Integration of STEM learning into the elementary curriculum in Indonesia: An analysis and exploration

D A M Lidinillah1,*, E H Mulyana, K Karlimah and G Hamdu

Universitas Pendidikan Indonesia, Kampus Tasikmalaya, Jl. Dadaha No. 18, Kota Tasikmalaya 46115, Indonesia

*dindin_a_muiz@upi.edu

Abstract. This research aims to develop the design principles of STEM learning in elementary schools using educational design research. In this study, five STEM learning projects have been designed for fourth grade elementary students. This article presents the results of analysis and exploration as the first phase of educational design research that includes initial orientation, literature review, field-based investigation, site visit, professional meeting and networking. The analysis and exploration phase was carried out through the methods: interview, focus group discussion, observation and document analysis with the strategies: policy synthesis strategy, portrait field, perception pool and SWOT analysis. The results confirm that the integration of STEM learning into the Indonesia elementary curriculum is very appropriate to be implemented to support the development of 21st century skills of elementary school students. Products resulting from this phase are problem definitions, long-range goals, partial design requirements and initial design requirements.

1. Introduction

"STEM", began as “SMET”, was introduced by the National Science Foundation (NSF) to emphasize the importance of the four disciplines both as competencies of workers and student competencies [1]. The fields of science, technology and mathematics have become part of learning at various school levels, but attention to engineering as content and the context for education often occur misconception [2]. STEM was defined as “an instructional approach, which integrates the teaching of science and mathematics disciplines through the infusion of the practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st century interdisciplinary themes and skills” [3]. STEM is the integration of the four disciplines thus producing a "meta disciplines”. STEM education is a new approach to learning science and mathematics in an integrated manner [2].

In the context of primary and secondary education, STEM education aims to develop students who have the STEM literacy [4]: having knowledge, attitudes, and skills to identify questions and problems in real situations, explain natural phenomena and design phenomena, and draw conclusions based on evidence regarding STEM-related issues; understanding the characteristics of fields in STEM as forms of human knowledge, as well as investigations and designs that humans can do; having an awareness of how the fields in STEM shape the material, intellectual and cultural environment; and has the desire to be involved in STEM-related issues and play a constructive, caring and reflective citizen by using ideas of science, technology, engineering, and mathematics.
Engineering is a method that encourages students to conduct discovery, exploration and problem solving [5], besides being expected to develop engineering habits of the mind such as system thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations [6].

Engineers are introduced to elementary school students not by adding other material but engineering becomes an activity related to a concept in science and mathematics, in this case engineering as a context in STEM learning, and not as separate content. That way, engineering provides an integrating function for all four disciplines [2]. STEM and engineering in the classroom when looking at the literature on STEM integration, there is not a single definition or conceptualization of STEM integration or should look like at the elementary level [6].

There are several reasons why engineering can be introduced to elementary students: engineering helps children and improve their world; engineering fosters problem-solving skills and disposition; engineering can increase motivation, engagement, responsibility, and agency for learning; engineering can improve math and science achievement engineering promotes educational equity engineering has the potential to transform instruction engineering is included in state and national standards [7].

The following four issues illustrate the problem of practicing education in elementary schools: engineering does not include material in the curriculum in elementary school, although there are several problem solving activities and innovations in science and mathematics learning; differences in interpretation of the meaning of technology at the elementary level; traditionally, elementary school teachers have weaknesses in proficiency and confidence in teaching science and mathematics; and lack of science and mathematics content learned by teachers during college to support STEM learning [8].

There are three approaches to the STEM learning approach that are commonly used and can be adapted for STEM learning in elementary schools, they include silo, embedded, and integrated approaches [9]. The silo approach to STEM education refers to isolated instruction within each individual STEM subject [10]. The embedded approach to STEM instruction may be broadly defined as an approach to education in which domain knowledge is acquired through an emphasis on real-world situations and problem-solving techniques within social, cultural, and functional contexts [11]. The integrated approach to STEM education envisions removing the walls between each of the STEM content areas and teaching them as one subject [12].

In figure 1, integration in STEM Education can be implemented in the form of content integration and context integration. Content integration means preparing a structured or flexible STEM education curriculum by which more than one discipline can be covered. Context integration, on the other hand, is putting one discipline into the center and teaching it in a meaningful way by selecting relevant contexts from other disciplines without ignoring the unique characteristics, depth, and rigor of the main discipline [13-14]. Two integration models and the three STEM learning approaches can be considered to be used as STEM learning models in the elementary curriculum in Indonesia.

