Promoting the middle school students’ engineering skills and conceptual understanding through STEM-based learning

A N Rusmana1*, A Widodo2 and W Surakusumah2

1Department of Science Education, Kangwon National University, Chuncheon-si, Republic of Korea
2Department of Biology Education, Universitas Pendidikan Indonesia, Bandung, Indonesia

E-mail: ainurlaelasarirusmana@gmail.com

Abstract. Incorporating engineering in STEM education equips the students with the 21st-century skills to design solutions for real-world problems, thus, STEM-based learning has been widely studied. This study aims to examine whether STEM-based learning can promote students’ engineering skills and conceptual understanding. The participants were 68 seventh-grade middle school students, divided into 35 STEM and 33 non-STEM students. This study was conducted in environmental pollution topic where students design and make prototype to clean polluted air and water. The students’ engineering skills during the project were measured by rubric while their conceptual understanding was examined by multiple-choice question. The independent t-test was employed for data analysis. The result showed that engineering skills of STEM and non-STEM students significantly improved (p < .001) from pre to post-test and had a large effect size ($d_{stem}$=5.87, $d_{non-stem}$=3.19). The N-gain value of STEM students (M=0.62, SD=0.14) was higher than non-STEM students (M=0.20, SD=0.06). However, although concept test scores of STEM students increased significantly (p<.001), STEM students’ N-gain value (M=0.19, SD=0.30) was lower than non-STEM students (M=0.23, SD=0.20), indicating that the improvement is solely a learning effect, not because of STEM-based learning. To conclude, STEM-based learning successfully promotes the student’s engineering skills, but not conceptual understanding.

1. Introduction

The interest of STEM (Science, Technology, Engineering, and Mathematics) education has been highly widespread for almost two decades. STEM education has been globally recognized as an education system preparing the students for the demands of the STEM workforce in the future. Besides, STEM education has been acknowledged to increase national development, societal wellbeing, and global competitiveness index [1]. It intrigued the enormous interest of global educators and policymakers toward STEM education, including in Indonesia. With the fascinating opportunities offered by STEM education, the Indonesian government put more concern on improving the implementation of STEM education in the school curriculum.

STEM is the combination of four disciplines (science, technology, engineering, and mathematics) into one class or lesson, and it is based on the relation between the subject and real-world problems. Hence, STEM challenged the students to encounter complex problem-solving where they must think numerous ideas for complex problems and provide innovative solution [2]. Through STEM, students...
learn the meaningful context of problems and will thereby hone pivotal skills such as higher-order thinking skills, design thinking skills, and collaborative working skills [3,4]. Additionally, the inclusion of engineering experiences in STEM increases students’ understanding of the role of engineering in contextualizing mathematics and science principle to improve problem-solving [5]. Therefore, STEM might probably promote the students’ engineering skills; the skills required to perform engineering design as the process of designing a system or component to fulfil the desired needs [6]. Besides fostering such skills, STEM education facilitates the students to improve their learning. In other words, students can increase their scientific knowledge [7]. The process of understanding the problem comprehensively from various disciplines requires the students to learn more in-depth the science content regarding the issue. With good scientific knowledge, students can generate and select the best possible solution for the problem [8]. Thus, we assumed that STEM-based learning supposed to develop the students’ conceptual understanding as well.

Even though the research on STEM education has been robust in Indonesia, there is still a limited number of studies concerning about STEM education in promoting students’ engineering skills and conceptual knowledge. Instead, most of the study focus on the other variables such as scientific literacy [9], critical thinking skill [10] and creative thinking skill [11]. To this end, this study aims to examine the implementation of STEM-based learning in fostering middle school students’ engineering skills and conceptual understanding. The research questions of this study are as follows:

- To what extent the STEM-based learning promotes the students’ engineering skills?
- How is the effect of STEM-based learning on students’ conceptual understanding?

