Analysis of Student Communication Skills in STEM Learning Using Engineering Design Process

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Abstract

Education in the current era of globalization requires schools to be able to create students to have the skills to face the challenges of the 21st century. This effort is in accordance with the objectives of science, technology, engineering, and mathematics (STEM)-based learning which is directed to stimulate students in applying concepts from various disciplines. This study was conducted to analyze students' communication skills in STEM learning using an engineering design process approach. The study involved seven junior high school students as participants, who were selected using a purposive sampling technique. The students accomplished STEM design-based learning through a "Rube Goldberg Machine" project. Data were collected by observation, interview, and documentation methods. Analysis of the research results using a thematic analysis approach is directed to understand students' communication skills in STEM learning. The results showed that students' communication skills were clearly exhibited at each stage of the engineering design process in STEM learning. This research is expected to be a reference in developing students' communication skills in EDP-based STEM learning.

Keywords
Communication Skills, Engineering Design Process, STEM Learning

1. Introduction

Education in the era of globalization as it is today requiring schools to be able to create students who are not only possessing cognitive skills but also 21st-century skills. Partnership for 21st Century Skills (P21) elaborated the skills as part of individual competencies known as "The 4 Cs" - communication, collaboration, critical thinking, and creativity. These four skills should be possessed by individuals to face the challenges of the 21st century.

STEM (Science, Technology, Engineering & Mathematics) education could be one of the efforts to equip the 21st-century skills. Bybee (2013) states that STEM offers students to learn to apply the main content and practice each of the STEM disciplines in all situations that students face in their lives. It provides an opportunity to communicate, collaborate, think at higher levels, and increase creativity as the demands of the 21st century. With STEM, students are expected not only to be able to solve problems in science, technology, engineering, and mathematics, but also to be able to solve various types of complex problems that can also develop their higher-order thinking skills, besides that STEM can also prepare 21st-century human resource needs and develop competencies in the STEM field (Bybee 2013).

The TIMSS (Trends in International Mathematics and Science Study) test for class VIII in 2011, reported that Indonesia was ranked 36th out of 38 test-taking countries. The students taking the test were shown to have low ability in applying scientific knowledge and reasoning abilities. This fact was similarly revealed from the PISA test in 2012 whereas Indonesia is in position 64 out of 65 countries (OECD 2012). The aim of the Program for International Student Assessment (PISA) is to measure students' skills in applying real-life problems. Based on this data, it can be seen that the thinking ability of Indonesian students in solving real-life problems is still relatively low. Actually, all the skills tested in TIMSS and PISA have been accommodated in the Graduate Competency Standards of Education Unit

Graduates of Indonesian junior high school. According to the Regulation of the Minister of National Education of the Republic of Indonesia number 54 of 2013, concerning the competency standards of secondary education graduates for science subjects on the skills dimension, the students should have the ability to think and act effectively and creatively in the abstract and concrete realms in accordance with what is learned in school and other sources. This shows the importance of 21st-century skills that must be possessed by junior high school graduates.

Communication skills are one of the skills that are included in the 21st Century Skills and are even one of the skills that a person must possess to be ready for employment after graduating (Bybee 2013). The low mastery of student communication skills in Indonesia is also shown by the findings of a study conducted on 70 class VIII students at a private junior high school in Bandung, which was conducted by (Taryono et al. 2006). It is expected to nurture communication skills while students do project-based activities. These communication skills will be stimulated when students exchange ideas or opinions with colleagues or groups when carrying out the project. Then, students' communication skills will also be trained when conveying the results of their projects through presentations in front of an audience, especially when students are asked to make project reports, their written communication skills will also be trained. Regarding communication skills, many students in the United States are facing a new challenge regarding communication. For example, it shows that in a science or physics book, for example, they are discussing glaciers in the highlands or waves at the beach, even though many students have never visited the beach so that it can lead to miscommunication in writing due to the inconsistency that arises between what is written in the book and in real life.

It is necessary to improve student's communication skills in order to appropriately convey the information avoiding what is conveyed is appropriate and does not cause misconceptions. The Engineering Design Process (EDP) approach can be used in STEM learning and is considered to enhance student communication skills. The engineering design activities could link each STEM subject. Therefore, it is important to conduct further research related to the analysis of student communication skills in STEM learning using the engineering design process. It aims to evaluate how design-based STEM learning could nurture students' communication skills.

