Solar cookers as a STEM-based learning media of heat transfer topic at middle school level

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Abstract. The rapid development of Science and technology challenges our education to be able to prepare literate community and workforce in the fields of Science, Technology, Engineering, and Mathematics (STEM) in order to survive in global competition. Contents and media of Science learning must continuously develop following the evolving era in order to remain concrete for students. This research aimed to develop STEM-based Science learning media for heat-transfer topic using solar-cookers. It consisted of 3 main stages of the Four-D development model. The developed learning media was validated by Science learning experts using a Likert-scale questionnaire. A field-test with 32 seventh-grade students in one-group was conducted to measure their responses to solar-cookers as a media in studying heat-transfer. The questionnaire was also given to 3 Science teachers to find out the responses from their perspectives. The collected data were tabulated and analyzed descriptive-qualitatively. The developed learning media (solar-cookers) was considered as feasible to be STEM-based learning media in heat-transfer topic with the feasibility level of 84.7%. The participants, both students, and teachers, also showed positive responses to solar-cookers as a learning media of heat-transfer topic in middle school level.

1. Introduction
The rapid development of technology becomes an inevitable thing in today's and future lives. Technology brings enormous impacts to both humans and the environment. This poses a challenge for education to prepare people who are literate on technology and its development. To survive in the global competition and the pace of technological development, many countries are increasing their education in Science, Technology, Engineering, and Mathematics (STEM) [1]. STEM education becomes one of the most developed trends in various parts of the world. The adoption of STEM education to be combined with the local curriculum (curriculum 2013) can be the first good step in facing global challenges. STEM-based Science learning is one form of Science learning enrichment with the additional contents of technology, engineering, and Mathematics integrated into one context.

One of the main characteristics of STEM education is presenting real-world problems to students to solve using the four disciplines of STEM. This emphasizes not only the competence of conceptual and process knowledge within each STEM discipline but also the competence in addressing situations, problems, or issues [2]. Energy efficiency and environmental quality are two of the recommended issues to be included in the educational context of STEM [2][3]. These issues are important enough to be included in education so
that students are educated and able to act appropriately in facing various problems related to the issues.

Energy has become a basic need that must be met to run all activities. Energy-related issues become important since life is directly affected by energy and its consumption [4]. Besides the issue of energy, the issues related to the environmental quality are also important. Climate-change and global-warming have been particular concerns for the last few decades. Deforestation caused by the taking of firewood for cooking energy still occurs in some places. More than two billion people, especially in developing countries, still use firewood as the energy source for cooking [5].

Solar-cookers have become one of the technologies that continue to be developed to overcome the energy problem. Solar cookers that apply the concept of solar heat-transfer have excellent potential to be used as STEM-based Science learning-media in schools. This research aimed to develop, to dig up, and to construct solar-cookers used as STEM-based Science learning-media, especially on heat-transfer topic.

2. Experimental Methods

This development research adopted Four-D development model that has been developed by Thiagarajan, Semmel, and Semmel [6]. Three of the four main stages has used as a research procedure, namely: 1). Define-stage; 2) Design-stage; and 3). Develop-stage. It starts with the first stage (Define) to defining the potentials of solar-cookers as a media to teach the heat-transfer concepts in accordance with the existing learning indicators at middle-school-level by collecting references. The second stage (Design) was done by choosing the appropriate solar-cooker design based on the references. The construction process of instructional learning was also done in this stage. The third stage (Develop) was done by formative evaluating the design that has been made through the expert appraisal and field trials.

The expert appraisal was conducted by 3 Science learning experts who provided rates on the media suitability to STEM learning characteristics and curriculum 2013. Field trials were conducted to determine the responses of Science teachers and students to solar-cookers as a STEM-based Science learning media. The data from the expert appraisal and qualitative and quantitative responses were collected with Likert-scale questionnaires. The data that had been collected is then tabulated, analyzed, and interpreted descriptive qualitatively [7]. Quantitative data is used to measure the feasibility of product in percent. It was analyzed by equation 1 and categorized by reference as in Table 1 [8].