2. Literature review

2.1. STEM and engineering design process

The STEM Taskforce Report [12] suggested that the implementation of STEM-based learning in the classroom is far more than instruction-based integration of four distinct subjects: science, technology, engineering, and mathematics. In STEM-based learning, students need to engage with cohesive and active teaching and learning approaches as the real-world, problem-based learning that employed the four disciplines integration. To this end, engineering design is seen as a promising approach. Engineering design is firstly defined as the process used by the engineers when they are solving engineering issues and developing their product [13]. NGSS [8] formally defined engineering design for the following three processes: 1) identifying and delimiting the engineering problem; 2) designing solutions; and 3) systematic testing to optimize the solution. In STEM education context, the use of engineering design balance the content representation and enhance students’ engagement and abilities in solving real-world and complex problems [14]. The engineering design process (EDP) teaches students to think systematically about the problems, develop creative thinking, formulate high-quality solutions, and consider alternative solutions to tackle those problems [1]. Through engineering design, students would understand that many ideas, solutions, and methods are decent to be used variously in encountering complex problems until producing the final desired product [2]. In the process, none of the failed ideas, solutions, and methods are useless as all were seen to be worthy of a better understanding of the issues. Therefore, teaching engineering design in STEM-based learning give opportunities for students to not only improving necessary skills for complex problem solving, but also learning more about how engineers work on the problem, participating in engineering design, and thereby will advancing their engineering skills.

The engineering design process (EDP) consisted of problem scoping, idea generation, design and construct, design evaluation, and redesign [14]. Problem scoping has two features that are having a meaningful context to the problem and familiarizing with the materials [15]. With regards to the idea generation, it includes brainstorm and develop the ideas, discuss the strategies for the idea implementation, and extend the collaborative design. Those processes encourage students’ collaborative problem solving and communication skills [14]. Next, in the process of design and construct, students can develop a variety of designs or solutions and modify it to meet the needs [14]. In the following
process, design evaluation, it is the time for students to test and reflect whether their designs worked for the problem. Besides, they can check the limitations of the current design for developing the better one if necessary. When the previous design did not work to solve the problem, in the redesign phase, students were allowed to create a new design based on their evaluation of the first design [14]. The five phases of EDP does not merely call for students’ participation in the design process procedurally. Yet, it is more into supporting students to be involved in the design process related to a context and connecting them with principles and concepts underpinned the problem solution [16]. We further adapt and develop the EDP framework of [14] as the dimensions of engineering skills studied in this research. This research examined nine engineering skills or design strategies developed from engineering design process which are 1) understand the challenge, 2) build knowledge, 3) generate ideas, 4) represent ideas, 5) weigh options and make decisions, 6) conduct experiments, 7) troubleshoot, 8) revise or iterate, and 9) reflect on process.

2.2. STEM-based learning for understanding concepts

Every five stages of engineering design process essentially require the proper content knowledge of students [14]. Therefore, we hypothesized that both students’ engineering skills and conceptual knowledge could be fostered through STEM-based learning. Design-based experiences that students got through STEM education can improve students’ learning as well as students’ mathematics and science achievement [17]. Rather than requiring students to memorize learning materials they have been learned, STEM-based learning encourages students to apply their knowledge to solve the problem. Thus, the class would be changed from the rigid and content-driven to a more problem-based engineering decision-making model [18]. In such a class, students can explore the problem to create efficient solutions. In exploring those problems, students deepen their understanding of the core concepts and connecting it to the principles within and across the STEM disciplines [2].

3. Research Method

3.1. Participants

The data were collected in a middle school in Bandung, Indonesia. The participant was 68 middle school students in the 7th grade. The STEM (experiment class) and non-STEM (control class) consisted of 35 and 33 students, respectively. Sample selection was conducted by purposive sampling.

3.2. Research design and procedures

The research design was quasi-experimental with pre-test and post-test non-equivalent control group design. The experiment and control group will be pre-tested and post-tested for their engineering skill and conceptual understanding. STEM-based learning was conducted in the experiment class, while non-STEM-based learning was in the control class.

