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Exploring the pre-service basic science teachers' misconceptions using the six-tier diagnostic test

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ABSTRACT

This study explored the pre-service basic science teachers' misconceptions using a six-tier diagnostic (STD) test. This study used a cross-sectional survey research model with respondents, namely pre-service basic science teachers (PBSTs) who are first-year students. The six-tier diagnostic test consisted of three questions about change in matter (CIM), classification of matter (COM), and separation of mixtures (SOM). Each test package consists of six questions ranging from questions at the macroscopic level, microscopic communication, level of confidence, symbolic visualization to represent microscopic conditions, and self-confidence in representing concepts. The combination of answers and decisions in six-tier diagnostic includes scientific conception (SC), almost scientific conception (ASC), lack of confidence (LC), lack of knowledge (LK), misconception (MSC), have no conception (HNC). The study showed that the conceptual mastery condition is dominated by the misconceptions (MSC) category. The condition for pre-service basic science teachers' mastery concepts having the most scientific conception category is related to changes in matter (CIM), while the condition that shows the least scientific conception category is related to material classification (COM). The results can map the conditions of mastery of the pre-service basic science teachers' concept so that strategies can be designed to correct the emerging misconceptions.

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1. INTRODUCTION

The existence of misconceptions is still a problem that is often found in the field of science education. The term misconception leads to differences in thinking between the concepts that learners have and the concepts established by experts [1]. Constructivists agree that knowledge cannot simply be transferred from educators to learners. Learners must actively construct their knowledge from new information and experiences and the new knowledge they get. Learners use their knowledge as a basis for evaluating new information. If new information is consistent with existing knowledge, this new information will be assimilated, but if it is completely different (contradictory), knowledge accommodation will be made to suit the new information. Constructivists also pay attention to the context of the knowledge that is formed [2]. In the process of conveying new information into cognitive structures, learners often experience difficulties, even failures. This then becomes the emergence of a cognitive misconception of learners.

Various literature examines the possibility of what happens in the mastery of scientific concepts. Difficulties can occur so that students do not fully master the concept [3]. One of the important reasons for the difficulty of students in understanding science is closely related to the multiple-level representations used in describing and explaining scientific phenomena that they encounter in everyday life [4], [5]. Students' mastery of scientific concepts should be demonstrated by the ability to transfer and connect between the three levels of representation consisting of macroscopic, submicroscopic, and symbolic levels [6], [7].

Macroscopic representations illustrate the essential nature of real and visible phenomena through everyday experiences. An example for learners is when observing changes in the properties of matter such as changes in color, foam, and gas formation and precipitation in chemical reactions. The submicroscopic (or molecular) representation explains the particulate level. This level is real and consists of particulate levels which are used to describe the movements of electrons, molecules, particles, and atoms. Matter is described as an arrangement of atoms, molecules, or ions.

Symbolic (or iconic) representation involves the use of chemical symbols, formulas, and equations, molecular structural drawings, diagrams, pictorial representations (pictures), algebra, as well as computational forms of submicroscopic representations [4], [8]–[10]. Representation is an important tool for building and communicating knowledge. The ability to solve problems in science as one of the higher-order thinking skills uses multiple representational abilities. Submicroscopic representation is a key factor in this ability. The inability to represent submicroscopic aspects can hinder the ability to solve problems related to macroscopic phenomena and symbolic representations [4], [11].

Various research findings have expressed difficulties with concepts related to the concept of solution [4], [12]–[16]. The concept of this solution is a part of the process of understanding the concept of material form, its classification, change, and separation. These concepts are very closely related to everyday life and are studied formally in school from the elementary level. Several previous studies have shown students' misconceptions on the subject of material classification including misconceptions about mixtures and compounds [17], water molecules contain constituent components other than hydrogen and oxygen [7], misconceptions about solids, liquids, and gas [18], students misunderstand the concept of homogeneous mixtures and heterogeneous mixtures [19], students' misunderstandings in distinguishing elements, compounds, mixtures and distinguishing material properties [20].

Many conceptions and misconceptions are formed when learners interact with nature. This is supported by constructivism theory where knowledge is constructed or constructed by the learners themselves from their interactions with objects, events, and the environment. When learners interact with their learning environment, it means that learners construct knowledge based on their experiences. When the knowledge construction process occurs in learners, errors will likely occur in the construction process because naturally, learners may not be accustomed to constructing their own knowledge appropriately, especially if they are not accompanied by clear and accurate sources of information [21]. To determine the level of mastery of students' concepts and representations, teachers can use diagnostic tests, one of the tests is the multi-tier test [22]–[25].