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P = \frac{n}{N} \times 100\%
\]

P = Percentage of product feasibility
n = scores obtained
N = maximum score

| Percentage of Product Feasibility | Category    |
|----------------------------------|-------------|
| < 70%                            | Bad         |
| 70% - 79%                        | Enough      |
| 80% - 89%                        | Good        |
| 90% - 100%                       | Very Good   |
3. Results and Discussion

3.1. Solar-Cookers
A solar-cooker is a tool capable of cooking food by using only energy in the form of radiation coming from the sun. This makes cooking activities more simple, safe, clean, environmentally friendly, and fuel-free [9]. That way, the use of fossil energy, especially for cooking purposes can be reduced. There have been many solar-cooking projects and applications in various regions of the world, especially in the areas where most people still rely on firewood as a source of energy for cooking. Solar-cookers have been widely developed in various designs and sizes, as well as using a variety of materials tailored to the conditions of use location [10].

Currently, there are about 60 main designs of solar-cookers [9]. But in general, Kimambo [10] divides them into four types, namely solar-box cookers, cooker-panels, concentrating (reflector) cookers, and collector-cookers. Each type has the same feature that is a glossy reflective surface that directs sunlight into a dark made cooking area to absorb radiation. Solar-box cookers are mostly made of insulating materials in which one side is made transparent using plastic or glass. The greenhouse effect has an essential role in this system. Cooker-panels use almost the identical principle, but without insulated boxes, and rely on large (often multi-faceted) reflective panels to direct sunlight to the cooking area. Concentrating-cookers directly concentrate sunlight to a focal point (cooking area) with a parabolic dish.

Collector-cookers have two separate parts between the solar collector and the cooking area, so the cooking area does not have to be in direct sunlight. Oil is used as a medium for transferring heat from the solar collector to the cooking area. Each type has their respective advantages and disadvantages shown in Table 2 [10][11].

| Type of Solar Cooker | Advantages                                                                 | Disadvantages                                                                                      |
|----------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Solar Box Cooker     | • Easy to construct                                                          | Widely divergent thermal performance                                                               |
|                      | • Very easy and safe to use                                                  |                                                                                                   |
|                      | • Requires little intervention by the user                                   |                                                                                                   |
|                      | • Uses both direct and diffuse radiation                                     |                                                                                                   |
|                      | • High acceptance angle                                                     |                                                                                                   |
|                      | • High tolerance for tracking error                                          |                                                                                                   |
| Panel Cooker         | Better input and performance than box cooker                                |                                                                                                   |
|                      | • Quite efficient                                                            |                                                                                                   |
|                      | • Can achieve extremely high temperatures                                   |                                                                                                   |
|                      | • Cooks quicker                                                             |                                                                                                   |
| Concentrating Cooker |                                                                               |                                                                                                   |
|                      | • Uses both diffuse and direct radiation                                     |                                                                                                   |
|                      | • Simple, safe and convenient to use                                         |                                                                                                   |
|                      | • Could use as a multicooker                                                 |                                                                                                   |
|                      | • Higher cooking temperatures                                               |                                                                                                   |

3.2. The Solar-cooker Design and Its Relevancies to The Concept of Heat-transfer in Middle Schools
Not all forms of solar-cookers can be used directly as the learning media for junior high school students. Therefore, it is important to analyze the relevant concepts between the competencies that students must master in learning and the concept of heat-transfer in a solar-cooker design.
Although they can cook fast with high temperatures, concentrating and collector cookers are less appropriate to be used as the learning media of the heat-transfer concept (conduction, convection, and radiation) because they are expensive, complicated, and difficult to build for use by the seventh-grade students. Concentrating-cookers will be more suitable for the learning media of light and mirror topics because they use the concave-mirror concept in their operations. The cooker-panels do not have an isolation space such as solar-box cookers, so they are less able to describe the concept of conduction and convection. Based on the characteristics in Table 2, solar-box cookers are considered the most appropriate type to describe the concept of heat-transfer in accordance with the competencies that must be mastered by the seventh-grade students.