Table 1. The difference of treatment for STEM and non-STEM class.

| Activity       | STEM class                                      | Non-STEM class                                    |
|----------------|-------------------------------------------------|---------------------------------------------------|
| Pre-test       | Multiple choice of environmental pollution topic | Multiple choice of environmental pollution topic   |
| Science lesson (Environmental pollution topic) | Learning science concept integrated to T, E, and M. | Learning science concept (conventional method)     |
| First project (Air pollution) | Using STEM worksheet | Using regular science project worksheet |
| Second project (Water pollution) | Using STEM worksheet | Using regular science project worksheet |
The brief summary of treatment for STEM and non-STEM class is shown in Table 1. Before starting the class, students in STEM and non-STEM classes were doing pre-test. They were given multiple-choice questions with reason and evidence to evaluate their conceptual understanding on environmental pollution. During the class, STEM students learn science concepts (i.e., environmental pollution), which is integrated into the other field’s perspectives. For instance, when learning the environmental issue, the teacher introduces them to the technology for overcoming those issues and teach them how engineering and math can be applied to technology. Meanwhile, in non-STEM class, students learn the environmental issue conventionally where they learn the science concept of pollution without integrated it into technology, engineering, and mathematics. Both STEM and non-STEM students were assigned two projects. The first project was designing and making a tool for cleaning the polluted air, and the second project was a tool for cleaning the polluted water. When they are doing the project, STEM students were guided by the STEM worksheet while non-STEM students were given the regular science project worksheet. STEM worksheet consists of step-by-step questions guiding the students to think about the problem, design the tool (e.g., draw the design, list the materials, the amount and function), test whether the tool worked considering some indicators, and do reflection. The regular science project worksheet consists of the text about the problem and some blank sessions (the aim of the project, design drawing, materials, procedures, and strengths and weakness of tool). The students’ engineering skills in both classes were assessed during the first and second projects.

3.3. Research instrument

The instruments were engineering skill scoring rubric to examine students engineering skills referring to nine design strategies of engineering design process [14,17] and 15 multiple-choice questions with reason and evidence to test the students’ conceptual understanding on environmental pollution. Engineering skill scoring rubric examine nine engineering skills developed from design strategies of EDP which are 1) understand the challenge, 2) build knowledge, 3) generate ideas, 4) represent ideas, 5) weigh options and make decisions, 6) conduct experiments, 7) troubleshoot, 8) revise or iterate, and 9) reflect on process. Furthermore, since [18] only presented the pattern of beginning and informed designers, we developed a rubric to provide information about the pattern of four designer levels. It aims to cover more various levels of students’ engineering skills. Therefore, the rubric measures nine engineering skills and categorizes the students in each strategy into four levels: level 1 (beginning designer); level 2 (emerged designer); level 3 (developing designer); and level 4 (informed designer).

Both instruments were validated which the engineering skill scoring rubric was tested to students who did STEM activity to determine the measurable indicators for each design process (Appendix 1). Some indicators were removed due to the measurability issue. In other words, some indicators were difficult to be graded. Regarding the multiple-choice questions, after being validated by two experts, we gave those items to the students for testing the item legibility. Meanwhile, multiple-choice questions were validated using Rasch analysis via Winstep v.4.1. Rasch analysis is the psychometric method to help researchers in constructing instruments and checking its quality with high accuracy [19]. As the result of Rasch analysis, all infit MNSQ values of the multiple-choice question were in the range (0.5-1.5) indicating that most of the students’ responses fit the Rasch model very well. Meanwhile, one outfit MNSQ value was out of range which is 1.51 for the 6th item [20]. However, the small outlier will not influence the validity of the instrument, and thus, this item was retained [21]. The item and person reliability were 0.92 (high) and 0.34 (low), respectively [22].

3.4. Data analyses

To examine the improvement of students’ engineering skills and conceptual understanding, we calculated N-gain value. Further, the independent t-test via SPSS IBM 24 compares significant difference between the first and second projects and pre and post-test in STEM and non-STEM classes.
Cohen’s d was used to test the effect size of significant difference. The effect size can be negligible (0-0.19), small (0.20-0.49), medium (0.50-0.79), or large (0.80 and above) [23].

