Spatial thinking in frame-based learning of plant anatomy and its relation to logical thinking

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ABSTRACT: A study on the framing of spatial thinking in a plant anatomy course was conducted to investigate spatial thinking in frame-based learning of plant anatomy and its relation to logical thinking. This research used a pre-experimental research design. A number of biology education students (n = 42) were involved as participants. Data were collected using instruments of observation, a spatial thinking test, and a Test of Logical Thinking (TOLT). The data were analyzed quantitatively. Research results show that the spatial thinking of students in the frame-based learning of plant anatomy involved: (i) generating a representation in 2D and 3D; (ii) maintaining the characteristics of tissue in working memory to construct 3D structures; (iii) scanning the 2D and 3D representations; and (iv) transforming the representations. These were factors that improved students' logical thinking on each indicator. The students' logical thinking before and after the frame-based learning instruction resulted in the following pretest and posttest scores: (1) proportional reasoning (42.9 and 64.3); (2) controlling variables (3.6 and 11.1); (3) probabilistic reasoning (9.5 and 15.5); (4) correlational reasoning (11.9 and 27.4); and (5) combinatorial reasoning (17.9 and 45.2). Analysis of the relationship between spatial thinking and logical thinking showed significant correlation. It is concluded that frame-based plant anatomy learning improves students' spatial thinking and logical thinking.

1 INTRODUCTION

Spatial ability is an important skill in various activities in daily life and some carriers depend heavily on spatial ability. Therefore, it is a fundamental ability in the 21st century (Diezmann & Lowrie, 2012). The importance of spatial thinking was also shown in the work of the National Research Council (2006), which stated that "learning to think spatially" is a key skill in various educational curriculums. The importance of spatial ability in science learning is related to one's ability to solve spatial problems, particularly mental rotation, which comprises the ability to manipulate and transform 3D objects in the brain (Brownlow et al., 2003). Visual representation, in the form of 3D objects, is a very important part of understanding the phenomena in biology and mechanics and in solving spatial problems (Bolotin & Nashon, 2012).

Logical thinking is a skill, which is determined in the period of abstract process in Piaget's cognitive development phase. Logical thinking is a mental operation used by individuals when they solve specific problems (Piaget, 1969). There are five different modes of formal logical thinking: proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning and combinatorial reasoning (Tobin & Capie, 1981). The students solve the problems by undertaking various mental practices or rules or by doing some abstraction and generalization. This activity is related to spatial thinking and logical thinking.

Spatial thinking is also very important in the plant anatomy course. The demands of the plant anatomy syllabus requires students to understand the structures and functions of the cells, tissues, or organs of plants, which are three-dimensional (3D) structures. Students need to recognize the characteristics of plant tissue (for example, the shape, size, positions, cell wall thickness, air cavity and another characteristics) and to relate it to its function. In order to understand the structure of plant anatomy, spatial thinking is much needed.

The results of the preliminary test in plant anatomy give the information that the plant anatomy course strongly requires spatial thinking ability in each student, because cell structure and plant tissue are 3D structures and are abstract, whereas the pictures contained in the student's handbook and the results of microscopic observation are two-dimensional (2D) structures. So to know the characteristics of plant tissues, students should be able to observe carefully and make representations in 2D and 3D. But in reality, the students' spatial thinking in plant anatomy was less than satisfying, especially for the parts related to thinking about three-dimensional structures, positions and knowing every part of the cellular structure of a tissue or an organ. In general, students find difficulties in constructing representations from 2D into 3D and transforming representations (for example, creating a new perspective) to understand the structure of plant anatomy as a whole.

Students' difficulties in understanding structure and function at a cellular level was also found in earlier studies (Lazarowitz & Naim, 2013). Spatial visualizations of 2D or 3D models might help to resolve the spatial difficulties encountered when learning anatomy (Hoyek et al. 2014). It is much needed to be able to understand spatial concepts in a better way (Hoffler 2010). The previous research on spatial concepts did not focus on the types of spatial thinking in framing based plant anatomy and its relation to logical thinking. The previous research instead focused on content and students' spatial ability (Hoffler 2010, Lazarowitz & Naim 2013), and the role of visualizations of 2D or 3D models to resolve spatial difficulties (Hoyek et al., 2014; Jones et al., 2011). Research on how to frame the cognitive processes in spatial thinking for the plant anatomy course and its relation to logical thinking is not yet available.

Based on the analysis of the previous studies, it is clear that studies on how to understand the cognitive processes of spatial thinking on a framing based plant anatomy course and its relation to logical thinking have never been done. This paper focuses on the discussion of the four cognitive processes in spatial thinking that seem to describe a student's spatial thinking in plant anatomy and the relation of the student's spatial thinking to their logical thinking ability.