Figure 1. Solar-box cookers design as a learning media of heat-transfer topic

Figure 1 shows the parts of the solar-box cookers that have conceptual interrelationships with the competencies that can be mastered by the students through them. The relevancies are as follows:

1. **An insulating transparent cover** is to describe that: 1) the radiation of visible light does not use a medium and can penetrate clear objects; and 2) glass as an insulator blocks the heat-transfer from inside the isolation chamber to the outside by conduction.

2. **Insulating and conducting materials** is to describe what the difference in material types and thickness affect the conductivity.

3. **Hot air** in the isolation box is to describe the concept of convection in which it flows upward and trapped by the isolation box.

4. **Black (dark) surface** and the reflecting surface (aluminum foil) are to describe that the surface of an object plays an important role in the process of radiation. Aluminum foil can reflect radiation while the dark surface absorbs radiation well.

5. **The greenhouse effect** inside the box can be used as an enrichment concept for students to understand the true global-warming phenomenon including the application of the heat-transfer phenomenon.

3.3. **The use of solar-cookers in STEM-based Science learning media**

As a learning media, solar-cookers can be used as a demonstration tool to show students the mechanisms of conduction, convection, and radiation within a system. Solar-cookers can also be used as a tool in heat-transfer experiments. The role of solar-cookers as a learning media is very dependent on the learning design that will be used by teachers.

In STEM-based Science learning, solar-cookers are used as a design object for students in applying the concept of conduction, convection, and radiation. This learning design challenges them to design their own solar-cookers, as well as test and evaluate their respective designs. The application can use 6E
Learning by design model developed by ITEEA [12]. Table 3 shows the learning steps of heat-transfer with solar-cooker media.

**Table. 3 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. |

3.4. **Expert Appraisal**

Science learning experts have assessed the solar-cooker media developed as STEM-based Science learning media in junior high school level. The results of the reviews based on several indicators of instructional media are shown in Table 4.

**Table 4. Expert appraisal results**

| Indicators                                | Feasibility (%) | Categories     |
|-------------------------------------------|-----------------|----------------|
| Suitability with learning objectives      | 91.7            | Very Good      |
| Suitability with the students' thinking levels | 75              | Enough         |
| Supporting the contents of the subject matter | 100             | Very Good      |
| Ease of learning media                    | 83.3            | Good           |
| Skills of teachers in using it            | 83.3            | Good           |
| Availability of time to use               | 75              | Enough         |
| Mean                                      | 84.7            | Good           |

Solar-cookers are considered feasible and meet the criteria as a STEM-based Science learning media, especially on heat-transfer topic. This media helps teachers by demonstrating the concepts of conduction, convection, and radiation within a system. Thus, the conceptual error assuming that conduction, convection, and radiation take place separately can be avoided.

3.5. **Reviews of Teachers and Students**

**Table 5. Teachers and students reviews**

| Suggestions                                      | Follow-ups                                                                                     |
|--------------------------------------------------|------------------------------------------------------------------------------------------------|
| Teachers: Although students make their own solar-cooker designs, teachers should be given the main design as a benchmark. | The blueprint of solar-box cookers is given to the teachers as a benchmark for all concepts that have been prepared can be delivered properly. |
| Students: The design-testing time is further extended, so students can test using diverse food types. | Follow-up project tasks can be provided outside the classroom so students can have a chance to test their designs more deeply with different types of food. |
Three Science teachers from three different schools and one group of seventh-grade students have responded positively to the solar-cooker learning media in the heat-transfer topic. The main responses to consideration in the development are shown in Table 5.

4. Conclusion

STEM learning trends can be adopted into Science learning in junior high schools to be STEM-based Science learning. In general, solar-cookers are considered feasible for use in junior high schools with the curriculum 2013 as the STEM-based Science learning media on heat-transfer topic with the percentage of 84.7% (good). The results of field-trials showed that teachers and students gave positive responses to the learning media. Box-type solar-cookers have become one of the excellent media in providing Science learning experience especially for the concept of heat-transfer through technology and engineering. Solar cookers are also an up-to-date topic relevant to global issues such as alternative energy sources and global warming.

5. References

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