4. Result and Discussion

4.1. Research instrument

To attempt the first research question regarding the STEM education in improving students’ engineering skills, we tested the change of the students’ engineering skills after STEM-based learning. Next, we compared the engineering skills of both STEM and non-STEM students by evaluating their performance on two projects. They made the tool to clean the air pollution and water pollution for the first and second phase, respectively. The following table is the comparison of STEM and non-STEM students’ engineering skills in the first and second phases.

Presented in table 2, both STEM and non-STEM students’ engineering skills were improved from the first to the second phase. The improvement of engineering skills in both classes was significant (p <.001) and Cohen’s d for both classes showed a large effect (d_{STEM} = 5.87, d_{non-STEM} = 3.19) [23], albeit the effect size of STEM students was larger than non-STEM students.

| Class  | 1st phase | 2nd phase | N-gain |
|--------|-----------|-----------|--------|
| STEM   | Mean      | 39.68     | 76.98  | 0.62   |
|        | SD        | 4.16      | 7.97   | 0.14   |
|        | t value   | -10.978   |        |        |
|        | p value   | .000      |        |        |
|        | Cohen’s d | 5.87      |        |        |
| Non-STEM | Mean    | 33.80     | 47.22  | 0.20   |
|         | SD       | 3.25      | 4.97   | 0.06   |
|         | t value  | -5.54     |        |        |
|         | p value  | .000      |        |        |
|         | Cohen’s d| 3.19      |        |        |

The normalized gain (N-gain) value of STEM students is middle level (M=0.62; SD=0.14) while N-gain of non-STEM students is low level (M=0.20; SD=0.06) [24]. Shortly, the STEM students’ engineering skills outperformed that of non-STEM students. STEM-based learning gives the structured experiences of the engineering process for students [25]. Therefore, students in the STEM class have a better opportunity to engage in the design process as a series of steps that engineers used to work on the problem, familiarize with meaningful engineering-based issues, and hone their engineering skills [14].
Figure 1. STEM students’ performance in nine engineering skills.

Figure 2. Non-STEM students’ performance in nine engineering skills

The present study also showed the level change of nine engineering skills for both STEM and non-STEM students to gain further insight into the improvement of engineering skills. The level is divided into four as follows: the 1st level (beginning designer), the 2nd level (emerged designer), 3rd level (developing designer), and 4th level (informed designer). Figure 1 and figure 2 depicted the change of STEM and non-STEM students’ engineering skills from the first to the second project, respectively.

Generally, STEM students’ engineering skills was improved in most of engineering skills while non-STEM students’ engineering skills experienced few improvements. Besides, the increase among non-STEM students limited to the developing designer level; there is no increase in achieving the informed designer level. In addition, non-STEM students showed a more unchanged pattern rather than STEM students. Specifically, a constant pattern was found in three design strategies includes 6th (conduct experiments), 8th (revise and iterate), and 9th (reflect on the process).

4.2. STEM and non-STEM students’ conceptual understanding

To examine if STEM-based learning improves students’ conceptual understanding, similar to engineering skills, we also calculate the STEM students’ conceptual understanding on the environmental pollution concept before (pre-test) and after (post-test) STEM-based learning. Further, we compare their score with non-STEM students’ scores. Table 3 below shows our findings.

| Class | Pre-test | Post-test | N-gain |
|-------|----------|-----------|--------|
| STEM  | Mean     | 33.46     | 47.23  | 0.19   |


Both STEM and non-STEM students’ conceptual understanding showed a significant increase from pre to post-test (p < .001) and both had a large effect (d_{stem} = 0.91, d_{non-stem} = 1.43). Nonetheless, differs from the engineering skills, the normalized gain value of STEM students was low level (M=0.19; SD=0.30) even showed lower value than non-STEM students (M=0.23; SD=0.20). Our finding contrasts with prior studies finding STEM-based learning encourage students’ achievement in the subject [17]. The result could not determine the exact reason underlying the phenomena; however, the possible explanation might be the lack of meaningful learning obtained from STEM-based learning in this study. The engineering in STEM supposed to be the connector between real-world problems and the science content to achieve meaningful learning [3]. Perhaps, students in the present study have difficulties in how to link their knowledge and the issue of environmental pollution on the project.

