STEM based learning to facilitate middle school students’ conceptual change, creativity and collaboration in organization of living system topic

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Abstract. A study using one group pre-post-test experimental design on Life organization system topic was carried out to investigate student’s tendency in learning abstract concept, their creativity and collaboration in designing and producing cell models through STEM-based learning. A number of seventh grade students in Cianjur district were involved as research subjects (n=34). Data were collected using two tier test for tracing changes in student conception before and after the application of STEM-based learning, and rubrics in creativity design (adopted from Torrance) and product on cell models (individually, in group), and rubric for self-assessment and observed skills on collaboration adapted from Marzano’s for life-long learning. Later the data obtained were analyzed qualitatively by interpreting the tendency of data presented in matrix sorted by gender. Research findings showed that the percentage of student’s scientific concept mastery is moderate in general. Their creativity in making a cell model design varied in category (expressing, emergent, excellent, not yet evident). Student’s collaboration varied from excellent, fair, good, less once, to less category in designing cell model. It was found that STEM based learning can facilitate students conceptual change, creativity and collaboration.

1. Introduction

Organization of living system is very abstract for middle school students, especially about the cells [1]. The students still have misconception about the structure of plant cell as found in science textbook as reconstruction of many plant cells, and animal cell as reconstruction of variety animal cells. The students will never find those cell models in real world. It had been found too that science teachers had poor understanding how to facilitate their students learn about life organization system [1].

Abstract concepts should be delivered in real or direct experience by students, not by being lectured, as stated by expert team [2]. Project based learning, with the integration with STEM based learning can facilitate students to understand abstract concepts better [3,4]. Nevertheless, student performance is often assessed by using paper and pencil tests by science teachers [5]. Nearly all target can be assessed by using performance assessment, or even by authentic assessment [6].

STEM education integrate studies about science, technology, engineering and mathematics by using scientific inquiry and engineering practice design as unifying theme [7]. In STEM education the
specific discipline content is no longer separated, but being handled and treated as one dynamic discipline [8]. The emphasis of STEM education is mainly on engineering design process that is potential to enhance mathematics and science competencies and technological literacy [9]. Besides, the student can apply their learnt science concepts by designing [10].

Conceptual change can be defined as remedial process of student pre conception which are not in line with scientific concept (misconception) or the process to construct right conception in order the students achieve deep comprehension [11]. Two processes (assimilation and accommodation) can be used to explain for changing conception [12]. Dissatisfaction, intelligible, plausible and fruitful are some requirement in order the accommodation process can occur [12].

The 21st century is indicated by the fusion of science and technology. Human resources should posses certain knowledge-skills in the 21st century [5]. In today’s world of global competition, innovative capacity and a creative spirit are fast becoming requirements for personal and professional success. Creative abilities involved sensitivity to problems, fluency (the ability to produce a large number of ideas), flexibility (the ability to produce a variety of ideas or use a variety of approaches), originality (the ability to produce ideas that are off the beaten track), elaboration, and redefinition (the ability to define or perceive in a way different from the usual, established or intended way [13]. Collaboration demonstrates ability to work effectively and respectfully with diverse teams, exercise flexibility and willingness to be helpful in making necessary compromises to accomplish a common goal by each team member [5]. Four standards concerning effective collaboration are works toward the achievement of group goals, effectively uses interpersonal skills, contributes to group maintenance, and effectively performs a variety of roles [14].

Competencies in creativity and collaboration nowadays become the concern of many educator experts [15]. As the study was also conducted by student in groups, so collaboration was included in this study. Student performance in STEM-based learning referred to the indicator of creativity and its collaboration becomes another focus of this study, besides the student’s conception and their pattern.

2. Methods

A number of seven grade students (n=34) from one state middle school in Cianjur district in West Java were involved as participants, divided into six groups of 5-6. One science teacher participated in delivering the STEM based learning and three science teachers as observers in the implementation of performance assessments on creativity and collaboration. All of the science teachers had direct experience in STEM based learning before.

