Play dough circuits: a tangible and friendly medium for understanding physics

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Abstract. Students consider that physics is difficult because of its abstract nature and the involvement of mathematics. One of the most difficult topics is a simple direct current circuit. Physics education research shows that students learn better when they construct their own understanding of scientific ideas within the framework of their existing knowledge. To accomplish this process, students must be motivated to engage with the content actively and be able to learn from that engagement. The purpose of this research was to compare the grade 6 students’ understanding of the scientific concept of simple direct circuits before and after participating in a STEM activity that involved the building of circuits from play dough. Twenty questions from the Interpreting Resistive Electric Circuit Concepts Test were selected to evaluate students' reasoning regarding direct current resistive electric circuits. Findings revealed that the students’ scores working with the different conditions after learning were significantly higher than they were before learning. However, analysis on learning progress showed that the group that had to create more works had higher normalized gain than the group that created less works. When the work was analysed with rubric criteria, it illustrated that more conditions caused more complexity and diversity to the work. In short, the condition or situation set to students affected work creation.

1. Introduction

Physics education researches affirm that passive learning did not develop students’ understanding of scientific concepts. Active learning is an approach emphasizing on practical skill and knowledge acquisition process to gain new knowledge and findings, and resolve students’ misconceptions. According to constructivist theory, the theory about knowledge construction in the learner through linking activities with their existing knowledge, active learning is considered a significant key to constructing knowledge [1].

STEM learning, is active learning emphasizing on solving real problems in daily routines and careers, and is an approach to learning and development that integrates the areas of science, technology, engineering and mathematics. This approach challenges the students and allows them to express their opinion and understanding. Besides, STEM based learning gives students credit for creating work, having design skills, and searching for solutions based on the actual state according to the Engineering Design Process (EDP). Integrating knowledge and engineering design to science education is not a fresh issue since EDP is similar to the scientific method (the difference is that the scientific method requires the outcome as the scientific explanation while EDP requires the outcome as the work created for the solution).
The core of the STEM approach is EDP because the learners shall “learn” with the learning process starting from designing a solution, applying the solution to a focus group in the classroom where everyone learns together via analytical thinking, criticism, comparison (evaluation), valuing, appreciation and etc. The results of solution design (innovation or work) are various as solutions are open-ended, there is no right or wrong. The learner creates learning resources whereas the teacher encourages them to learn. EDP comprises of seven steps involving 1) identifying the problem, need, or preference, 2) information gathering to develop possible solutions, 3) selection of the best possible solution, 4) design and making, 5) testing to see if it works, 6) modifications and improvement, and 7) assessment. Moreover, EDP includes working under conditions and limitations to design and create the optimal work system applying scientific knowledge represented by mathematics.

Students’ misconceptions in electricity are among the most frequent and persistent [2]. Students develop a variety of misconceptions; current, potential difference, the power dissipated within the circuit element and electric circuit. Researches revealed that these misconceptions are common to both students and teachers, and are consistent in various countries [3]. The inclusion of play in the learning process has repeatedly been shown to be an effective method. Exciting learning experiences can occur when children are engaged with materials, not just through simple interaction, but through designing, creating, and inventing [4]. There are numerous tangible mediums for introducing the concept of simple direct circuits such as conductive textiles and conductive paints that contribute to visual and playful education techniques. Play dough is an effective material for designing a circuit building activity which replaces the electrical wire in the circuit. By eliminating the need for soldering or breadboards, it becomes possible to very quickly incorporate movement and light into sculptures.

The objective of this research was to compare the understanding of the scientific concept of simple direct circuits of grade 6 students applying STEM activities among the Complex Conditions Group (CC–group) and Simple Conditions Group (SC–group).

2. Methods

2.1. Participants
The sample group was 48 and 56 grade 6 students from two schools, respectively, under Ubonratchathani primary educational service area region 3 and 4, selected using purposive sampling. Ordinary National Educational Test results of the grade 6 students, from the academic year 2017 in science indicated that the average scores of both schools were 29.42 and 27.25 respectively, which were lower than the average score of the educational region, provincial level, and national level. Most students were poor and living with their grandfather and grandmother because their parents worked in Bangkok. Both schools were located about 100 kilometers from Ubonratchathani.

