System thinking as a sustainable competency in facilitating conceptual change through STEM based learning in biology

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Abstract Pro-contra about concept mastery in STEM learning inspired this study to encounter conceptual change and STEM-project at the same time using R and D at different educational (junior, senior, university) levels. System thinking was chosen as medium to combine conceptual change and STEM learning, as it was found as part of Scientific Literacy in PISA and STEM approach, and as a UNESCO competency for Education for Sustainable Development. Groups of students from different levels of education were involved as research subjects. Certain consideration in choosing the biology topics and pre-posttests (concept mastery and system thinking skills) was administered for all level. Using system thinking oriented learning material it was reported that 7th graders can understand (plant & animal) cells structure well, no misconception for new concepts (prokaryote, plant tissue system), as they experience EDP in STEM-project and produce cell models. Conceptual change in high schools still resulted in misconception when the pre-post tests were taken once, but not for pre-post tests taken in each meeting. Topic choice and specific learning material for STEM based learning with system thinking oriented are very important to have complex system topic that enable to develop three types of system thinking.

1. Introduction
There is tendency that equipping transferable skills as competency that can be used further for lifelong learning in sustainable society as two sides of coin. Mastering essential concepts is as important as transferable skills, as they seem interchangeably. One can improve the other or else one fail when the other stuck too.

Preliminary studies on STEM based learning in Primary Education resulted in something not very expected. The school principal asked whether STEM based learning can equip the students essential concepts. During the design and re-design process in digestive system and nutritious material, it seems that the students looks very enjoy learning science and conduct the projects through engineering design process (EDP) in STEM based learning. Still in digestive system for Junior high school, scientific engineering process design is unique and can’t achieve the real redesign taught by science major S2 student. The students seem emphasized in art of presentation, not on the practical aspects in presenting Indonesian traditional food. While the students give presentation, the practical aspect of packing is not considered at all, quite different from Japanese “onogiri”. The students can’t imagine the benefit of experiencing EDP. They just have fun and spent lots of time in making or producing, not in design and redesign. The concepts too are not understood by the students and their science teachers.
How can students improve students’ EDP and enhance their concept mastery as well? How can this condition be overcome for sustainable society through STEM based learning? Study about it should be carried out by choosing certain thinking skills and processes. System and system thinking! STM based learning mostly related to Physics major in Science (such as lever, simple equipment), not in Biology or Life sciences.

Based on literature review it was found that there are systems of content in scientific literacy in PISA 2006 [1], such as living system, environmental system, physical system, technological system, earth and space system. In STEM education movement too, it was found that system and system model is one of cross cutting concepts and system thinking is part of STEM Literacy. In Education for Sustainable Development (ESD), system thinking is found as one of eight competencies according to [2].

In “A new Biology for the 21st century” [3], Biology as a system need other system to overcome and facilitating life-long learning for the next generation. Multi-discipline and interdisciplinary approach is badly needed to equip next generations with certain ability to face new era of next generations [4].

So, problem and questions raised later are as follows.

**Problem:** How can STEM based learning facilitate student concept mastery and scientific engineering design process at the same time?

**Research Questions:**
1.1. How are students’ concept mastery in certain system thinking based Biology topics?
1.2. How are system thinking skills achievement through STEM based learning for Biology?
1.3. How can system thinking prevent student misconception through STEM based learning that facilitating students’ conceptual change in certain Biology topics?

**2. Methods**

2.1 Subjects: Age above 12 years old students (JHS=36; SHS=25; University=35)
2.2 Location: Bandung (City, Urban)
2.3 Instruments: Learning material special constructed to debrief system thinking and STEM oriented in System of Living Organization [5]; Tests (TOLT, three tier test on concepts, STS test), Observation sheet, Tasks & Rubrics, Interview.
2.4 System thinking skills Test (18 items, individual, n=35; pre-post, n-gain criteria and paired t test) [6], mostly in GST and Cybernetics [7].
2.5 Biology topics as context to investigate: System of Living Organization (JHS: 7th grade); Reproduction: cell, plant, fungi, vegetative (SHS: 10th grade); Urban Farming (application of Microbiology in daily life problems).
2.6 STEM using PDBU: **Pikir** (Think), **Desain** (Design), **Buat** (Make), **Uji** (Test/Evaluate): modified from PGBU: **Pikir** (Think), **Gambar** (Draw), **Buat** (Make), **Uji** (Test/Evaluate) from Pendidikan Teknologi Dasar (PTD)/Basic Technology Education [8].
2.7 Data Analyzing:

| No | Groups of Participants | Concrete Operation | Transitional | Formal operation |
|----|------------------------|--------------------|--------------|-----------------|
| 1  | Junior High School (7th graders) | 73.5 | 23.5 | 2.9 |
| 2  | Senior High School (10th graders) | 36.0 | 28.0 | 36.0 |
| 3  | University/College (5th semester) | 18.2 | 30.3 | 51.5 |

