Sample learning design of heat transfer course: A STEM-based science learning

S Murnawianto¹*, S Sarwanto¹ and S B Rahardjo²

¹ Science Education Department of Postgraduate Program, Universitas Sebelas Maret, Jl. Ir. Sutami 36 A Kentingan, Surakarta, Indonesia 57126
² Mathematics and Natural Science Faculty, Universitas Sebelas Maret, Jl. Ir. Sutami 36 A Kentingan, Surakarta, Indonesia 57126

*s.murnawianto@student.uns.ac.id

Abstract. The learning design gives a huge effect on the success of the learning process and needs to be continuously developed by teachers. Learning design that is based on Science, Technology, Engineering, and Mathematics (STEM) can be an alternative to enrich the content of science learning. This study focused on developing STEM-based learning design as a science learning for secondary school. The study is a development research that consists of defining stage, designing stage, and development stage of Four-D instruction development model. The developed learning design structured in a syllabus, lesson plan, worksheets, learning modules, and assessments. The expert validators in science learning design were giving a rate to know how appropriate it to STEM-based learning characteristics and how worth it can be used in Indonesian secondary school. Data which collected were analyzed in descriptive qualitative. The results show that the developed learning design was already appropriate to STEM-based learning characteristics with 93%. It was also worth rated to be used in Indonesian secondary school as a science learning design with 93% or categorized very good. These study results become the basis to continue the development of STEM-based science learning design to next stages that are the field test on the real class environment.

1. Introduction

The development of science and technology have become part of every aspect of modern life. The development of science and technology can bring easiness and new way to live, but on the other side of the development of science and technology also become new challenge for society. Society is required to have certain ability in order to compete and live properly in the rapid development of science and technology. In the field of job, one must have skills in science and math, creativity, information mastery and communication technology, and able to solve complex problems [1]. These skills are usually referred to as 21st century skills.

One of the valuable assets of a country is educated people and workforce which is established through a good educational system so that they are not only able to accept and adapt to the rapid changes of time, but also can play an active role to form a better future for the environment [2]. In facing the era of global competition, Indonesia also needs to participate in preparing human resources both in quantity and in quality that are reliable in the fields of Science, Technology, Engineering, and Mathematics (STEM) through the development (reformation) of education [3].
STEM is an acronym of Science, Technology, Engineering, and Mathematics that has become a concern in the development of educational curriculum over the last few decades. STEM acronyms may refer to an educational program and may also refer to related fields. STEM education needs to be a framework for future education in Indonesia [3]. Through the program or STEM education, students can develop 21st century skills [4,5].

The implementation of STEM education in the classroom provides an opportunity for students to understand the importance of relationships and interdisciplinary linkages, as well as their application to real-world problem solving [6]. STEM has become a very relevant and necessary education today [4]. STEM education has characteristics that integrate S-T-E-M subjects into collaboration and student-centered learning through inquiry approach and engineering design process to make solution from real-world problem. Student can solve new problems and draw conclusions based upon previously learned principles applied through science, technology, engineering, and mathematics [7].

Education curriculum in Indonesia (the 2013 Curriculum) provides space for the development and implementation of STEM education. The initial stage of STEM education development is to design STEM-based learning unit models for effective implementation in school or outside [3]. The development of STEM-based learning design can be carried out on science learning by incorporating STEM characteristics without changing the curriculum itself. The development of STEM-based science learning can be started by developing the learning descriptions embodied in syllabus, lesson plans, worksheets, modules, assessments, etc. This development was carried out with the aim of constructing a sample of STEM-based learning design on heat transfer material and knowing its feasibility as an Indonesian secondary school science learning.

2. Method
This study was a research and development study that referred to the Four-D development model developed by Thiagarajan, Semmel, & Semmel [8]. It was divided into 4 main stages namely: 1) Define; 2) Design; 3) Develop; 4) Dissemination.

However, this study was a part that only focuses to discuss on process and outcome of define stage until expert appraisal at the develop stage. At define stage, a questionnaire randomly assigned to 64 students and 7 in-service-science teachers in one of the middle schools in Sragen, Central Java. The design stage is carried out by developing a syllabus draft, lesson plans, worksheets, modules, and assessment for heat transfer materials based on STEM learning characteristics but still adjusted to the 2013 curriculum. The designed draft then validated in the development stage by three science-learning experts. Each validator provides both quantitative and qualitative evaluations of the learning designs on it regarding how far the draft is in line with the STEM learning characteristics likewise how appropriate the draft is used for science learning in middle school that using 2013 curriculum.

