The effect of multiple external representations (MERs) worksheets toward complex system reasoning achievement

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Abstract. The application of a systems approach to assessing biological systems provides hope for a coherent understanding of cell dynamics patterns and their relationship to plant life. This action required the reasoning about complex systems. In other sides, there were a lot of researchers who provided the proof about the instructional successions. They involved the multiple external representations which improved the biological learning. The researcher conducted an investigation using one shoot case study design which involved 30 students in proving that the MERs worksheets could affect the student's achievement of reasoning about complex system. The data had been collected based on test of reasoning about complex system and student's identification result who worked through MERs. The result showed that only partially students could achieve reasoning about system complex, but their MERs skill could support their reasoning ability of complex system. This study could bring a new hope to develop the MERs worksheet as a tool to facilitate the reasoning about complex system.

1. Introduction

Nowadays, there is a paradigm shift in studying biology, from fragmentation to being integrated and holistic. Hence, it's essential to see the biological systems as complex systems. It is indicated by the boundless enhancement of last decade studies about the biological system perspective as complex systems, reasoning systems thinking and developing pedagogical as multiple external representations (MERs) to assist students handling the complex systems. Many studies related to this topic have been conducted in various domains of biology learning, e.g. modeling a dynamic immune system [1]; representational competence to think multilevel systems in evolutionary learning [2]; scaffolding with MERs to think across systems between photosynthesis and cellular respiration [3]; investigation based on ecosystem modeling for retreading thinking systems [4]; along with the use of representation map concept to assess the systems thinking capabilities of the human body system [5].

The result of the studies suggested that worksheets could lead learning activities [6], facilitated developing conceptual frameworks [7] and helped increasing knowledge based on microscopic representation to solve problems [8]. Moreover, the worksheet needs to be designed based on the MERs pedagogies function to help students using reasoning dealing with complex systems. This is because of the idea of studying biology with a system approach relevant to the characteristics of a biological system as a complex nesting system. It is also characterized by multiple levels of systems
with interconnected components related to the macroscopic, microscopic, and even submicroscopic levels [9,10]. On the other hand, most biological text learning sources (including worksheets) only support biological learning as a tool to present facts to be studied rather than as a set of ideas that could support the students developing a systematic and integrated understanding of complex systems [11].

MERs-based on worksheets are tools to help students working with different representation dimensions by translating representational representation across cross-level biological organizations, as well as across domains of biological knowledge as the main activity of learning [12]. Working with MERs involves students reasoning for interpretation and uses of an external representation to solve a problem; visualizes orders size, relative size, and scale; translates horizontally across multiple external representations of a concept; constructs an external representation to explain a concept or solve a problem; translates vertically between external representations that depict the various levels of organization and complexity [13]. It shows that reasoning during representational work considers the reasoning of complex systems, for example analyzing components and processes which contained in system, explaining the dynamic relationships which occurs in the system (horizontal coherent), thinking the dynamic relationship between the organizational level of the system (vertical coherent), and thinking temporary which means being able to explain the past events based on the components structure in the current system and predict the development of the system components structure and their functions due to adaptation to the environment [1, 14, 15].

In this article, the researchers want to explain the effect of using MERs-based on worksheets to help students achieving complex systems reasoning abilities, especially on the topic of cell structure dynamics. This is because the topic shows complexity and represents a dynamic abstract relationship from microscopic to macroscopic levels to explain the relationship of cellular mechanisms plant structure and changes in plant structure and function due to plant-environment interactions on both past and future time scales [16].

2. Methods
This study used one-shoot case study design which supported by qualitative data to get deep understanding and verification in order to answer research questions [17]. The research was conducted by involving 30 first-year students in the biology education program of PGRI University of Semarang. Participants involved in the intervention were prospective biology teacher students who followed the course of developmental structure. They were selected by using simple random sampling method. The reasoning ability in a student's complex system was assessed using complex system reasoning test instruments. The performance of representational skills as qualitative data was obtained through worksheets examination that reflected the performance of learners.

Quantitative data analysis had been done descriptively to know the frequency of students based on the quality of reasoning in complex systems in each indicator. Furthermore, the researchers conducted Shapiro-Wilk normality assumption test. It's because the sample size was less than 50. After obtaining the normality assumption test, then the researchers organized the average comparison test with the test value of 2.20 and the 95% confidence level to know the effectiveness of using MERs based worksheet toward achievement of reasoning complex systems. There were two steps how to obtain the qualitative data analysis sources, first by converting qualitative data in the form of quantitative data using scoring and the second by conducting subsequent analysis with descriptive statistics to determine the frequency percentage of maximum score achievement of representational skills.

3. Results and discussion
The result of descriptive analysis of quantitative data is presented in Figure 1. according to the result, it shows that most students had complex system reasoning ability at a moderate level, except on the ability to think coherently vertically. This indicates that the student was in a transitional state of reasoning in a complex system, meaning that it could explain some relationships between
components, processes and cell behavior dynamically. However, the ability to think dynamically across organizational lines was still in a simple category.

