Designing Integrative STEM Learning Materials for Junior High School Mathematics Classroom: What Works (and Not)?

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Abstract
The demand to make science and mathematics learning more relevant and meaningful leads to integrative stem learning, a teaching approach that integrates science, technology, engineering, and math (STEM) into a cohesive and interdisciplinary learning experience. Even though STEM has been consistently increasing in popularity in Indonesia, the lack of learning materials is persistent. This paper reports the first stage of design research aimed at developing integrative STEM learning materials for junior high mathematics classroom. The result is three sets learning materials that is compatible with the national mathematics curriculum of Indonesia. The development process suggests that feasible learning materials can be developed by matching science and mathematics standards, then tie it with appropriate problem context.

Keywords: Integrative STEM, Design Research, Mathematics Education

1. Introduction

STEM is an acronym for Science, Technology, Engineering, and Mathematics that was first introduced by the National Science Foundation (NSF) to acknowledge the growing significance of these four disciplines in various fields such as national security, immigration policy, and education (B.Gonzales & J.Kuenzi, 2012). STEM subjects are traditionally taught separately in schools, but the demand for Science and Mathematics curricula to be more relevant and applicable in the real-world gave rise to the idea of integrating the four fields (English, 2016; White & Delaney, 2021). Hence, in this paper, the term STEM refers to integrative STEM, which is a learning approach where students utilize knowledge and skills from all four disciplines to resolve real-world problems (English & Mousoulides, 2015; Hourigan & Leavy, 2020; Margot & Kettler, 2019; Shaughnessy, 2013).

Although integrative STEM has not been officially recognized in Indonesian national curriculum, it has gained widespread attention within the education community. This has resulted in a proliferation of workshops, seminars, conferences, and training programs on STEM organized by both private and government institutions. These events are primarily targeted towards educators and promoted as a means of enhancing classroom instruction. As a result, the implementation of STEM education in Indonesian schools is predominantly driven by the initiative of individuals or institutions rather than government. While there have been studies on the incorporation of STEM education in the classroom, the majority of these studies are focused on science education (Hanif et al., 2019; Jauhariyyah et al., 2017; Khaeroningtyas et al., 2016). The recent national curriculum, the Emancipated Curriculum, mandated that the students should participate in at least three project-based learning a year, which is a strong support for teachers interested to implement integrative STEM activities.

Despite its popularity, there is a considerable lack (if not absence) of research-based, ready-to-use STEM resources for teachers. Teachers in countries which are more seasoned in implementing STEM education, such as United States, have vast option of ready-to-use STEM curriculum, either paid or free. As a comparison, teachers in Indonesia interested in implementing STEM usually have to make it themselves or use online resources which cannot be accounted for. This create issues because teachers often cannot be sure about the quality of STEM teaching materials they make or use. Reliable online resources are often in English, which creates language barrier for the teachers.

To tackle this issue, this project aims to develop STEM learning materials for junior high school mathematics classrooms through design research (Gravemeijer & Cobb, 2006). This paper will report the first phase (Design), which results in the initial drafts of the learning materials. This paper is expected to provide points of consideration for educators, especially in mathematics, who are interested in developing integrative STEM activities to enhance their classroom. The research question this study aims to answer is *how to develop integrative STEM learning materials for junior high school mathematics classroom?*

2. Method

The methodology used in this study to address the research question is design research, which focuses on developing theories related to the process of learning and designing the means to aid in that learning process (Gravemeijer & Cobb, 2006). Considering the research question and goals, this approach is considered the most well-suited. Design research involves three stages - preparation and design, classroom experiment, and retrospective analysis - as shown in Figure 1 according to van Eerde (2013).

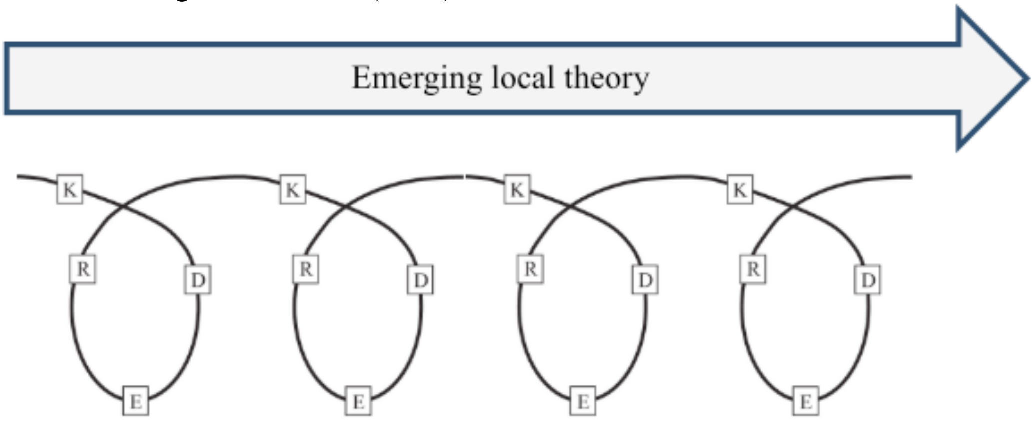

Figure 1: The stages of design research

Each letter – K, R, D, and E – denotes each stages and is explained as follow. The research process starts with the existing knowledge (K), including literature review, curriculum documents, perspective and experience of related stakeholders, and exemplary STEM activities, to prepare and design (D) the learning activities. These activities are then tested in the classroom during the classroom experiment (E) stage, and the researcher reflects on the results (R) in order to obtain new information with which the learning materials will be revised and refined. This process is repeated in cycles, leading to the development of a local instruction theory that includes both instructional activities and a theory of how students' understanding may develop.