Data collected through pre-test and post-test results on concept mastery and on test of logical thinking (TOLT) [16], as well as during the designing and producing cell models using analytical rubrics for creativity (in group, and individually) and collaboration among students. The instruments for the two tests were similar, consists of 20 test items with four options and each reason in form of double multiple choice. The observation sheet was prepared to assess the observable creativity and the quality of the products, as well as the rubrics planned by the help of science teachers involved. Documents from each group were collected after being presented and revised based on other groups and teacher’s comments as input.

Six sessions (meetings) of two period presentation from the science teacher was delivered. The first two sessions facilitated students to observe animal and plant cell under the microscopes in group. In the third session the students learnt about organ, organ system and organisms. In the fourth session they designed cell models through integrated STEM based project and communicated their plan. The fourth session was on presentation of the design by each group. The fifth and sixth session was conducted by the group of students based on their design after getting input or feedback from other groups and the teacher and presentation conducted by each group about the product of cell model (animal and plant cells). The learning process was done by using Project based Learning (PjBL) that integrated STEM in cell model making. STEM based learning with PjBL model consists of five steps, namely Reflection (problem identification), Research (brainstorming), Discovery (design individually and in group, construct), Application or test, and Communication or solution sharing [17].
3. Results and Discussion

3.1. Students’ conception on organization of living system
Research findings show that there was improvement of students’ conception on organization of Living system after the STEM based learning through test on concept mastery (Table 1). Based on post-pre-test results, four patterns of conception were found for the entire concepts in organization of living system [18].

Based on the information in Table 1, it can be stated that there are some sub concepts still negative (cell characteristics, prokaryotes and eukaryotes, organ characteristics, plant tissues, plants organ, organ system characteristics); some sub concepts are changed into negative higher than 10% (cell characteristics, structure & function of parts of cell, human & animal organ systems, plant organ systems). Over all and on average 50% of sub concepts are positive and changed into positive, and 43% of sub concepts are still negative, only 7% changed into negative (compared to positive: 12%).

Table 1. Recapitulation percentage of students’ conceptions pattern of each sub concept on organization of living system

| No. | Concept | Sub Concept | Patterns of Conception |
|-----|---------|-------------|-----------------------|
|     |         |             | I (%) | II (%) | III (%) | IV (%) |
| 1   | Cell    | Cell characteristics | 24    | 6      | 53      | 18     |
|     |         | Prokaryotes and eukaryotes cells | 29    | 3      | 68      | 6      |
|     |         | Uncellular and multicellular organisms | 50    | 9      | 35      | 6      |
|     |         | Structure and functions of parts of cell | 35    | 29     | 24      | 12     |
|     |         | Animal and plant cells structure | 48    | 17     | 29      | 7      |
| 2   | Tissue  | Tissue characteristics | 41    | 0      | 47      | 12     |
|     |         | Plant tissues | 39    | 2      | 57      | 2      |
|     |         | Tissue systems of plant | 53    | 0      | 47      | 0      |
|     |         | Animal tissues | 76    | 12     | 12      | 0      |
| 3   | Organ   | Organ characteristics | 24    | 6      | 71      | 0      |
|     |         | Plant organs | 18    | 12     | 65      | 6      |
|     |         | Animal and human organ | 41    | 21     | 32      | 6      |
| 4   | Organ   | Organ system characteristics | 18    | 12     | 65      | 6      |
|     |         | Human and animal organ systems | 29    | 12     | 47      | 12     |
|     |         | Plant organ systems | 47    | 35     | 0       | 18     |
| 5   | Organism| Organism | 32    | 12     | 44      | 12     |
| Average | | | 38    | 12     | 43      | 7      |

Notes: Pattern I: (-, +); Pattern II: (+, +); Pattern III: (-, -); Pattern IV: (+, -)

Even though the average of conception 1 pattern was not as high as conception III, its amount was not far (38%) as it is shown in Figure 1. It was different from Septiani’s finding which is this pattern earned the highest percentage of others [19]. It happened because every student experienced different stimulus. Students formed the conception that was appropriate to stimulus grouped by particular ways. The conception leads to individual’s personal concept that was obtained after receiving and processing
the new information in his cognitive structure. The form of this conception cannot be received after getting formal lesson only, but along with his experience. Therefore, there are relevant and irrelevant conceptions to the experts meant [20].