Data were collected by literature study method, interview, and questionnaire both for needs analysis and expert appraisal. Likert-type questionnaires were used to provide a quantitative score. Interviews were conducted to collect data qualitatively as input and revision regarding the feasibility and suitability of learning designs having been developed. The data that had been collected was then tabulated, analyzed, and interpreted descriptively qualitative [9]. Quantitative data was analyzed by equation 1 and categorized by reference as in Table 1 for expert appraisal data.

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\text{Percentage} = \frac{\sum \text{obtained score}}{\sum \text{maximum score}} \times 100\%
\]  

| Percentage (P) | Category         |
|----------------|------------------|
| 0% - 50%       | Bad              |
| 50.1% - 70%    | Bad enough       |
| 70.1% - 85%    | Enough           |
| 85.1% - 100%   | Good             |

Table 1. Reference of categories percentage score.
3. Result and discussion

3.1. Defining stage
In order to be called STEM-based science learning, learning design developed by using STEM learning characteristics as a reference of conformity. There are 6 main characteristics of learning STEM which become reference of development such as 1) Based on concrete problem (real-world problem); 2) Containing integrated Science, Technology, Engineering and Mathematic content; 3) Inquiry learning; 4) Engineering design process; 5) active, collaborative, and student-centered learning; and 6) using authentic assessment. The syllabus scoring indicators, lesson plans, materials, and assessments which is in line with the 2013 curriculum are also used as guidelines in order that learning designs which is developed can be easily implemented in secondary schools in Indonesia.

Heat transfer material was chosen to be an example in the development of science learning design for several reasons. Based on requirement analysis conducted in SMP N 1 Masaran, material of heat transfer became one of the material which was difficult enough to be mastered by students. In the process of learning heating transfer, the teachers admitted the difficulty of finding realistic learning media related to the concept of conduction, convection, and radiation. The concept of radiation was the most difficult concept to be understood by students as it was without any concrete learning with realistic media.

3.2. Designing stage
Learning design was arranged in the form of syllabus, lesson plans, worksheets, modules, and assessment based on STEM learning characteristics having been determined at the planning stage.

3.2.1. Concrete problem-based learning. Students should get real experience in science learning. Thence, students succeed in learning STEM [10]. Activities in STEM learning should be based on concrete problems that students could feel. "Rising prices of fuel as well as lack of fuel for cooking (kerosene & LPG)" were the main concrete issues in the design of this lesson. Students were provided with news as challenges to create a tool of cooking with an alternative energy source (solar cooker).

3.2.2. Science, Technology, Engineering, and Mathematics Content. The embedded integrity pattern adopted from Harry, Amanda and Diana [3,7] is used in the learning design on heat transfer materials. Figure 1 shows how Technology, Engineering, and Mathematics content are incorporated in science learning in the context of designing solar cookers.

Embedded integrity was chosen based on the consideration that it was most likely to be applied alongside with the Indonesian education curriculum (the 2013 Curriculum). Higher integration such as transdiscipline or interdiscipline require considerable reconstruction on the existing curriculum as it requires the full integration of two or more disciplines [3]. In addition, secondary schools in Indonesia had not provided the disciplines of technology and engineering in particular. The existence of embedded integrity, Technology, Engineering, and Mathematics content were presented in a science learning that based on the STEM.

Solar cooker as a technology that is developed continuously by using the concept of heat transfer such as conduction, convection, and radiation. It is considered highly relevant as a context in STEM-based science learning. The integration of the scientific method and the engineering design process as an approach to solving problems in STEM-based science learning is a way to incorporate engineering disciplines in a science learning. Scientific methods are used to test hypotheses logically, prove theory, and draw general conclusions. While engineering design is an important concept in the development of technology to solve problems [2]. Using tables and graphs as a way to analyze data in a science context (heat transfer) can be a tool for training students to build logical reasoning. In addition, tables and graphs are represented perfectly regarding mathematical principles and concepts in the context of using science [11].
Figure 1. Embedded integration patterns in STEM-based science learning on heat transfer materials.