5. Conclusion
The notable finding in this study is STEM-based learning can successfully promote the student's engineering skills, but not the conceptual understanding. The finding provides evidence that integrating science learning with other fields (technology, engineering, and math) has positive impacts on engaging students with the engineering design processes, thus, develop their engineering skills. Meanwhile, the improvement of conceptual understanding is unlikely due to STEM-based learning; rather, it is solely because of the learning effect. The lack of meaningful learning through STEM might be a reason for this case. The further study is necessary to explore qualitatively of students’ obstacle on deepening their conceptual knowledge in STEM-based learning. How students use prior knowledge, merge it with new information until they build new knowledge to gain a more in-depth understanding of the problem are important to investigate in the future work.
6. Appendices

APPENDIX

The engineering skills' scoring rubric

| Engineering skills/Design strategy | Level |
|-----------------------------------|-------|
|                                   | Beginning designer | Emerged designer | Developing designer | Informed designer |
| 1. Understand the challenge       | 1       | 2               | 3                  | 4                  |
| Problem-solving vs. problem framing | Unable to define the problem | Having limited ability to define the problem | Having sufficient ability to define the problem | Able to define the problem very well |
|                                   | Prematurely and immediately solving the problem without any understanding of the problem | Solving the problem with a simple understanding of the problem | Solving the problem with sufficient understanding of the problem | Solving the problem with a good understanding of the problem |
|                                   | Believing there is only a single solution to solve the problem without doing any research | Believing there is more than one solution to solve the problem without doing any research | Believing there is more than one solution to solve the problem based on research | Believing there is more than one solution to solve the problem based on research, brainstorming, and technological investigations |
| 2. Build knowledge                | 1       | 2               | 3                  | 4                  |
| Skipping vs. doing research       | Skip researching problem in favor of generating solutions immediately | Doing simple research on the problem to find a solution | Doing sufficient research on the problem to find a solution | Doing comprehensive research on the problem and collect information about the effectiveness of potential solutions |
| 3. Generate ideas                 | 1       | 2               | 3                  | 4                  |
| Idea scarcity Vs. Idea Fluency    | Start designing the solution with just one idea | Designing the solution with two ideas | Designing the solution with three ideas | Designing the solution with more than three ideas |
|                                   | There is no willingness to develop the idea. | There is little willingness to develop ideas. | Adequately develop the ideas | Explore and develop the ideas very well to avoid favoring any single solution |
| 4. Represent ideas                | 1       | 2               | 3                  | 4                  |
| Surface vs. deep drawing and modelling | Propose an obscure idea | Propose an idea verbally and explain the ideas verbally | Propose and explain the ideas verbally and design the ideas via sketching | Propose and explain the ideas verbally, design the ideas via sketching, and make simple prototypes |
|                                   | Propose a superficial and inapplicable idea | Propose the idea that might work if applied, but not effective | Propose the idea that would work if applied and it is quite effective | Propose ideas that would work very well if applied and it is highly effective |
| 5. Weigh options and make decisions | 1       | 2               | 3                  | 4                  |
|                                  | Do not know what challenges that might occur during design making | Guessing what challenges that might occur during design making | Limited understanding of what challenges that might occur during design making | Well understanding of what challenges that might occur during design making |
| Engineering skills/Design strategy | Level | Beginning designer | Emerged designer | Developing designer | Informed designer |
|------------------------------------|-------|--------------------|-----------------|---------------------|-------------------|
| **Ignore vs. balance benefits and trade-offs** | 1     | Make a design decision without considering the pros and cons of the design | Make a design decision by only considering one of the pros or cons of the design | Make a design decision by considering the pros and cons of the design | Make a design decision by considering the pros and cons of design as well as thinking the solutions to overcome the cons of the design |