For concept mastery, every correct answer was also given certain score (three) and zero for incorrect answer. As the test was given twice (pre- and post), then there were N-gain for each
respondent. The information collected was recorded and then each of them was determine have which pattern (see Table 2).

Table 2. Data Analysis for Conceptual Change

| No | Change from _ to _ (x, y) | Type | Pattern       | Interpretation         |
|----|---------------------------|------|---------------|------------------------|
| 1  | (-, +)                    | I    | Change into positive | Conceptual Change      |
| 2  | (-, -)/(+, +^)            | II   | Static Negative/UH | Not Understand         |
| 3  | (+, +)                    | III  | Static Positive | Understand             |
| 4  | (+, -)                    | IV   | Change into negative | Misconception         |

For determining which concept conceive incorrectly by most of the students, or remain incorrect, or change from incorrect to correct one was then used to come to be interpreted as (positive) conceptual change. While the concept which was conceived remain incorrect or not been answered at all, means not understand or understand but in hesitation.

3. Result and Discussion

3.1. Junior high school: system of living organization

STEM-PjBI about System of Living Organization was conducted in 7th grade 7th grade urban school by their science teacher, observed by other science teacher who had planned together in a group of three and learning material prepared by other science teacher who specifically design with system thinking oriented and STEM based learning. The instruments for learning material and test validation had been done in another 7th grade school. The Project on designing animal cells and plant cells task was given after they had experienced observed some real or preserve cells under light microscopes in groups of 4-5 students.

The findings show that the students enjoyed learning science through STEM-PjBL and curious to plan or design cell models based on what they have seen under the light microscopes. Each group of students produced one plant cell model and one animal cell model. They enthusiastically presented what they have planned and made about the cell models. They understand the cell concept clearly based on their experiences. When they were given the test about cell and system thinking, they could answer correctly, no misconception for new concepts.

STEM-PjBL about Fungi and Cell reproduction towards 10th grade City SHS in Bandung, some constraint found there. No homework and no assignment for the students out of school schedule. The project assignment in taking care (maintaining) the cultivation of macroscopic fungi within the group, which was not very successful resulted in specimens to be observed under the light microscopes at school laboratory.

The finding shows low achievement in Fungi reproduction, even though misconception tend to decrease at the next meetings. When personal communication was addressed for some students representative from high-, middle- and low achievers, it was found that there too many terminology in learning Fungi. The terminology are even more in Fungi reproduction, such as variety generative spore (zygo-, basidio-, asco-) and vegetative spore (zoo-, conidio-), as well as parts of macroscopic Fungi (stipes, coleus, …) and hypha, mycelium, etc.

At university level, about 35 students teachers were involved as research subjects. Topics in Microbiology chosen to be implemented for them were composting, nata de soya, and bio-pesticide. Even their achievement tends to increase for the next meeting, the achievement of concept mastery and the system thinking skills are not very high, but the average achievement is 74.3. Most of them working in groups using learning cycle (LC) or cooperative learning (Coop) while disseminating the STEM learning. Actually they are in the fifth semester, but still some of them in concrete operational stage.
In line with test results on concept mastery (conceptual change and misconception) it was found unfamiliar findings. The pre-test and the post-test frequency taken seem influenced the misconception, or “not understand” or “understand but hesitate (not quite sure)”. Students, who have experience design their product by the group and the test taken twice for each meeting, have better understanding in new concepts and no misconception when the concepts are too difficult for them. Unfortunately, students who have experienced only once pre-test-instruction-instruction-post-test tend not very high their achievement and still found misconception.