Engineering integration in elementary education can encourage students to be more aware of their role and presence in society and be able to apply to the solution of real-world problems [6]. The Engineering design process (EDP) for elementary students can be done in a five-step process that leads
students to: ask (define the problem and identify constraints); imagine (brainstorm ideas and choose the best one); plan (draw a diagram and collect materials); create (follow the plan and test it); and improve (discuss possible improvements and repeat steps 1-5) [7].

Elementary students still need scaffolding in the engineering process, especially in problem solving process which is the core of engineering design [15]. Each stage of EDP is not a set of rigid steps that students can remember, but the stages of EDP are more directed to regulating and creating work structures that can guide students in the engineering process [7].

STEM education at the elementary level requires the readiness of elementary school teachers. Teachers must be able to understand science, technology, engineering and mathematics (STEM) in an integrated manner. The teacher must be able to convey that mathematics has a role in science which then contributes to the development of technology through engineering.

There are two problems for teachers related to STEM learning: primary school teachers have less proficiency and confidence to teach science and mathematics; and the lack of science and math content learned by teachers in universities to support STEM learning [8]. It is natural that the responses of elementary school teachers to STEM learning are: “i don’t have any extra time”; “there are so many materials to prepare”; “how am i going to manage my students’ varied, creative design”; and “i don’t know how to grade my students on engineering” [7].

Elementary teachers are very required to master STEM and STEM learning to have a positive attitude towards STEM learning and to develop engineering mindset in facing problems in learning, school management and common everyday problems. With these views in mind, the purpose of this paper is to present the results of analysis and exploration to describe problems, contexts and the need to integrate or infuse STEM education into Indonesia elementary school’s curriculum.

2. Method
The research method used in this study is Educational Design Research (EDR). Design research is defined as the systematic analysis, design and evaluation of educational interventions with the dual aim of generating research-based solutions for complex problems in educational practice, and advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them [16].

The definition of design research is a development study variant that is different from the form of validation study. There are three steps to EDR, namely: analysis and exploration, design and construction and evaluation and reflection which can be illustrated as follows.

This article presents a research report for the first phase, namely analysis and exploration. The analysis phase consists of the initial orientation, literature review, and field investigation and the exploration phase consists of site vision, meeting and networking professionals. All of these stages are focused on three main objectives, namely: problem definition, context analysis, and need assessment. The strategies used in collecting data in the analysis and exploration phase are policy synthesis, field portrait and full perception, with the exclusion of SWOT analysis. While the data collection methods used were interviews, focus groups, observation and document analysis. The results of the research obtained from the analysis phase are partial design requirements and initial design propositions, which will then become material for the next stage of research.

The study was conducted by involving teachers and 4th grade students of four Public Elementary Schools, and 11 Elementary School Teacher student of Univeritas Pendidikan Indonesia, Tasikmalaya Kampus. The overall research aims to develop the STEM learning design for 4th grade students.

3. Results and discussion
Result and discussion are presented simultaneously which are divided into two parts, namely the results of analysis and the results of exploration.
3.1. Analysis
The analysis phase consists of the initial orientation, literature review, and field investigation, where each stage is directed towards the objectives (1) definitional problems, (2) context analysis, and (3) assessment needs. The analysis phase was carried out through focus group discussion activities involving teachers and students.

The initial orientation stage produces data related to problems, contexts and needs related to STEM integration in the SD curriculum. It is illustrated that STEM learning is not yet commonly carried out in elementary schools. Elementary teachers are still focused on applying thematic-integrated learning models and scientific approaches as the main approaches to the SD curriculum. Learning models that meet the criteria include product-based learning, project-based learning, problem-based learning and inquiry and discovery learning. While STEM, as integrated learning, has not become an important concern to be applied in elementary schools, so that science and mathematics are often presented separately, especially mathematics learning can be carried out separately from thematic learning. Although the teacher conducts learning that involves students to design and create simple media that contains science concepts, but it is not yet understood as an engineering process that combines science, technology and engineering, which excludes mathematics independently. In this case it can be emphasized that STEM Education has not been integrated into a part of the elementary curriculum.

This research was conducted by public elementary school which is an elementary school partner who has collaborated for three years for early professional development activities for PGSD students as well as research and service activities carried out by lecturers. Partner elementary school is accustomed to being involved in the development of learning in elementary school with lecturers and students. The principal and elementary school teachers welcomed the plan to develop STEM learning that involved them in the research process directly and were willing to facilitate it.

The literature study phase is conducted to obtain theoretical answers to the problem of integration of engineering in the SD curriculum. The study is directed at obtaining a rational account of the urgency and feasibility of engineering integration for SD; type of engineering integration that can be used for SD; the STEM learning approach that is right for elementary school; engineering design process models that are appropriate for elementary school as well as the role of elementary teacher for STEM learning. The results of this literature review have been presented at the beginning of the article. The results of literature review are the basis for building a theoretical framework in developing the design of STEM learning in elementary schools.