The multi-tier test was first developed from the conventional multiple-choice test model, with choices predetermined by the question maker. Further development is carried out in the form of adding answer choices that can be filled in by the test takers themselves to accommodate if there is disagreement between the test taker's answers with the existing choices. Multi-tier tests are excellent for diagnosing students' conceptions of the concepts they are learning [22], [23]. This type of test not only asks for the conception but also the reasons for the answer so that educators and researchers can find out the level of confidence of the learners [26]. Several research studies have done a combination of a multiple-choice test and multi-tier test with two, three, four, and five levels to get the best test to find out students' misconceptions [1], [23], [24], [27], [28].

In Indonesia, the use of misconception identification tests has been familiar in research relating to prospective teachers, teachers, and students at the elementary and secondary levels. The form of the test used also varies with the level of confidence in the answers. The scientific concepts identified are also varied, such as those related to Newton's laws, spring oscillations, heat, and propagation, as well as changes of states [25], [29]–[31]. The problem of misconceptions needs to be studied further to break the chain of errors in terms of transferring knowledge of science concepts, especially at the elementary school level.

This research is a modification of the type of multi-tier test questions. This study uses a six-tier diagnostic which is a development and modification of the previous five-tier diagnostics [28]. This development is added to the sixth level, namely the confidence from the fifth level which shows the level of confidence of the respondent in the symbolic depiction given of microscopic phenomena. This research instrument is called a six-tier diagnostic (STD) test because it uses the multiple-tier choice (five-tier) and adds one more tier in the form of confidence in representing images. This instrument can diagnose the learner's conception in more detail and can also be used by educators to diagnose formative and summative assessments.

This research becomes the starting point for developing appropriate science concept learning by emphasizing the relationship between the three aspects of science representation. This research is interesting because the investigation aims to describe the condition of pre-service basic science teachers (PBSTs), where the future of young learners (elementary school students) is determined by how the current mastery of the PBSTs' concept. PBSTs have a variety of educational backgrounds, not only science, but may come from major social, religious, vocational, and others. The description of the misconceptions that occurred can be used to determine the appropriate learning strategy for PBSTs so that the misconceptions can be corrected and not carried out by PBSTs when they become teachers in the future. Thus, this condition seeks to be the starting point for efforts to break the chain of misconceptions in the future.

2. RESEARCH METHOD

This study used a cross-sectional survey research model with respondents, namely pre-service basic science teachers (PBSTs) who are first-year students. The cross-sectional survey collects data from a sample of the target population at a specific point in time and provides reflective feedback for various variables at a specific time [32]. The sampling used was purposive sampling with survey criteria, namely the similarity of groups in the major and the same level, the elementary school teacher candidate program [32]. The number of participants who participated in this study was 155 PBSTs, consisting of 17 males and 138 females (science major=63; non-science major=92). Participants are student volunteers who are willing to fill out forms and take diagnostic tests. The survey was carried out with an ethical review by the research and community service center, as well as the Tarbiyah Faculty, Institut Agama Islam Negeri (IAIN) Kudus, Indonesia. The distribution of the characteristics of PBSTs by educational background is shown in Table 1.

Table 1. Characteristics of PSBTs' educational background

No	Educational background	Major	Total
1	Vocational school	Social science	9
2	Vocational school	Natural science	8
3	Islamic high school	Religious science	10
4	Islamic high school	Linguistics	3
5	Islamic high school	Social science	57
6	Islamic high school	Natural science	39
7	High school	Linguistics	1
8	High school	Social science	10
9	High school	Natural science	18

Data collection for PBSTs misconceptions used a STD test. The STD pattern is the development and modification of the five-tier diagnostic concept previously worked on [28]. This development is added by adding a sixth level, namely the confidence of the image or the fifth tier. The test instruments in this study consisted of three questions about change in matter (CIM), classification of matter (COM), and separation of mixtures (SOM). CIM identifies how the mastery of the concept of particles occurs in the phenomenon of changing the state of matter, namely the freezing process. COM identifies the mastery of concepts related to elements, compounds, and mixtures. SOM covers how PBSTs understand the particulate concept that occurs in the filtration process. Each test package consists of six questions ranging from questions at the macroscopic level, microscopic communication, level of confidence, symbolic visualization to represent microscopic conditions, and self-confidence in representing concepts.