The objectives of this research are:

1. To evaluate students' communication skills in the STEM learning process through the EDP (Engineering Design Process) approach.
2. To analyze teacher's perception of students' communication skills in the STEM learning process through the EDP (Engineering Design Process) approach

2. Literature Review

Engineering Design Process (EDP) is a strategy in STEM integration. The National Research Council (2014) defines engineering design as an iterative process with explicit goals governed by specifications and constraints (p.82). In another study, Dym et.al (2005) defined engineering design as a systematic process that requires the application of concepts to create a device or system that can fulfill a given purpose under defined constraints. Engineering design is a challenging activity because it tackles a largely unstructured problem that is important to the needs of society. The engineering design process creates something that didn't exist before, requires a choice between many variables and parameters, and often requires a balance of multiple and sometimes conflicting requirements. Dieter and Schmidt (2009) simplify the design process into three main phases as follows:

Phase 1. Design Concept

1. Defining the Problem
2. Gathering Information
3. Develop the Design Concept
4. Concept generation involves generating a broad set of concepts that have the potential to satisfy a problem statement. Team-based creative methods, combined with efficient information gathering, are key activities.
5. Choosing Alternative Design Concept

Phase 2. Realizing the Design

1. Define the Architecture (physical function of the product)
2. Configuration Design (preliminary selection of material, modeling, and component size)
3. Parametric Design (creating a robust design, and selection of final dimensions and tolerances)

Phase 3. Detailed Design

3. Methods

This study uses a qualitative descriptive method that aims to evaluate students' communication skills and teachers' perceptions of students' communication skills in STEM learning using the engineering design process. This research was conducted at a natural-based school in Central Java, Indonesia. The indicators of communication skills used in this study are adapted from Hutagalung (2007) and (Jacob 2002). The stages of the engineering design process were taken from Dieter et.al (2009). In the design concept phase, the code for the stage of defining a problem is DP. The code for the information gathering stage is GI. The code for the stage of developing the design concept is DC. And the code for selecting alternative design concepts is CC. In the realizing design phase, the code for the defining phase of the product architecture is AP. The code for the component configuration design stage is DK. The code for the component parametric design stage is PK. In the detail design phase, the code for the specification phase of the product analysis is SS.

The data collection method used is by observing students' communication skills during the engineering design activities. The student behavior was observed in a STEM based learning module on simple machines with an engineering design of a Rube Goldberg Machine. The design activity consisted of two sessions. The first session was an introduction to a simple machine and measurement experiment, while the second session is the design of a marble run. In the second learning session, the student had to create a marble run consisting of various types of simple machines in order to pop the balloon at the end of the pathway.

A. First Session

The researchers take a role as the teacher which initially introduced students to simple machines. The students were then encouraged to identify other types of simple machines used in their surrounding environment. Student worksheets were given to measure the level of students' understanding of the content. Then, the students learned basic calculations of force, work, and mechanical advantage on an inclined plane. Based on the instructions provided on the worksheet students conducted experiments on different designs of inclined planes.

B. Second Session

In the second session, the researcher still took the role of the teacher. Students firstly observed the marble run had been prepared by researchers. In the group, students systematically design the marble run by placing several components of a simple machine to have the marble flow to pop the balloon. In the final stage, the students presented their work in front of the class.

4. Data Collection

The observation data was mapped into the stages of the engineering design process to identify what indicators emerged in each stage. The interview data was analyzed using thematic analysis in indicators shown in Table 1.

Table 1. Mapping of Communication Skills Indicators

No	Dimension	Indicator
1.	Presenting or conveying understanding orally	1) Dare to convey information or ideas in front of the interlocutor (K1) 2) Able to present information or material properly and correctly (K2) 3) Understanding the material presented (K3)
2.	Use of good grammar	1) Using polite language and in own words (O1) 2) Use language that is easy to understand and understand by the interlocutor (O2) 3) Using articulation and intonation clearly (O3)
3.	Give opinion	1) able to provide new ideas with good language (M1) 2) able to express opinions in accordance with the material from the interlocutor (M2) 3) able to give positive and constructive input to the interlocutor (M3)
4.	Asking relevant questions	1) able to ask questions according to the material presented by the other person (U1) 2) able to ask questions clearly and in a language that is easily understood by the interlocutor (U2)

5.	Listening effectively	1) able to listen to the conversation of the interlocutor (N1) 2) able to receive new understanding from the interlocutor (N2) 3) do not disturb the other person when explaining (N3)
6.	Writing comprehension	1) able to write the understanding of the interlocutor clearly (I1) 2) write the understanding of the interlocutor in their own language and easy to understand (I2)

5. Results and Discussion

This study reveals several indicators of communication skills that emerged during each step in the engineering design process. It also revealed students' performance and teacher perception of the communication skill.