3.2.3. Learning Activities. Learning activities were designed by using the learning model 6E Learning by Design™ by ITEEA. Learning by using this model was divided into 6 syntaxes such as 1) Engage; 2) Explore; 3) Explain; 4) Engineer; 5) Enrich; and 6) Evaluate [12]. Table 2 shows the learning activities that had been synchronized with the scientific method, engineering design process and inquiry learning.

Table 2. STEM-based science learning activities on heat transfer material.

| Syntaxes | Students’ Activity |
|----------|--------------------|
| Engage   | Identifying the problem of energy source (heat) for cooking; finding that solar has potential solar cooker; finding the concept of conduction, convection, and radiation. |
| Explore  | Using the concept of heat transfer to create solar cooker design. |
| Explain  | Explaining how their design might work. |
| Engineer | Building prototype based on design; Testing the prototype; Finding and fixing prototype deficiencies |
| Enrich   | Discussing the potential design on problem solving |
| Evaluate | Evaluating the process which has been through, identifying problems to test and repairing the prototype. |

3.2.4. Authentic Assessment. STEM-based learning requires authentic assessment as the aim of assessment for learning and assessment as learning [10,13]. The assessment of attitudes and knowledge were developed likewise the assessment of skills as an authentic assessment consisting of performance assessment in data collection and concept of heat transfer as well as project assessment that included the planning stage, implementation phase, until the reporting stage of solar cooker project results. Authentic assessment is required to measure students' skills [6].
3.3. Validation stage
In general, the validator expert stated that the learning design developed in accordance with the characteristics of STEM learning and appropriate to be used as science learning in secondary school. Some revisions committed based on expert validation are shown by table 3.

| Input from Validator | Follow-Up |
|----------------------|-----------|
| Make sure the element of the presented problem had two components, namely contextual and complex. | Communicating issues used news videos and/or news articles related to "scarcity of fuel for cooking (kerosene and LPG)" so that problems were more complex and contextual according to material of heat transfer. |
| Assessment of solar cooker project as long as possible referred to the specific uniqueness of the product. | The assessment aspect of the solar cooker project had been prepared based on the characteristics of it including the project planning stage, the project implementation stage, and the reporting stage of the project results. |
| Learning indicators should be elaborated more specific. | Several indicators of learning both in the attitude and the knowledge became more specific on one measurement. |
| It was advisable to add discussion on the phenomenon of heat transfer in the module. | The module had been added discussion of the phenomenon of fever (rising body temperature) viewed from the concept of conduction and discussion of the effect of color clothing on comfort was viewed from the concept of radiation. |

Based on the obtained data, the conformity of the draft design which was developed on the STEM learning characteristics had been obtained 93% or good categorization. Viewed from the feasibility of learning design for secondary schools in Indonesia in accordance with the 2013 curriculum, the draft design had been developed and stated eligible with 92.9% (good).

One of the main characteristics that used in STEM-based learning is the inquiry that place students as a center in the learning process and play an active role to solve real-world problems cooperatively so that they can gain a deep understanding of the contents that they learn [2]. The Embedded model can encourage students to reach their best potential to develop problem-solving skills and develop a more effective reasoning strategy [14]. It can also improve students’ conceptual understanding because of the concepts they are learning using the relevant context [15]. With the real-world problem situation through STEM-based learning, students will realize that what they are learning is important and applicable to their life so that meaningful learning can be realized [16].

This development was focused on developing STEM education characteristics in science learning because it was considered capable of improving the quality of learning process. STEM-based science learning design was expected to improve literacy skills not only in science and mathematics but also in technology and engineering literacy (TEL) so that students will eventually have STEM literacy. It is also considered important to be the goal of students in 21st-century education. Both are related each other and be realized as assets for facing the 21st-century challenges [17] [18].

4. Conclusion
Learning design in the form of syllabus, lesson plan, worksheet, module, and assessment can be easily implemented in class. It is in accordance with the STEM learning characteristics with 93% (good). This design was also considered feasible with 92.9% (good) for secondary schools in Indonesia as it met the science learning criteria of the 2013 curriculum. A validated and feasible learning design can be continued into the field test stage in the real class before being used as a learning tool. The development of learning designs on STEM-based heat transfer materials is expected to be an example of design STEM-based science learning for secondary school. Although it is not an easy task for teachers to take an active role in STEM learning [19], adopting STEM learning characteristics into science learning can be a first step in developing learning design especially science learning.
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