The PBSTs' responses were analyzed step by step at each level. The first level (1st tier) is the main question. The respondent's answer was corrected for whether it was true or not. At the second level (2nd tier), the response given makes corrections to the respondent's answer whether the respondent is sure or not with the answer. At the third level (3rd tier) make corrections to the respondent's answer whether it is correct or wrong in the microscopic concept. This tier is a question about the sub-micro phenomenon which leads to the reasoning of the answers in tier 1. The 4th tier contains confirmation of confidence in whether PBSTs believe or not in the answer regarding the reasons given. The 5th tier contains questions about symbolic representations with images that are still related to the 1st and 3rd tier. At the 6th tier, there is a re-confirmation of self-confidence about the image. An example of a package of questions on the STD test is shown in Table 2.

Table 2. An example of a question pack in a six-tier diagnostic test (change in matter)

Tier	Representation	Test
1st tier	Understanding macroscopic phenomena	 Today's weather is very hot. Riza wants to drink cold drinks so that his body will feel fresher. He put the water in the bottled water in the freezer to cool it down. After a while he took bottled water and it turned out that there was a change in the shape of the water as shown on the side.
		What form changes occur in the water? a. Freezing b. Condensation c. Sublimation d. (If you have your own answers, please write them down) …
2nd tier	Self-confidence in understanding	Are you sure of your answer? a. Sure b. Not sure
3rd tier	Communicating understanding macroscopically	Why did this change happen? a. Because temperatures are below the freezing point of substance, the particle arrangement is tight and has small bonds of attraction between molecules b. Because temperature is above the freezing point of substance, it makes the particle arrangement very tight and has large bonds of attraction between molecules c. Because temperatures are below the freezing point of substance, the particle arrangement is tight and has large bonds of attraction between molecules d. (If you have your own answers, please write them down) …
4th tier	Self-confidence in understanding	Are you sure of your answer? a. Sure b. Not sure
5th tier	Communicating microscopic conditions by depicting symbols	Draw the arrangement of water particles in the picture! Use symbols to indicate the condition and arrangement of the particles in the container. ○ = particle   Before putting bottled water into the refrigerator / After putting bottled water into the refrigerator
6th tier	Self-confidence in understanding	Are you sure of your answer? a. Sure b. Not sure

The validation of the STD test instrument includes face validity which refers to the appearance of the instrument. Besides, content validity was carried out through focus group discussions (FGD) between researchers and experts in the field of evaluation using rubrics and grids containing STD test indicators. The reliability results show that the tests are sufficiently arranged to be implemented with Cronbach's alpha of 0.412 (N=50). Because in the instrument there is a drawing test with six categories. The categories were adapted from Dikmenli's and Kose's ideas [22], [33]. The categories are described in Table 3.

Table 3. The drawing category

Category	Explanation
Scientific drawing (SD)	Respondents provide a comprehensive picture following scientific concepts.
partial drawing (PD)	Respondents provided visuals that were close to scientific conceptions with minor deficiencies in visualization.
Misconception drawing (MD)	Respondents provide visualizations that are less precise or different from scientific conceptions but they draw visualizations at the sub-microscopic level.
Undefine drawing (UD)	The respondent provided a visualization that could not be understood even though the visualization provided was at the sub-microscopic level.
Non-microscopic drawing	Respondents provide visualization but not at the sub-microscopic level.
No drawing (ND)	Respondents did not describe at all or only wrote down their answers.

Like the STD test, it also has a formula for making decisions between the accuracy of the answers and the level of confidence in providing answers. The main combination of answers and self-confidence in the STD was developed from five-tier diagnostic research [28] which was used to make decisions on the conditions of concept mastery. This STD test provides the results of decisions on the variety of answers given

by students. There are two possibilities for converting a verbal explanation into a symbolic image: If the explanation matches the picture, it is called "connected" and if the explanation does not match the picture it is called "disconnected". The main decisions regarding the description of PBSTs answers are presented in Table 4.