The average percentage of conception pattern II was 12%, percentage of pattern II was not too high because students’ preliminary concept generally was irrelevant to scientific conception. Sub concept which has the highest percentage of pattern II that is sub concept of plant organ system of 35%. In this sub-concept, the preliminary conception of students has been much relevant to the scientific conception. So, students can keep it after the learning process. The lowest pattern for conception II was tissues characteristics and tissues systems sub concept of 0%. In both sub-concepts, students tended to retain the concepts that are irrelevant to the scientific conception.

The pattern of conception III was negatively defensive. In this pattern of conception, students’ conceptions which are irrelevant to scientific conceptions were retained in the final test. This pattern of conception earned the highest average of 43%. The high percentage of this pattern of conception showed that there were still many students answered incorrectly both on pre-test and post-test. This happens because this material consists of several abstract concepts. This is in line with research finding, that abstract concepts existed in molecular biology require multiple representations to help provide a picture of a concept from various schemes [21]. STEM-based learning has also made various representations, including through images, video and even cell modelling. The results achieved cannot be separated from the level of student’s development that are mostly still in the concrete category. So, they were still experience difficulty in understanding the abstract concepts.

There was the conception change of students’ conceptions with negative characteristic (pattern of conception IV). The scientific conception of students turned into irrelevant to scientific conception in post-test. The average of this pattern was the lowest among other patterns of 7%. The sub-concept that has the highest percentage of this pattern was cell characteristics and organ systems sub concept of 18%. While the lowest percentage obtained by plant tissues system, animal tissues and organ characteristics of 0%. These results can be explained as follows. Most of the seventh grade students were still in concrete operational level, which indicate that they cannot understand abstract concepts, especially prokaryote and eukaryote cells, organ characteristics, plant organs, and organ system characteristics [1].

3.2. Creativity and collaboration
In the problem identification stage, students observed animal/plant cell using microscope. The identified problem was that not all part of the cell was visible under a microscope. Generally, only the cell membrane was visible. The students were then given a challenge to solve the problem, i.e. how to display complete cell parts without using microscope. This was in line with the criteria of appropriate
A task should be challenging and ignited curiosity [22]. In the design stage, students began to design the model individually, followed by a group session of drawing the design. The designing process was the step employed by engineers to find a solution [23]. The next stage involved students constructing the animal/plant cell model based on the design they had made.

In every stage of STEM-based learning, students were encouraged to actively participate in the learning process [2]. Students’ performance assessed in this STEM-based learning was their creativity in constructing animal/plant cell model design individually, constructing animal/plant cell model design in group, and constructing animal/plant cell model product. The targets of performance assessment in this study were application of knowledge to solve problem and create product [24]. Performance assessment was implemented on animal/plant cell model design that students made individually. Figure 2 shows the achievement of students’ creativity in individual model design, for each indicator.

Implementation of performance assessment on STEM learning is conducted to facilitate the development of student creativity and collaboration. This is supported by the study that STEM learning can improve student creativity [25]. In addition, STEM learning can improve the thinking habits or habits of mind, including system thinking, creativity, optimism, collaboration and communication [26].

Figure 2 indicates that the highest creativity indicator was the abstractness (excelling category), as they have to give title should suitable with the design (picture) they made. Meanwhile the lowest score is originality (emerging category), because students had to create a cell model design that differed from other students’ design. Originality is the ability to generate out-of-the-box ideas [27]. Girls elaboration appears higher than boys, but al little bit lower in originality. The low score of originality was due to many students designing similar cell shape. The high similarity percentage lowered originality score. The result showed that the average of animal and plant cell model design is at expressing category which means that their products, projects or performance include evidence of fluency, flexibility, originality, or abstractness that are consistently spontaneous in individual work. This indicates that students were able to perform the design process [28]. In STEM-based learning, students had possessed the potentials to create design and redesign [28]. Through the design process, the students were involved in the initial engineering process, in which they could implement their STEM knowledge. Teacher’s guidance was critical for improving the design to be more detailed.