Female Biology teacher seems more patient to facilitate student’s concept mastery, as well as conceptual change. Topics for SHS students have been selected the difficult ones and still confuse sometimes for them. The tests for SHS concepts were given before (pre-test) and after the instruction (post-test). Male biology teachers gave the pre—post-test once overall the session, while female biology teachers gave pre-post-test for each meeting. The results are quite different. The increased of the score is much higher for each meeting, and no misconception at all.

Some misconception was still found in certain type of students’ reasoning. Certain concepts which were found in concrete and transitional operation thinker, was not found any more in formal operation thinker. When the concept were too difficult for them, they just do not understand (do not choose the answer for MC type, or did not write the answer). When they were asked the reason not answering the questions, they explained that they really did not know the answer, not gambling.

About System thinking skills that was achieved by the students in JHS and in University level, it was found that they have similarity in certain cases. JHS students achieved less for level 3, while university students achieved only components of system, not analysing the interaction among the components within a system, as well as between one component and other system’s components. It seems that even University students need medium to learn more focus about system thinking. Certain learning materials should be prepared in system thinking orientation. The preparation should be well planned as the JHS learning material did. System thinking skills test should be combined with other instruments (concept map + “modules”).

3.2. Many complex material in biology
For young generation especially for Junior high school level, introducing important concepts such as cells (animal, plant, eukaryote, prokaryote) and tissue system in plants are very well constructed in
student’s mind through STEM based learning. From beginning they learn that there are variety of cell structure, and they learn that plant cell structure (and its components) is quite different from animal cell structure. The achievement of Junior high school students in concept mastery as well as system thinking skills had been facilitated by learning materials specifically prepared using system thinking based and STEM approach that was specially designed using concept/content analysis and concept mapping. Their system thinking skills increased moderately as shown in Table X.

| Level | System Thinking Skills                  | Pre-test | Post-test | N-Gain | N-gain Category |
|-------|----------------------------------------|----------|-----------|--------|-----------------|
| 1     | Analyzing component of a system         | 24.31    | 63.89     | 0.54   | Moderate        |
| 2     | Construct component of a system         | 17.01    | 51.74     | 0.43   | Moderate        |
| 3     | Implement system thinking skills        | 11.81    | 43.40     | 0.36   | Moderate        |

The increasing of students’ system thinking skills through STEM-integrated learning material can be done due to the learning material have the structure of presenting systematic material and figures, practicing items that reasoning demand and higher order thinking skills, namely system thinking, and the learning material has cross cutting pattern; structure and function; scale, proportion ad quantity; system and system model that help students to understand the components, process and relation among component within the sistem. This is inline with previous study [10], that whenever want to improve students system thinking skills, the approach to be used should be also system approach. In other words whwn we want to increased ceain skills, so that skill should be learned and practice accordingly [11].

For senior high school level, due to the complex terminology in cell reproduction as well as in Fungi reproduction, SHS students still find difficulties in achieving the real concepts through STEM based learning [12]. It seems that the students them-selves should construct their own concepts in such a way that can improve their concept mastery, it might used concept maps or other vehicle. Assessment that is considered effective in analyzing system thinking skills is concept maps [13; 14; 10].

As complex science, Biology is very challenging to be investigated through STEM based learning which oriented to System Thinking. Even these researches had tried to investigate from cell level (JHS), to cell and plant reproduction (SHS), and to the implementation of Microbiology to solve problem from Urban Farming, system thinking skill test individually could not improve significantly the concept mastery due to the characteristics of the concepts. Later it was found that the system thinking skills test should be combined with the construction of concept map by the student teachers to facilitate the concept construction and re-construction by the learners [15]. Even though expert stated as follows: Complexity in Biology can be manifested in variety of Levels of Living Organization, from molecular level up to ecosystem [16; 17; 18]. System thinking skills can use General System Theory (GST), cybernetics and dynamic system [19; 17].

4. Conclusion
4.1 It is wiser to consider preventing misconception rather than remediating misconception already happened, as we have to know what misconception on certain topic first, find out the cause of the misconception, and then try to remedy the learning.
4.2 It is wiser to introduce the abstract concept in the right way rather than telling them orally.
4.3 Instrument for detecting misconception can be either one (MC/CRI or Essay) through System thinking and STEM based Learning and concept mapping.
4.4 System Thinking (skills) as one of Sustainable Competence can be used widely in some levels of education to prevent misconception for certain degree.
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