![Graph showing reasoning complexity]

**Figure 1.** Level of reasoning complexity in complex systems

The results of the effectiveness test of the intervention of using MERs based worksheets to facilitate reasoning on complex systems are presented in Table 1.

| Parameter                        | n | M    | SD  | t (29) | p       | test value |
|----------------------------------|---|------|-----|--------|---------|------------|
| Reasoning complex systems        | 30| 2.56 | 0.41| 3.848  | 0.000*  | 2.20       |

Table 1 shows that \( t (29) = 2.045, p < 0.05 \). It indicates that the alleged student achievement rate in complex system in 2.20 is not proven and otherwise the use of MERs based worksheets can be used to reasoning in complex systems for students. At least, it's an adequate level. The development of complex system reasoning has gradually facilitated through the understanding of the cell as a dynamic system. Then, it subsequently extended to the relationship between the level of cellular organization and organism as a hierarchical system concept. Furthermore, it developed regarding the relationship between organism and ecosystem organisms with plant adaptation dimensions.

This is supported by qualitative data analysis of reasoning ability using MERs presented in Table 2. Based on Table 2 students engaged reasoning during the activities involved in worksheets designed to be loaded with MERs. Most students were able creating reasoning skill using MERs, except on the ability to translate between levels of representation along with the complexities of organizational life to organism level.
Table 2. Percentage reasoning ability using MERs

| Activity | Reasoning thinking based on multiple representation targets | Frequency and percentage of maximum score (n=30) |
|----------|----------------------------------------------------------|---------------------------------------------|
| Identification macroscopic plant phenomenon | Interpret concrete representation to understanding of natural phenomena | 21 70.00 |
| | Translate vertically between representations that depict various levels of organization and complexity | 8 26.67 |
| Cell body component systems | Visualize orders of magnitude, relative size, and scale | 16 53.33 |
| | Translate horizontally across multiple representations to understanding of concepts relationship | 13 43.33 |
| Structural relationship between cell wall and cells body systems | Interpret a visual representation to understanding of concept and solve a problem | 17 56.67 |
| Complex system modeling | Construct a representation to explain are complex concepts or solve a problem | 18 60.00 |
| Relationship between structural cells adaptation and the way plant live | Using a representation to solve a problem | 13 43.33 |
| | Translate vertically between representations that depict various levels of organization and complexity | 14 46.67 |

Based on the data analysis above, it shows that there was a relationship between MERs based reasoning and complex system reasoning. Moreover, the designed activity sheers could contribute to reasoning ability in complex systems. The motive for doing reasoning associated with complex systems has gradually done by the students, starting from making a tentative explanation of how the relationship phenomenon at the organism-level organization to the structure and process components on the cell system. The tentative explanation was subsequently verified through a series of instructional activities that involved multiple representations arranged in such a way that students made logical reasoning through the worksheet.

Cell component identification activities involved the students visualizing the concrete representations in microscopic. Then, it translated the visualization results with other representations mode to explore the cell components to explain the complex relationships within them. The high frequency of students' interpretation ability to interpret visual representation and their translation ability to translate cross-representation are evidence that students involved in reasoning to identify components and processes of the cell system. However, the students were not yet optimal to train the dynamic thinking ability. Students found it was difficult to explain the relationship between the components contained in the cell system dynamically. It was strongly suspected that the features contained in the image represent only the structure and not yet related to the abstract process so that it was difficult to integrate knowledge.

Student modelling activities involved exploring the functional relationship of cells with higher organizational levels. They must create a model that represents the relationship between the macroscopic systems with the microscopic system at the cellular level. This activity involved students working using and making representations with a high level of abstraction. The ability to organize components, processes, and interactions within the framework of relationships between systems showed that students were involved in complex system reasoning. In this case, the hierarchical system
model was successfully used as a tool for obtaining a vertical coherence understanding of the synthesis process of wax and its implications for plant life as an organism. Nevertheless, students were still difficult to show the complex multi-causal relationship that occurred between systems.

The use of argumentation activities involved the students in using the hierarchical model system had been constructed. This activity was intended to find the hidden dimension, i.e. adaptation at the organism level, structurally involves adaptation to a smaller but functional system of cells. Students worked back and forth from the models and issues to be solved. Based on the pervasiveness of complex systems and the use of multiple representations for reasoning, it showed that the use of self-constructed representations helped to explore the functional relationships between cells, organs, and organisms. By doing so, they could think temporally. It means that structural changes of the system were the result of past interaction and they were able to predict structural changes which will occur when there is a change of interaction.

4. Conclusion
MERs-based on worksheets were able to facilitate students to represent cell dynamics as a way of understanding the development of plant structures. The results of studies on complex systems reasoning abilities as implications of using MERs based on worksheets showed significant achievements. While the analysis of the worksheet artifacts showed that students were facilitated to conduct MERs-based reasoning, thus facilitating the complex system of reasoning in accordance with the worksheet design.

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