| **Conduct experiments** | 2     | Prepare the tools and materials to execute the idea (i.e., make the product) | Prepare the tools and materials to execute the idea (i.e., make the product), but it is incomplete (less than 50% of required tools and materials) | Prepare the tools and materials to execute the idea (i.e., make the product), but it is incomplete (more than 50% of required tools and materials) | Prepare the tools and materials to execute the idea (i.e., make the product) completely by 100% of required tools and materials |
| Confounded vs. valid tests and experiments | 3     | Do not prepare the tools and materials to execute the idea (i.e., make the product) | Write a procedure to make the product, but it is an incorrect procedure | Conducting an experiment to test whether the product works but not assessing the effectiveness of the product | Write the correct and complete procedure to make the product |
| | 4     | Do not write the procedure to make the product | Making the product that is a little bit similar to the initial design | Conducting an experiment to test whether the product works but not assessing the effectiveness of the product | Making the product that is totally similar to the initial design |
| **4.Conduct experiments** | 5     | Do not conduct the experiment to test whether the product works | Do not conduct the experiment to test whether the product works | Conducting an experiment to test whether the product works but not assessing the effectiveness of the product | Conducting an experiment to test whether the product works and assessing the effectiveness of the product |
| **Troubleshoot** | 6     | Use an unfocused, non-analytical way to find the problematic part of the product. | Use a less focused, less analytical way to find the problematic part of the product. | Use a proper focused and analytical way to find the problematic part of the product. | Use focused and analytical way to find the problematic part of the product. |
| Unfocused vs. diagnostic troubleshooting | 7     | Unable to explain why the trouble could happen. | Give a superficial explanation of why the trouble could happen. | Give the proper explanation of why the trouble could happen. | Give an in-depth explanation of why the trouble could happen. |
| | | Unable to propose the strategies to solve the issue. | Propose ineffective strategies to solve the issue. | Propose quite effective strategies to solve the issue. | Propose very effective strategies to solve the issue. |
| Engineering skills/Design strategy | Level | Beginning designer | Emerged designer | Developing designer | Informed designer |
|-----------------------------------|-------|--------------------|------------------|---------------------|-------------------|
| **8. Revise/iterate**             |       |                    |                  |                     |                   |
| Haphazard or linear vs. managed and iterative designing | 1     | Haphazardly revise the product without any understanding of the problem | Haphazardly revise the product with limited understanding of the problem | Revise the product in a planned way with the proper understanding of the problem | Revise the product in a planned way with a good understanding of the problem |
|                                   |       | Do not revise the procedure of product making | Revise the procedure of product making, but it does not make any improvement | Revise the procedure of product making, and it makes little improvement | Revise the procedure of product making, and it makes a huge improvement |
|                                   |       | Ignoring the feedback and no willingness to improve understanding of the problem when revising the product | Accepting the feedback but no willingness to improve understanding of the problem when revising the product | Accepting the feedback and improve little understanding of the product when revising the product | Accepting the feedback and improve a better understanding of the problem when revising the product |
| **9. Reflect on process**         |       |                    |                  |                     |                   |
| Tacit vs. reflective design thinking | 1     | Do not have the ability to do a reflection on design processes that have been done | Lack of ability to do a reflection on design processes | Having sufficient ability to do a reflection on design processes that have been done | Having a good ability to do a reflection on design processes |
|                                   |       | Do not conduct the review of procedures and product at all | Conduct a simple review of procedures, but do not review the product (or vice versa) | Conduct a simple review of procedures and product | Conduct a comprehensive review of procedures and product |
7. References

[1] Wang H H, Moore T J, Roehrig G H, and Park M S 2011 STEM integration: Teacher perceptions and practice Journal of Pre-College Engineering Education Research 2 1-13

[2] Lachapelle C P, and Cunningham C M 2014 Engineering in pre-college settings: research in synthesizing research, policy, and practices Eds Purzer S, Strobel J, and Cardella M (Lafayette: Purdue University Press) pp 61–88

[3] Brophy S, Klein S, Portsmore M, and Rogers C 2008 Advancing engineering education in P-12 classroom Journal of Engineering Education 97 369-387