2.2. Data collect and analysis
Research tools were a scoring rubric for assessing piece work and a test of students’ understanding of the scientific concept of simple direct circuits, called the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT test) by Engelhardt and Beichner [5]. It was the four objective questions. This research used 10 questions testing the students’ understanding of the fundamental principles rather than problem solving. It was consistent with the simple direct circuit content for primary students. The researcher asked the students to do the DIRECT test via the Pickers program for 30 minutes before and after learning [6]. Data obtained from the DIRECT test was analyzed to establish the learning progress and to find the normalized gain <g> applying the Hake method [7]. The normalized gains, a measurement of the increase in score between pre- and post-testing (actual gain) expressed as a fraction of the range of possible score increases (maximum possible gain), were calculated as <g> = (<%post – %pre) / (100 – %pre).
2.3. Context of study
The STEM activities consisted of four learning plans, 12 hours in total. Firstly, students made two types of play dough: 1) a conductive dough that allows for current flow because three of the ingredients, salt, cream of tartar and regular tap water, conduct electricity and 2) an insulating dough that helps isolate different areas of a circuit. Most purchased play doughs will work as conductive dough and most modeling clays will work as insulating dough. Secondly, the students learnt what the components of a simple direct circuit are and that there are series and parallel circuits. Thirdly, the students designed a circuit to identify the conductor and insulator from the brightness of an LED in the circuit. Lastly, the students had to create a piece work following the EDP. The CC–group had to work under the following conditions and limitations; creating a taxi and designing an electrical circuit in the taxi with the conductor and insulator. The taxi must consist of 5 lights: two front lights, two rear lights, and one roof light. The SC–group worked more independently than the CC–group; creating a tourist site and designing a circuit system without instruction about lights and materials used. Some sample piece works of the students are shown as figure 1.

Figure 1. Electrical wires from the battery pack are inserted into the conducting dough. Different electrical wires are inserted into the different pieces of conducting dough. To connect the LED circuit, the different wires are plugged into different conducting dough. (a) Sample piece works of the CC–group, the taxi was created, the electrical circuit was separated by insulating material such as plastic transparent sheets, modeling clay, straws, plastic wraps, and insulation dough. (b) Sample piece works of the SC–group, the tourist site was designed by separating two pieces of conducting dough with a space.

3. Results and discussion
3.1. Piece work analysis
The CC–group consisted of 56 students divided into 16 groups. The piece work was the taxi (figure 1(a)). The SC–group consisted of 48 students divided into 12 groups and the piece work was the tourist site (figure 1(b)). The piece work of both groups was analysed under four criteria: brightness, type of simple circuit, type of material, and task duration, and indicated that all lights of the SC–group worked. The circuit was a parallel circuit type and all materials were conductors. It was different from the CC–group in which all lights worked in 8 of the 12 groups, and which used a mixed circuit and both a conductor and an insulator. For the other 4 groups, only 1 out of 4 lights worked and only a parallel circuit was used. Insulating dough and other insulators were used for decorating only. Considering the task duration, the CC–group spent almost double the time of the SC–group on their work.

3.2. Students’ learning gain
Table 1 showed the number of students, mean and standard deviation, obtained from 10 questions from the DIRECT test. The pre– and post–experiment paired sample t–test results for the CC–group and showed a significant difference: t(.05,df=110)=10.04, p<.05. In the same way, the pre– and post–experiment results also showed a significant difference in the SC–group t(.05, df=110)= 11.23, p<.05. Independent t-tests were used pre– and post–experiment in the CC–group and the SC–group. There was no significant difference in the DIRECT test results of the CC–group and the SC–group prior to the experiment: t(.05, df=102)=0.27, p>.05. No significant difference could likewise be seen in the group
after the experiment: $t(0.5, df=102) = -1.50$, $p>.05$. Since a significant difference did not occur in the CC–group and SC–group before the experiment, no need was seen to carry out covariance analysis.

Table 1. Showing the number of students, mean and standard deviation, obtained from 10 questions of DIRECT test.

| Group             | Complex Conditions Group | Simple Conditions Group |
|-------------------|--------------------------|-------------------------|
|                   | Pre-test                 | Post-test               | Pre-test | Post-test |
| n                 | 56                       | 56                      | 48       | 48        |
| mean              | 4.1                      | 7.1                     | 4.2      | 6.9       |
| standard deviation| 2.2                      | 0.4                     | 1.4      | 0.9       |

Results of learning progress analysis showed that normalized gain of the CC–group was 0.51 which was higher than that of the SC–group, which was 0.47. However, the learning progress of students from both groups was in medium level.

Although students from both groups had the same understanding about simple direct circuits after learning, with the different condition, the researcher noticed that if the students were challenged to create piece work which suited their capability, they were confident, enjoyed working, and were proud of their success. When they were concentrated and focused on learning, they realized the importance of science and understood why they had to study and how to apply it to their daily life. It reflected that challenging and interesting conditions or situation engagement allowed them to exhibit their potential to complete piece work [8].

4. Conclusion

The study compared students’ understanding of the scientific concept of simple direct circuits before and after learning with a STEM activity by creating piece work based on EDP with different conditions. The conclusion was that the students’ understanding of the scientific concept of simple direct circuits in both groups of students increased, in both t-test and normalized gain. However, piece work analysis using a scoring rubric for assessing piece work illustrated that the CC–group had more varieties of piece work by considering the criteria: 1-5 working lights, series, parallel, and mixed circuits, and conductors and insulators were used, and more time was spent creating the work. This was different from the SC–group in which all piece work had the same pattern: using a parallel circuit and conductor material solely.

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