Table 4. The decision based on description of PBSTs' answers

Decision	Explanation
Scientific conception (SC)	Respondents provide correct answers at the macroscopic and sub-microscopic levels and believe in their answers and the images following scientific conceptions.
Almost scientific conception (ASC)	Respondents provide correct answers at macroscopic and sub-microscopic levels, trusting in their answers. The picture does not fully conform to scientific conceptions or is unrelated to expectations.
Lack of confidence (LC)	Respondents provide correct answers at the macroscopic to sub-microscopic level and the images were following scientific conceptions, but they were not sure about the answers given.
Lack of knowledge (LK)	Respondents provide answers that are partially correct at the macroscopic or sub-microscopic level they may or may not convince of the answer. Some of the pictures conform to scientific conceptions.
Misconception (MSC)	Respondents provide right or wrong answers at the macroscopic level and the sub-microscopic level, they are confident in their answers. Their picture does not fit scientific conceptions.
Have no conception (HNC)	Respondents provide wrong answers at every level. Not having self-confidence with picture answers does not fulfill scientific conceptions.

3. RESULTS AND DISCUSSION

The test results indicate the condition of the conceptual mastery of pre-service basic science teachers diagnosed by six-tier diagnostic. The first and third-tier show how PBSTs communicate an understanding of the macroscopic and microscopic components, while the fifth tier reveals how PBSTs communicate their microscopic understanding through symbols represented by their depiction. PBSTs show confidence in each answer by answering the second, fourth, and sixth questions. The results of the mastery of representation are shown in Table 5.

Table 5. PBSTs' representation mastery in the six-tier diagnostic test

Topics	Tier	Correct answer				Wrong answer			
		Science major		Non-science major		Science major		Non-science major	
		N (63)	(%)	N (92)	(%)	N (63)	(%)	N (92)	(%)
CIM	1st tier	62	98.4%	90	97.8%	1	1.6%	2	2.2%
	3rd tier	30	47.6%	36	39.1%	33	52.4%	56	60.9%
COM	1st tier	45	71.4%	61	66.3%	18	28.6%	31	33.7%
	3rd tier	23	36.5%	42	45.7%	40	63.5%	50	54.3%
SOM	1st tier	61	96.8%	89	96.7%	2	3.2%	3	3.3%
	3rd tier	37	58.7%	71	77.2%	26	41.3%	21	22.8%
Average			68.3%		70.5%		31.7%		29.5%

Table 5 describes the conditions for right and wrong answers based on the educational background group of pre-service basic science teachers. The PBSTs group, both the science majors and the non-science majors, did not show consistency in the percentage of correct answers. The major science background group did not always get higher scores and vice versa. PBSTs with major science backgrounds did not always answer correctly and master science concepts. In each of the topics of CIM, COM, and SOM, the third-tier condition showed that the percentage of correct answers was always lower than the first tier. The first-tier condition shows the condition of understanding microscopic phenomena, the third tier shows how PBSTs communicate their microscopic understanding of macroscopic phenomena. Furthermore, the mastery of concepts is shown by how PBSTs communicate their macroscopic and microscopic understanding using the symbol. This condition is revealed from the PBSTs answer in 5th tier. Some examples of depiction provided by PBSTs are shown in Figure 1.

Pre-service basic science teachers (111) showed the image condition in the SD category because it has shown how water molecule modeling is commonly used scientifically. In contrast to PBST (63), which only showed how different modeling is on molecules consisting of hydrogen and oxygen elements, but still does not show any bonds that occur to form water compounds (H_2O). PBST (83) showed a misconception condition because the concept shown in the image is different from the scientific concept even though the image attempts to show particulate conditions as well. PBST (80) showed incomprehensible visualization even though experimental particle modeling was demonstrated. Another thing is also shown by PBST (43) which described the condition of the image at the macro level.