[4] Koh J H L, Chai C S, Wong B, and Hong H Y 2015 Design thinking for education: Conceptions and applications in teaching and learning (New York: Springer)

[5] Cunningham C M, and Lachapelle C P 2014 Designing engineering experiences to engage all students Engineering in pre-college settings: Synthesizing research, policy, and practices Eds Purzer S, Strobel J, and Cardella M (Lafayette, IN: Purdue University Press) pp 117-142

[6] Schubert T F, Jacobitz F G, and Kim E M 2012 Student perceptions and learning of the engineering design process: An assessment at the freshmen level Research Engineering Design 23 177-190

[7] Kelley T R, and Sung E 2017 Sketching by design: teaching sketching to young learners International Journal of Technology and Design Education 27 363-86

[8] NRC 2012 A framework for K-12 science education (Washington: United States)

[9] Khaeroningtyas N, Permanasari A, and Hamidah I 2016 STEM learning in material of temperature and its change to improve scientific literacy of junior high school J. Pendidikan IPA Indonesia 5(1) pp 94-100

[10] Mutakinati L, Anwari I, and Kumano Y 2018 Analysis of students’ critical thinking skill of middle school through STEM education project-based learning J. Pendidikan IPA Indonesia 7 54-65

[11] Lestari T P, Sarwi S, and Sumarti S S 2018 STEM-based Project Based Learning model to increase science process and creative thinking skills of 5th grade Journal of Primary Education 7 18-24

[12] STEM Task Force Report 2014 Innovate: A blueprint for science, technology, engineering, and mathematics in California public education. (Dublin: Californians Dedicated to Education Foundation)

[13] Shahali E H M, Halim L, Rasul M S, Osman K, and Zulkifeli M A 2016 STEM learning through engineering design: Impact on middle secondary students’ interest towards STEM EURASIA Journal of Mathematics, Science and Technology Education 13 1189-211

[14] English L D, and King D T 2015 STEM learning through engineering design: fourth-grade students’ investigations in aerospace International Journal of STEM Education 2 1-18

[15] Dorie B L, Cardella M E, and Svarovsky G N 2014 Capturing the design thinking of young children interacting with a parent Paper presented at the 121st SEE Annual Conference and Exposition, Indianapolis

[16] Daly S R, Yilmaz S, Christian J L, Seifert C M, and Gonzalez R 2012 Design heuristics in engineering concept generation Journal of Engineering Education 101 601-29

[17] Crismond D P, and Adams R S 2012 The informed design teaching and learning matrix. Journal of Engineering Education 101 738-97

[18] Koehler C, Faracelas E, Sanchez S, Latif S K, and Kazeroniun K 2005 Engineering frameworks for a high school setting: guidelines for technical literacy for high school students Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition

[19] Boone W J 2016. Rasch analysis for instrument development: Why, when, and how? CBE—Life Sciences Education 15 rm4 1-rm4 7

[20] Linacre J M 2002 What do infit and outfit, mean-square and standardized mean Rasch Measurement Transactions 16 878

[21] Smith A B, Rush R, Fallowfield L J, Velikova G, and Sharpe M 2008 Rasch fit statistics and sample size considerations for polytomous data BMC Medical Research Methodology 8 1-11
[22] Bond T G, and Fox C M 2001 *Applying the Rasch model fundamental measurement in the human sciences* (London: ERL Lawrence Baum Associates Publishers).

[23] Cohen J 1992 A power primer *Psychological bulletin* **112** 155-159

[24] Hake R R 2002 Relationship of individual student normalized learning gains in mechanics with gender, high-school physics, and pretest scores on mathematics and spatial visualization *Physics Education Research Conference* **8** 1-14

[25] Suwarma I R, Astuti P, and Endah E N 2015 Balloon powered car sebagai media pembelajaran IPA berbasis STEM (Science, Technology, Engineering, and Mathematics) *Prosiding Simposium Nasional Inovasi dan Pembelajaran Sains 2015* pp. 373-76