5.1 Emergence of student communication skills during the Engineering Design Process

STEM-based learning (Science, Technology, Engineering, and Mathematics) with an engineering design process approach facilitated the students to actively engage in the learning activities. The observations as presented in Table 2, clearly show the relevance of the engineering design process with students' communication skills.

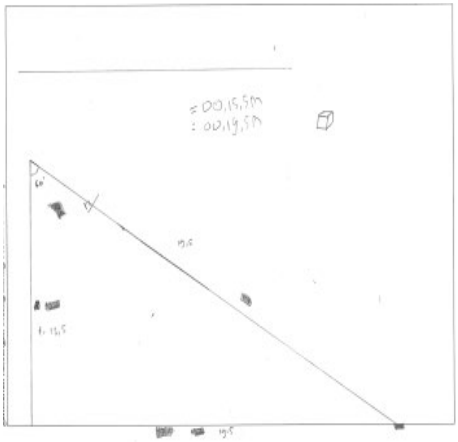
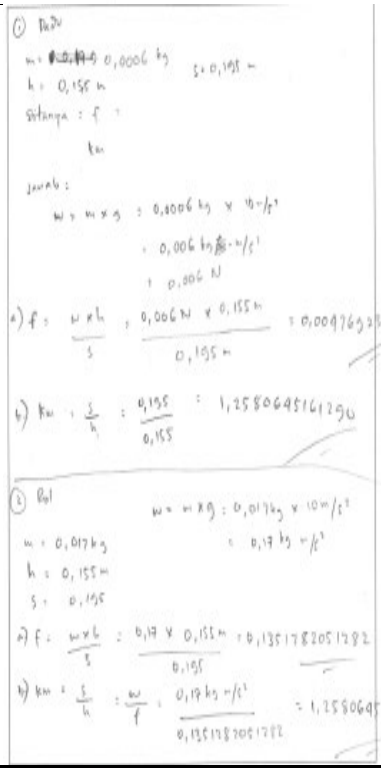
Table 2. Mapping of Communication Skills Indicators Emerged in Stages of the Engineering Design Process

No.	***Engineering Design Process* Indicator**	**Communication Skill Indicator**
1.	DP	K1- O1- O2- O3- N1- N3
2.	GI	K1- O1- O2- O3- N1- N3
3.	DC	K1- O1- O2- O3- M1- M2- M3- N1- N2- N3
4.	CC	K1- O1- O2- O3- M1- M2- M3- U1- U2- N1- N2- N3
5.	AP	K1- O1- O2- O3- M1- M2- M3- U1- U2- N1- N2- N3-I1- I2
6.	DK	K1- O1- O2- O3- M1- M2- M3- U1- U2- N1- N2- N3- I1- I2
7.	PK	K1- O1- O2- O3- M1- M2- M3- U1- U2- N1- N2- N3- I1- I2
8.	SS	K1- K2- K3- O1- O2- O3- M1- M2- M3- N1- N2- N3- I1- I2

5.2 Achievement of Student Communication Skills Graphical Results

Based on the results of observations, it can be seen that the students actively and enthusiastically participated in the learning activities. They enjoyed the group work, as shown from the laughter and jokes during the project. On the student worksheet as shown in Table 3, the students' writing ability was obvious.

Table 3. Analysis of Student Worksheet

No.	Worksheet	Description
1.		this worksheet, one of the students sketched the inclined plane design that has been discussed in the groups. The sketch is neatly produced, equipped with the size of each side of the inclined plane and its units.
2.		After designing and conducting a trial run of several objects on an inclined plane, the students calculate the force and mechanical advantage of each object and then determine which object slides faster. In their worksheet the students wrote clearly using their own writing style and were able to write down the experiment result of their groups. In addition, students' analytical skills in the form of calculating mechanical forces and advantages using the formula and analyzing which objects slide the fastest shows the stages of the engineering design process in the detail design phase.