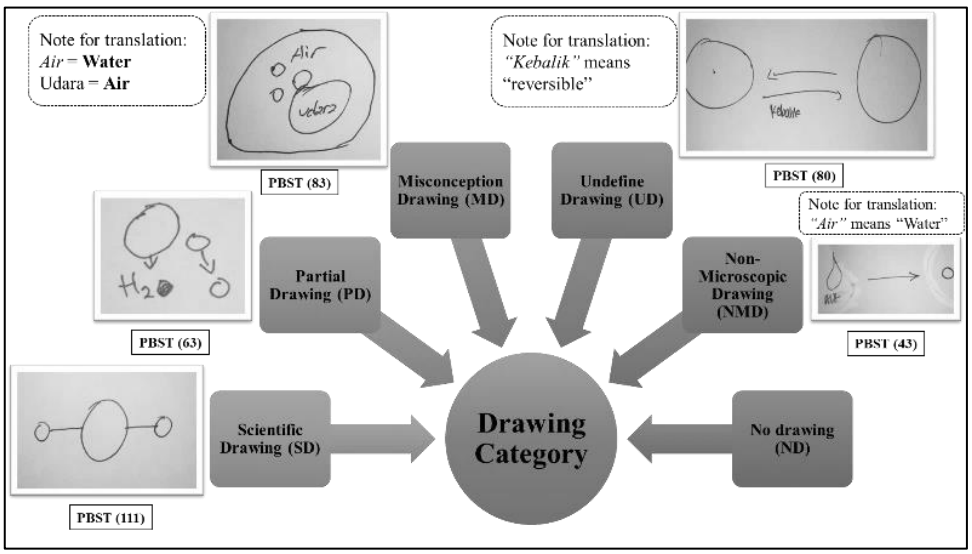

Figure 1. Some examples of PBSTs' drawing categories based on mastery of the concept

Based on the recapitulation of images obtained in the fifth tier, it can be seen the condition of PBSTs' understanding in representing microscopic-symbolic conditions as shown in Table 6. PBSTs are not used to using modeling abilities. This modeling ability is related to the representation of the macroscopic and submicroscopic levels of a substance [10].

Table 6 shows that the scientific drawing mastery in the CIM test package is very high. Continued the image answers for COM and SOM test packages, many of the PBSTs' drawings are included in the misconception drawing and undefined drawing categories. This happens because PBSTs are possible to use their analogy at the macroscopic level in answering questions about phenomena or images at the microscopic level. Meanwhile, to understand the chemical structure of water (COM), PBSTs must first understand the concept of compounds. In the concept of mixture separation (SOM), PBSTs also have difficulties in the arrangement of particles in a mixture. There can be an orderly arrangement of particle images in the filtrate, even though the conditions of the particles should be evenly distributed without high regularity when compared to the symbolic particles in solids. The details of PBSTs' condition when viewed from their educational background also do not show any differences in trends as presented in Figure 2.

In CIM, the PBSTs showed almost the same pattern, whereas, in COM, the MD pattern was more dominant in PBSTs with major non-science educational backgrounds. Whereas in SOM, both tend to have the same pattern. This is because the fifth tier used in COM requires PBSTs to represent the symbolic compound. PBSTs with a science major background are becoming more familiar than PBSTs with a non-science major. PBSTs have shown a pattern of drawing in the SD category, while the condition of misconceptions occurs in PBSTs, especially those with non-science educational backgrounds. The educational background of PBSTs affects how the condition of the microscopic-symbolic depiction visually of the macroscopic phenomena.

Table 6. PBSTs' microscopic-symbolic representation through drawing categories (5th tier)

No	Category	Science topics		
		CIM	COM	SOM
1	Scientific drawing (SD)	136	11	38
2	Partial drawing (PD)	4	16	19
3	Misconception drawing (MD)	9	53	66
4	Undefined drawing (UD)	2	73	15
5	Non-microscopic drawing (NMD)	4	2	17
6	No drawing (ND)	0	0	0

Change in Matter (CIM); Classification of Matter (COM); Separation of Mixtures (SOM)