2 LITERATURE REVIEW

In this section, we described two points from the research literature that were related to this research. The first point describes the concept of spatial thinking and the second point describes the framing concept.

Spatial thinking can be developed based on: (1) the concept of space; (2) the representation; and (3) the process of reasoning (National Research Council, 2006). Spatial thinking involves several cognitive processes, such as visualizing relations; imagining between one scale transformation and another scale; remembering locations of objects, their shapes, and moves; rotating the objects to see other sides; creating a new perspective; transforming object orientations, and others (National Research Council, 2006). Visualizations of 2D or 3D models might help to resolve the spatial difficulties encountered when learning anatomy (Hoyek et al., 2014). Moreover, involving students in constructing the 3D structure models of the cell will improve the students' understanding of the cellular structure and function (Lazarowitz & Naim, 2013).

Framing is a dynamic and ongoing process, where people continue to constantly frame and reframe how to understand "what is happening" in a small adjustment of the scheme (Berland & Hammer, 2012). Frame is an individual feeling about "what is it that's going on here?" (Goffman, 1974). Framing in the biology lesson and class and the social reality, particularly in the biology learning process, influences the ability of scientific argumentation of the students. (Berland & Hammer, 2012; Boerwinkel et al., 2014), resolves the cognition pressure (Autin & Croizet, 2012), recalls and transfers information stored in the memory (Engle et al., 2011) and builds the ability to explain (Boerwinkel et al., 2014).

3 RESEARCH METHODS

This research was pre-experimental research with one group of pretest-posttest designs. The instruction of the plant anatomy course was generally consistent with framing.

3.1 *Participants*

This research was conducted at the Biology Education Study Program at a state university in South Sumatra, Indonesia. This research involved 42 students (41 females and 1 male), who were enrolled in the third semester and taking the plant anatomy course.

3.2 *Instruments and procedures*

The instruments used in this research were a spatial thinking test and a Test of Logical Thinking (TOLT) instrument. The spatial thinking test was self-developed based on the spatial thinking cognitive process (Kosslyn, 1978). The spatial thinking test was specifically designed for the research and it was validated by experts through field testing. The test instrument employed four indicators, namely: (1) generate a representation; (2) manage and maintain the representation in working memory;

(3) scanning the maintained representation in working memory; (4) transform a representation with rotation or view the object from a different perspective (Kosslyn, 1978). Whereas, the logical thinking test instrument consisted of 10 test items, in the form of multiple choice questions with four options with reasons (Tobin & Capie, 1981).

The dynamic of framing was adopted and modified from framing terms in earlier studies (Engle et al., 2011; Autin & Croizet, 2012, Goffman, 1974). Framing was especially designed into: concepts questions, spatial-related concepts questions, directing sentences, and also examples of 2D and 3D plant anatomy pictures that had been constructed well (worked examples). Framing directed the students to think spatially about plant anatomy concepts.

The instruction at each stage of learning is consistent with framing that directs students to think spatially. Students work in a group to solve spatial problems and concepts of plant anatomy. After solving the problems related to the concepts of plant anatomy, the participants worked on the posttest.

3.3 *Data analysis*

A test was administered at the beginning and at the end of the frame-based plant anatomy learning. Quantitative data were obtained by calculating the average or percentage in each spatial thinking and logical thinking indicator. The criteria of the test scores were classified by the referencing and modifying of Bao et al. (2009), namely: ≤ 34 (very low); 35–50 (low); 51–65 (moderate); 66–80 (high); ≥ 81 (very high). The improvement in students' spatial thinking and logical thinking was measured with an average N-Gain (Meltzer, 2002). Statistical analysis was performed with SPSS version 22 for windows. The descriptive analyses were used to explain the students' cognitive processes in spatial thinking during the frame-based plant anatomy learning process.

4 RESULTS AND DISCUSSION

The results showed that there was an improvement in the students' spatial thinking activities. The spatial thinking activities were observed by focusing on the spatial activities that were expected to emerge at every step of the frame-based plant anatomy course. The analysis of the students' spatial thinking activities in learning with frame-based instruction involved several cognitive processes that supported the students' spatial thinking, such as recognizing the shape, size, positions, cell wall, cellular air space and other characteristics of plant tissue. Students identified and scanned the characteristics of each tissue from a microscopic slide and created a 2D representation to help them to keep the concepts in their working memory. Students scanned a 2D representation and maintained in their working memory the relative shape, size, positions, cell wall, cellular air space and other characteristics of plant tissues. They focused their attention on some parts to construct these into 3D. By scanning the picture from the examples, students can construct the 2D pictures into 3D or vice versa.