Student creativity in making cell model design is in the excellent category (11.79 %), expressing category (55.88 %), emerging category (26.74 %), not yet evident category (5.88 %). Creativity of female students (79.37) higher than male students (76.79). Female students score is higher on almost all creativity indicators (fluency, elaboration, and abstractness of title) (Figure 2).

![Figure 2. Student Creativity in Creating Model Design based on Gender](image-url)
These results are consistent with the research showing that female students tend to have higher score than male students in creative tasks and games [29]. The findings indicate that female students are better at showing complete cell sections, calculating cell-scale, using more complete stationery technology, and providing different colors and description on parts of cell of the designs created more in detail. Students’ ability to think in detail and reflectively and their motivation to be creative (elaboration) increases steadily through high school, then static, then declines in adulthood [30].

Table 2. Student’s Collaboration based on Gender

| Collaboration Indicators                          | Collaboration-Design | Collaboration-Product |
|---------------------------------------------------|----------------------|-----------------------|
|                                                   | Male     | Female    | Male     | Female    |
| Works toward the achievement of group goals        | 76.75    | 83.75     | 89.25    | 85.00     |
| Effectively uses interpersonal skills              | 67.75    | 83.75     | 76.75    | 82.50     |
| Contributes to group maintenance                   | 78.50    | 77.50     | 82.25    | 83.75     |
| Effectively performs a variety of roles            | 72.50    | 71.25     | 78.50    | 78.75     |
| Average                                           | 73.21    | 79.06     | 81.70    | 82.19     |

Table 2 shows that average scores female students (girls) are higher than male students (boys) in designing and modelling cell products. Female students exhibit effective interpersonal skills than male students. This is in line with the results of studies showing that female are significantly more interpersonally oriented than men. Male style involves giving orders, while women’s style is more democratic focusing on participation [31]. Other studies have also suggested that group collaboration is greatly enhanced by the presence of female in groups [32]. Female interaction and communication within groups more than male can improve group process and facilitate the improvement of collective achievement of the group [32].

Male students are more active when creating more cell model involving hands-on activities. This is consistent with the results of the study that project learning involving “learning by doing” and direct activity has shown to improve student achievement, imagination, curiosity, and student interest in science [33]. The results of other studies have shown that students who are given hands-on activity can understand science better than text-book based learning, although attitude differences do not correlate significantly with test scores [34]. The students then constructed animal/plant cell model design in small groups. Working in teams will develop student’s collaborative skills. Collaborative is one of the 21st century skills [5]. Collaborative work is one of the characteristics of STEM based learning. The detail of each creativity indicator’s score in group design could be seen in Table 3.

In this study, students’ creativity in designing and creating cell models was in expressing or good category, indicating that performance assessment could be implemented to investigate students’ creativity in STEM-based learning. This was in line with Larkin’s finding that creative project activity could be an alternative assessment method to evaluate students’ achievement, instead of conventional assessments such as traditional tasks and summative examinations [35]. Previous study on performance assessment implementation in STEM-based learning indicated that senior high school students’ soft- and hard skills in Yogyakarta were low [36], as well as another study showed that vocational school students’ scientific process skills in STEM-based learning assessed with performance assessment were in good category [19]. Performance assessment might provide the students with opportunities to demonstrate their implementation of skills and meaningful knowledge.

4. Conclusion
Based on the results and research finding it can be concluded as follows. Conceptual change occurred in seventh grade students after STEM based learning varied for each sub concept of organization of living system with conception pattern varied from pattern III (last negative), pattern I (conceptual change), pattern II (last positive), and pattern IV (changed into negative= misconception). There was more pattern III than pattern I due to the intellectual development level of the students (mostly in
concrete operational level), which means that some sub concepts in organization of living system were too abstract for seventh grade students. It needs extra effort to help them understand abstract concepts.

Based on the findings and discussion, it could be concluded that performance assessment implementation in STEM-based learning was able to investigate students’ creativity and collaboration. The student’s creativity in designing and making cell model is in expressing category which means that student’s products, projects, or performance include evidence of fluency, flexibility, originality, or abstractness that are consistently spontaneous in individual work or as part of a team or group. The student’s creativity should continue to be developed in order to obtain better results.

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