car can go up the ramp without needing too much force, with a maximum of 11 marbles. ● Wasting little space outside of the building.	● Made using the same material, namely cardboard. ● Tested with a toy car and marbles of the same weight and size.

The engineering aspect is also manifested through the phases of the Engineering Design Process, which will be explained further in the next section. The technology aspect of STEM is manifested through the use of simple and advanced technology in this activity, which makes students' work easier, more effective, and more efficient in achieving their goals.

Task structure

To incorporate the principle of inquiry learning, the lesson is structured into two parts, Activity 1 and Activity 2. The students will solve the ramp problems in Activity 2, but in Activity 1, they will formulate hypotheses that help them devise the solution.

Activity 1

In this part of the lesson, the students work in groups to test the relationship between the steepness of the ramp and the force needed to pull the toy car. They are provided with a miniature ramp 50 cm long, which they should lean against a stack of boxes of varying height. They will test the different gradients that ensue with a toy car, pulled by marbles as load (Figure

2). To fulfill the constraints, all ramps are made from the same material, namely cardboard. All toy cars weigh the same (65 grams) as the case with the marbles (5 grams). The data of the experiment is filled in an experiment table (Figure 3).

Figure 2. The gradient test with cardboard ramp.

The big idea expected to be discovered by the students is that the steeper the ramp, the larger the force (and the more marbles) needed to pull the toy car. They will also discover the relationship between a particular gradient and a certain number of marbles, which they will need in the next activity.

No.	Height	Gradient	Minimum numbers of marbles needed during experiment ...					Average number of marbles	What can you notice?
			1	2	3	4	5		
1.	22,4 cm								
2.	15,8 cm								
3.	12,1 cm								
4.	9,8 cm								

Figure 3. Table for Activity 1.

Activity 2

In this part of the lesson, the students work in groups to build the miniature ramp guided by the problem, the success criteria of the solution, and constraints (Table 3) and following the Engineering Design Process phase. They will start by establishing the problem (*Ask*), brainstorming the problem (*Imagine*), designing the ramp on paper (*Plan*), building and testing the ramp (*Create*), and improving the ramp based on the result of the test (*Improve*). Similar to Activity 1, the ramps are made from cardboard, and the cars and marbles have the same weight. In addition, each group are assigned a cardboard box to design the ramp. Each group's box has a different height, which serves as an additional challenge. The data of the experiment is filled in an experiment table (Figure 4).

No.	Height of the ramp	Gradient	Minimum number of marbles needed during experiment #					Average number of marbles needed	Area occupied outside of the building	What needs to be improved?
			1	2	3	4	5			
1.										
2.										
3.										
4.										
5.										

Figure 4. Data table for Activity 2.

In principle, a successful ramp is defined as needing only a little force to climb, so the students must build their ramp as flat as possible to ensure that only little marbles (or none) are required. A flat ramp is, of course, not an ideal design, as it will waste too much space outside the building. This is balanced by the second success criterion, which is for the ramp to use as little space as possible outside the building. The students are expected to use their discovery in Activity 1 to help them establish the correct gradient of the ramp so that only 11 marbles (or fewer) are needed to pull the toy car up the ramp without too many trials and errors that waste too many resources. An example of the students' designed ramp is shown in Figure 5.

Figure 5. An example of a ramp designed by the students.

Conclusion

Social justice is an essential aim of mathematics education that can be potentially taught through STEM activities. The STEM activity in this study focused on mathematics and social justice is designed through design research and literature-based design consideration, entitled 'Disability-Friendly Environment with Ramp'. The lesson uses real-life context and low-cost materials and is structured according to the Engineering Design Process phases. This paper is expected to give some insights for junior high school mathematics teachers interested in designing or implementing STEM lessons to promote social justice issues or responsible citizenship.

As the paper only reports the first phase of the design research process, the experiment and retrospective analysis phase still need to be carried out to ensure the finalization of the learning materials. Several limitations are also apparent, including the lack of emphasis on science concepts, as the learning materials are designed mainly for mathematics lessons, as well as not enough discussion on social justice and how the students' solution will contribute. Future studies are encouraged to seek collaboration between mathematics and science teachers in designing the lessons, as well as more cycles of implementation if necessary.

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