From the results of the literature review three characteristics of STEM learning for elementary school were obtained in accordance with the SD curriculum. First, the type of context integration is more appropriate for STEM learning in elementary school. Second, the appropriate STEM learning approach for elementary school is Integrative Approach. Third, the appropriate engineering design process includes the Ask, Imagine, Plan, Create, and Improve phases.

There are several things that also become problems in the implementation of STEM learning in elementary schools, namely: elementary school teachers have weaknesses in proficiency and confidence in teaching science and mathematics; lack of science and math content learned by elementary school teachers during college to support STEM learning [8]; STEM learning takes longer so the teacher must be able to do guidance more thoroughly; the school does not have a laboratory or STEM learning support equipment; and the teacher has not fully understood assessment techniques to assess the engineering process [7]. These problems can arise due to teacher competency, school management and curriculum models that have not integrated STEM learning.

3.2. Exploration
The exploration phase is carried out through three activities, namely site visits, professional meetings and networking. Site visits to elementary school were conducted several times to dig deeper into the context including school management, learning, teacher and student activities. Professional meetings are held at school and on campus to discuss plans and implementation of research. While networking is intended as an effort for researchers to improve relations between research participants.
The results of the exploration phase are problem definition, long-range goals, partial design requirements and initial design proposition [17]. In the previous stage, the problems related to STEM learning at elementary school were explored more fundamentally so that they could explain the causes and impacts. Some of the problems presented above are explained below.

- The teachers consider learning science and mathematics to be difficult learning compared to other fields it can affect the teacher's confidence;
- The integrated STEM learning has not yet become a special field studied by elementary school teacher students, so STEM learning becomes new knowledge for elementary school teachers;
- The STEM learning requires a short period of time so that it must do more careful guidance;
- The schools have not shown attention and support to STEM learning;
- The teachers face difficulties in designing and implementing a thematic-integrated learning;
- The teachers face difficulties determining specific science and mathematical content for engineering process;
- Teacher does not yet have knowledge about STEM learning either through in-service training or professional development activities;
- Teacher does not have the support of facilities and supporting equipment for STEM learning in elementary school.

The results obtained from the previous research stages are used as the basis for continuing the research to the next stage. This analysis and exploration phase resulted in the mapping of basic competencies from science and mathematics as well as identifying and establishing alternative technology and engineering that can be carried out for 4th grade students. Other results obtained are examples of the design principle of STEM learning for 4th grade students. The following is an example of competence analysis for the STEM project developed for 4th grade students, namely STEM Periscope project.

### Table 1. Competence analysis for the STEM project.

| Project Name | Science                  | Technology                  | Engineering                  | Mathematics                  |
|--------------|--------------------------|-----------------------------|------------------------------|------------------------------|
| Periscope    | Applying the properties of light and its relation to the sense of sight | Makes it easy to observe objects on the surface around them. | The activity of designing a simple periscope design and placing the position of the mirror can be moved. | Explain building flat and build space based on its characteristics. Classify flat build and build space based on their characteristics. |
| Material: carton, glue gun, mirror | Presenting report on trial results about the characteristic of light |                            |                              |                              |
| Tools: electric glue, ruler, scissors, pencil |                            |                              |                              |                              |

Based on Table 1, In the literature study, it has been concluded that the most appropriate STEM learning for elementary school is STEM learning integrative approach with the type of context and engineering design process integration with the stages of Ask, Imagine, Plan, Create, and Improve. Mapping STEM content for 4th grade and partial design requirement will be used to determine initial design proposition in the form of a design principle. Design principles can be presented as follows:

If you want to design intervention X [for purpose/function Y in context Z], then you are best advised to give that intervention the characteristics C1, C2, ..., Cm [substantive emphasis] and to do that via procedures P1, P2, ..., Pn [methodological emphasis], because of theoretical arguments T1, T2, ..., Tp and empirical arguments E1, E2, ..., Eq [18]

Examples of STEM learning design principles for Periscope projects are as follows:
Table 2. Design principles for periscope projects.