The learning materials were developed by four academic specialists of SEAMEO QITEP in Mathematics. All specialists took part in the preparation and design phase, but then worked independently to draft the learning materials. The preparation and design phase took around three months in duration.

3. Result

The preparation and design phase was started by reviewing literature review, curriculum documents, and exemplary STEM activities, as well as interviewing several teachers. This process resulted in a list of several aspects that needs to be considered in designing the learning materials. These aspects, which is referred to as Design Consideration, is described in Table 1, which is adapted from Li et al. (2022).

Dimension	Design Decision	Description	Supporting literatures
Process Design	Designed according to the national curriculum using embedded approach	The task is designed according to the national curriculum. To circumvent the traditional school curriculum which still teach STEM subjects in siloed approach, embedded approach is used.	(Roberts & Cantu, 2012)
	Starting from content	The priority is put on the mathematics and science contents taught in the same year/semester. The contextual problem is then chosen accordingly, where the mathematics and science contents can be applied.	(Nicol et al., 2019)
Task Design	Disciplinary integration through contextual problem	Integration of the four STEM subjects is achieved by having the students apply the knowledge and skills from the subjects to solve problems set in real-life contexts.	(English & Mousoulides, 2015; Hourigan & Leavy, 2020; Margot & Kettler, 2019; Shaughnessy, 2013).
	Inquiry-based learning	The students are encouraged to do investigation and exploration aimed to formulate hypotheses and build knowledge.	(Leung, 2018)
	Emphasize on engineering	Through Engineering Design Process, an iterative process consisting of five stages (Ask, Imagine, Plan, Create, Improve), in applying STEM knowledge and skills to devise solution for real-life problems; and the establishment of criteria and constraint of successful solution.	(Cunningham, 2018).
	Low-floors, high-ceiling, wide walls activities	The activities are designed such a way that it can be solved by students with different levels of content knowledge attainment.	(English, 2017)
Strategy Design	Group work	Students are divided into mixed-ability groups during the task.	(Goodsell, 1992)

Table 1: Instructional design decision for integrative STEM learning materials

The design of the learning materials was conducted with these decisions as guidelines, resulting in three draft of learning materials each for grade 7, 8, and 9. The details of the learning materials are provided in Table 2.

Title	Grade	Description
Parachute for isolated disaster areas	7	Difficulty in distributing aid often happens after natural disaster occurs, especially in remote and isolated areas. One of the solutions that can be used to tackle this problem is using parachute to deliver the aids. In this activity, the students will use the knowledge and skills related to areas of quadrilateral, coupled with engineering principles and technology, to design ideal parachute that can be used to land aids in isolated disaster areas.
Disability-friendly environment with ramp	8	It is important for students to understand that all individuals, including those who have to use wheelchairs due to disabilities, are entitled to equal access to public facilities as part of social justice. To teach this, students will apply the principles of gradients and simple machines, as well as engineering principles and technology, to build ramps that provide an alternative to stairs in public buildings.
Earthquake-resistant building	9	As a country located on the Pacific Ring of Fire, earthquakes happen frequently in Indonesia. Through engineering design process, this lesson provides opportunities for the students to apply the knowledge and skills related to volume and surface area of solids to design earthquake-resistant residential buildings.

Table 2: The details of the initial draft of the integrative STEM learning materials

Conclusion

The growing popularity of integrative STEM as innovative teaching approach in Indonesia is not supported by the availability of research-based learning materials applicable to be used with the national curriculum. Through first stage of design research, draft of learning materials is designed that are potential to be used in accordance to Indonesia national curriculum. The design consideration including the process, strategy, and task design is expected to be able to provide points of consideration for educators interested to attempt similar learning materials. Some of the useful approach identified namely starting by matching science and mathematics content followed by identifying relevant problem context, allocating time twice or three times longer that is planned for classroom implementation, as well as emphasizing the constraint and successful criteria to students, not only to incorporate engineering, but to secure convergence for such an open learning approach.

As this paper only report the first stage of design research, the limitation is that the learning materials still need to go through classroom experiment and retrospective analysis to be considered final. The learning materials are also drafted only by mathematics education specialist and might be biased to one subject. Future studies are encouraged to incorporate perspective from multiple experts in different subjects.

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