The visualization of the tissue structures in 2D and 3D representations gave students complex information about the shapes and locations of one of the tissues or one of the various tissues. In addition, the students created the representation with multiple anatomical views (for example, an analysis of a microscopic slide from a cross section, longitudinal section or radial section) from different perspectives. These cognitive processes support students' spatial thinking.

This result was supported by research findings that show an improvement in the spatial thinking and logical thinking of students after having experienced framing based learning with an average N-Gain of 53.7 and 17.3 respectively (Table 1). The posttest score was significantly different when compared to the pretest score, with $\alpha < 0.05$. The percentage of spatial thinking in each indicator can be seen in Table 2.

Based on Table 2, it can be seen that there was an improvement of spatial thinking in each indicator.

Table 1. The mean score pretest-posttest spatial thinking and logical thinking.

	Score			
	Spatial thinking		Logical thinking	
	Pretest	Posttest	Pretest	Posttest
Average	28.11	67.27	17.14	31.67
Normality	0.20	0.16	0.07	0.08
N-Gain	53.7		17.3	

Table 2. Percentage of spatial thinking in each indicator.

Spatial thinking	Pretest	Posttest	Criteria
Generating a representation	30.00	73.95	High
Maintaining a representation	22.21	69.79	High
Scanning representation	20.00	71.94	High
Transforming representation	15.00	64.46	Moderate

It gives the information that frame-based plant anatomy learning can facilitate students in spatial thinking. Framing resolves the students' difficulties in thinking spatially. This result was also supported by the previous result, which showed that framing can resolve cognitive pressure in solving task difficulties, so it enhances working memory capacity (Autin & Croizet, 2012). Besides, framing in a learning context can enhance the ability to recall what is stored in the memory and sharing the knowledge with the students (Engle et al., 2011).

The framing of spatial thinking in plant anatomy also improved logical thinking ability (Tables 1 and 3). The posttest score was significantly different when compared to the pretest score, with $\alpha < 0.05$. The percentage of logical reasoning can be seen in Table 3.

Based on the posttest scores shown in Table 3, it can be seen that the highest score of the logical reasoning was proportional reasoning, with 64,29 (moderate), and the lowest was controlling variable, with 11,09 (very low). Framing based plant anatomy learning had more trained proportional, combinatorial and correlation reasoning compared to other reasoning. This is due to framing using trained cognitive spatial processes to create spatial visualization (for example, 2D representation and constructing 3D representation). It is directly related to students' ability to combine and analyze the proportion of 2D representations. Students had analyzed a 2D representation to its component parts and then combined these parts to construct a new 3D representation. These are strongly related to logical reasoning (for example, proportional reasoning, correlation reasoning and combinatorial reasoning).

The analysis of the relationship between spatial thinking and logical reasoning showed r (42) = 0.69 ($p < 0.01$) (significant correlation). Students with high spatial thinking have high logical reasoning. Improvements in spatial thinking will improve logical reasoning. This result is also supported by previous studies, which showed that visualizing the structure of 2D into 3D requires spatial perception, which is related to logical reasoning of cognitive aspects in formal situations (Lazarowitz & Naim, 2013). Students with a concrete operational cognitive stage were not masters in formal operational skills (Shemesh & Lazarowitz, 1988), because they could not conceive concepts at an abstract level (for example, constructing a 2D microscopic structure into 3D) (Yenilmez et al., 2005).

Table 3. Percentage of logical reasoning.

Logical reasoning	Pretest	Posttest	Criteria
Proportional reasoning	42.86	64.29	Moderate
Controlling variable	3.57	11.09	Very low
Probability reasoning	9.52	15.48	Very low
Correlation reasoning	11.90	27.38	Very low
Combinatorial reasoning	17.86	45.24	Low

5. CONCLUSIONS

Based on the pretest-posttest scores and N-Gain, there was improvement in spatial thinking and logical thinking after having experienced framing based learning. This research also indicated that students have spatial thinking activities during the frame-based learning of plant anatomy: (i) creating a representation in 2D and 3D; (ii) maintaining a representation in working memory; (iii) scanning the representation; and (iv) transforming the representation. These were factors that improved students' logical thinking on each indicator. These results showed that framing based plant anatomy learning led to more trained proportional, combinatorial, and correlation reasoning compared with other reasoning. Analysis of the relationship between spatial thinking and logical thinking showed significant correlation.

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