| Design Principle Component | Description |
|----------------------------|-------------|
| **Intervention X**         | The Perikop engineering project in STEM learning in 4th grade |
| **Purpose/function Y**     | - Students can use the properties of light and their relevance to the sense of sight through a Periscope engineering project.  
- Students can present reports on experimental results about the properties of light (Science)  
- Students can understand the function of the Peaches that applies the concept of the properties of light to observe objects on the surface around (Technology)  
- Students can design and develop a simple Periscope and use it (Engineering)  
- Students can use the concept of building a flat and building space based on their classification and characteristics to design and develop a Periscope (Mathematics) |
| **Context Z**              | Periscope Engineering is one of the STEM projects for 4th grade students as the development of STEM learning for the elementary curriculum |
| **Characteristic C1, C2, ...Cm (substantive emphasis)** | STEM learning for Periscope projects uses:  
- integrative approach  
- context integration  
- the phases: Ask, Imagine, Plan, Create, and Improve  
- collaborative  
- simple and safe materials and tools |
| **Procedures P1, P2, ... Pn (Methodological emphasis)** | - prepare a prototype periscope  
- test prototype periscope to one group of students  
- prepare a guide for making periscope  
- prepare teaching materials for making periscope  
- prepare assessment instruments  
- develop a lesson plan  
- conduct testing and evaluation |
| **Theoretical argument T1, T2, ... T3** | Note: Theoretical arguments can refer to the result of literature study |
| **Empirical argument E1, E2, ... Eq** | Note: Empirical arguments can be developed from empirical finding |

Table 2 shows that design principle is a tentative design principle that might be improved after the trial process is carried out. The results of the research that will be obtained are in the form of a final design principle which is a form of knowledge produced in addition to products in the form of complete STEM learning designs. There is a design principle that applies generally to all STEM projects in elementary schools, also applies specifically in accordance with their respective projects.

4. Conclusion
This article presents the first stage of the Educational Design Research stage, which only focuses on the analysis and exploration stage. However, this stage contains important and decisive results for the next stage. This stage of analysis and exploration provides an overview of the problem, the context and the need for the development of STEM Learning in 4th grade elementary school which is a form of engineering integration in the elementary curriculum. STEM learning is very likely to be developed in the context of an elementary curriculum with an integrated approach, context integration and the stages of Ask, Imagine, Plan, Create, and Improve. However, efforts are needed to improve teacher understanding and readiness of teachers and schools in designing and implementing STEM learning in elementary schools. The teacher is expected to be able to develop a STEM learning that starts from the development of the design principle and the necessary learning materials to the implementation.
Acknowledgments
The research was financially supported by LPPM UPI and Ministry of Research, Technology, and Higher Education of Republic Indonesia.

References
[1] N Z Chesky and M R Wolfmeyer 2015 Philosophy of STEM Education A Critical Investigation 44
[2] E L Mann, R L Mann, M L Strutz, D Duncan and S Y Yoon 2011 Integrating Engineering Into K-6 Curriculum J. Adv. Acad., 22 4 639–658
[3] S M Journal 2012 Ssm journal 367–368
[4] R W Bybee 2013 The Case for Education Challenges and Opportunities
[5] R M Hall 2010 Engineering in K – 12 Education 1–85
[6] National Academy of Engineering and National Research Council 2009 Engineering in K-12 education: Understanding the status and improving the prospects
[7] C Cunningham 2018 Engineering in elementary STEM education: Curriculum design, instruction, learning, and assessment
[8] S Blackley and J Howell 2015 A STEM narrative: 15 Years in the making Aust. J. Teach. Educ., 40 7 102–112
[9] A Roberts and D Cantu 2012 Applying STEM Instructional Strategies to Design and Technology Curriculum PATT 26 Conf. Technol. Educ. 111–118
[10] W E Dugger 2010 Evolution of STEM in the United States 6th Bienn. Int. Conf. Technol. Educ. Res., 1–8
[11] M Chen 2001 A Potential Limitation of Embedded-Teaching for Formal Learning
[12] J M Breiner, S S Harkness, C C Johnson and C M Koehler 2012 What Is STEM? A Discussion About Conceptions of STEM in Education and Partnerships Sch. Sci. Math., 112 1 3–11
[13] M S Corlu and M M Capraro 2014 Introducing STEM Education : Implications for Educating Our Teachers For the Age of Innovation FcTeMM E ğitimi ve Alan Öğretmen i Eğitimine Yansımları Bilkent University Texas A & M University 39 171
[14] M Kertil and C Gurel 2016 Mathematical Modeling: A Bridge to STEM Education Int. J. Educ. Math. Sci. Technol., 4 1 44
[15] C M Cunningham and K Hester 2007 Engineering is Elementary: An Engineering and Technology Curriculum for Children Eng. Educ., 1–17
[16] T Plomp 2013 Educational Design Research: An Introduction in Educational Design Research : part a: An Introdution, T. Plomp and N. Nieveen, Eds. Enschede, the Netherlands, 2013, p. 16
[17] S McKenney and T C Reeves 2014 Educational design research Handb. Res. Educ. Commun. Technol. Fourth Ed., 49 131–140
[18] J V D Akker 2013 Curricular Development Research as a Specimen of Educational Design Research in Educational Design Research 67