5.3 Teacher's Perception of Students' Communication Ability in STEM Learning through the Engineering Design Process Approach

Teachers' perceptions of students' communication skills are shown in Table 4.

Table 4. Mapping of Educator Interview Result

No	Question	Answer
1.	How is the ability of students to present or convey their understanding orally in EDP learning takes place?	"Yesterday, after I saw some children dared to express their opinion to the supervisor, they gave their opinion politely. Giving an opinion indicates how the student understands learning content. The students were also able to present the result of the experiment even though the attempt to pop the balloon failed.
2.	How is the students' ability to use language when discussing or conveying their ideas in EDP learning?	"Yesterday we were divided into 2 groups, one in 7th grade & 8th, the other in 9th grade. I think that the 7 & 8th graders are not able to express their language well compared to 9th graders, maybe their age influences too, but in general I see it is still normal for their age. The language used is polite and in their own language, especially when they enjoy their presentations in their own language as evidenced by them using their body gestures to explain like Faris, Shofi, Fathur, Ms.
3.	How is the ability of students when giving opinions to the interlocutor in EDP learning takes place?	"When they give their opinions spontaneously, they immediately ask and express their opinions, for example, Ms. is like this, Ms. The response was direct, sis, so the input given was also in accordance with what was being discussed and it would also come in like that, sis."
4.	How is the ability of students in asking questions to the interlocutor in the EDP learning takes place?	"Yesterday the material that was presented was about a simple plane. When they did not understand, they directly asked (the teacher). It was confirmed that some of them immediately asked questions, the questions submitted as a whole were in accordance with the material, but there were some children whose questions were punctuated or outside the material because of their curiosity. In asking questions.
5.	How does the ability to listen to the interlocutor of students in EDP learning take place?	"For them to feel that the explanation is interesting, he is very attentive, his attention is full. If it's not interesting, you will also pay attention, even though it is not full of attention.
6.	How does the ability to write a student's understanding of EDP learning take place?	"Yesterday Ara in grade 9 told that in giving answers in writing, she felt proud to give her writings. We have encouraged the students to write journals of their daily experience. However, the portion to write something that was not a problem for him turned out to be passed from UNS as an inspiration for us. The worksheet enabled students to write their respective opinions.

The resulting themes of the student's interview are problem solving and teamwork

A. Problem Solving

Krulik & Rudnick (1987) define problem solving skill as the individual ability to employ previously acquired knowledge, skills, and understanding required to unfamiliar situations. The students should be able to make synthesis from what they have learned, and then apply that into the new and different situations (p. 4). In line with the activities carried out by students in this study, where students collected various information about simple planes with the skills they possessed so that they could solve problems during each the engineering design process steps by applying knowledge about simple planes, students' communication skills were also found, for example communication skills. students when giving their opinions and presenting the results of their group work. This can be seen in table 2 showing indicators of student communication skills that appear at each stage of the engineering design process. In the transcript of interviews conducted with educators, where students' communication skills appear at the engineering design process stage in an effort to solve a problem. Problem solving is a category of high thinking skills (Ellis 2005). So that it can be said, where students are able to solve a problem, students have reached the stage of high thinking. Many integrated STEM programs cover problems requiring design in which students create prototypes or models as solutions to a given problem. Within this program, a set of design practices guides student problem solving, which are sometimes called design-based activities (Fortus et. al 2004).

B. Teamwork

Teamwork is defined by Scarnati (2001) "as a collaborative process that enables ordinary people to achieve extraordinary results". Harris (1996) also explained that a team has a common goal or goals in which team members can develop effective reciprocal relationships to achieve team goals. Based on the results of the observations above, it can be seen where students form groups to complete projects in the form of an inclined plane and a balloon popping machine with instructions on the student worksheet. Moreover, collaboration and communication are emphasized during the teamwork performing design-based learning (Davis 1998). It is recommended that the teamwork focuses towards a common and clear goal of one of the essential elements of a team (Fisher et.al. 1997). Therefore, in the process of student communication when discussing work, it is very evident that students are able to complete their design.

6. Conclusion

This study shows that indicators of student communication skills appear at each stage of the engineering design process. In this activity, students actively carry out discussions through group work to solve the problems. The teachers viewed that the expressions displayed by students in discussion groups and the way students think in solving a problem are the indicators of the student's ability to communicate well in verbal and written format.

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