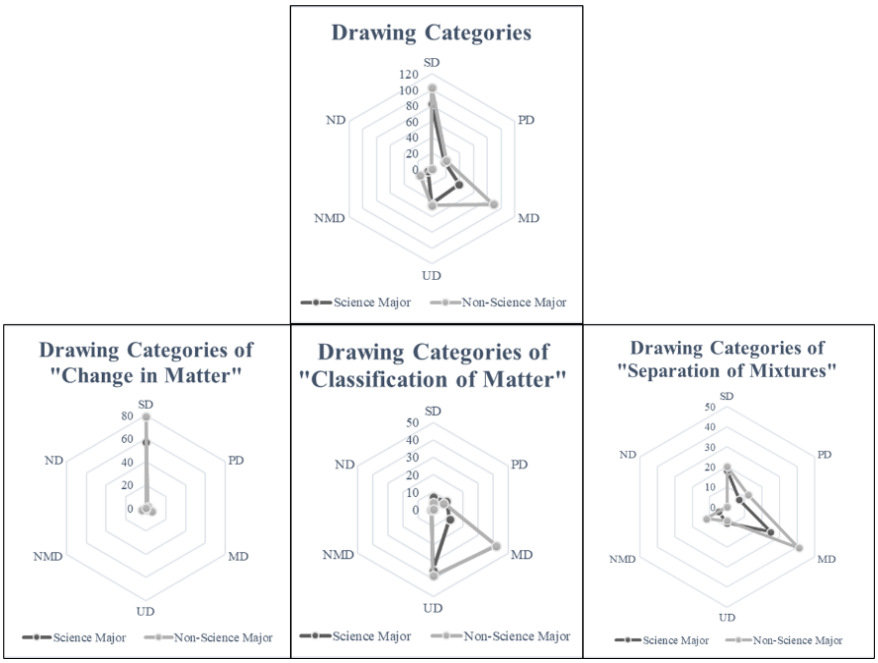

Figure 2. The trend of drawing categories based on major education background

Through drawing, learners begin to move to higher-order thinking while working at a conceptual level. In this way, the images provided can assess conceptual knowledge of science, observation skills, and reasoning abilities [34]. Learners demonstrate their ideas, as well as their level of understanding through the drawing process. Not only at the student level, the condition of the depiction that is not following scientific concepts also occurs at the teacher level [30]. This research shows evidence of the importance of focusing on the need for PBSTs to optimize visual understanding and communicate microscopic-symbolic phenomena through images. The transfer of knowledge to prospective students in the future does not get problems that lead to the re-emergence of misconceptions. In each tier (1st, 3rd, and 5th), PBSTs are asked to confirm their answer through the 2nd, 4th, and 6th tiers. This level of confidence indicates whether the PBSTs answer is included in the category of misconceptions. The misconceptions that occur show how the PBSTs really believe the responses given to the questions on the STD test, both true and false. Misconceptions are shown through the belief of the respondents in the answers given even though they are wrong and do not show scientific principles [1], [21], [28]. The confidence level conditions of PBSTs are shown in Table 7.

Table 7. PBSTs' self-confidence in the six-tier diagnostic test

Topics	Tier	Confidence				Unconfidence			
		Science major		Non-science major		Science major		Non-science major	
		N (63)	(%)	N (92)	(%)	N (63)	(%)	N (92)	(%)
CIM	2nd tier	63	100.0%	92	100.0%	0	0.0%	0	0.0%
	4th tier	59	93.7%	87	94.6%	4	6.3%	5	5.4%
	6th tier	60	95.2%	90	97.8%	3	4.8%	2	2.2%
COM	2nd tier	58	92.1%	90	97.8%	5	7.9%	2	2.2%
	4th tier	56	88.9%	82	89.1%	7	11.1%	10	10.9%
	6th tier	56	88.9%	82	89.1%	7	11.1%	10	10.9%
SOM	2nd tier	62	98.4%	92	100.0%	1	1.6%	0	0.0%
	4th tier	59	93.7%	89	96.7%	4	6.3%	3	3.3%
	6th tier	61	96.8%	91	98.9%	2	3.2%	1	1.1%
Average			94.2%		96.0%		5.8%		4.0%

Table 7 shows that both science and non-science majors of PBSTs have high confidence in each answer. At CIM, COM, and SOM, the most confidence is in first-tier answers. This shows that PBSTs have high confidence in understanding macroscopic representations, while at the microscopic and symbolic level, they still have uncertainty in representing. Other research also showing pre-service teachers' difficulties in representing the microscopic and symbolic levels of the concepts of solution [4], phase change, and

dissolution [20]. Skills in representing the symbolic level are closely related to representation and communication skills [35]. Based on the pattern of answers at each tier, the misconception profiles of PBSTs are categorized as presented in Table 8.

Table 8 shows that both the PBSTs science group and the non-science major, of them, had high misconceptions. Most misconceptions are in the COM topic related to the use of elements and compounds and the representations in microscopic-symbolic terms. The trend conditions are shown in Figure 3.

Table 8. PBSTs' misconception categories of the concepts based on their major educational background

The pattern of PBSTs' answers	Science major (N=63)			Non-science major (N=92)		
	CIM	COM	SOM	CIM	COM	SOM
SC	26	4	11	28	3	17
ASC	1	9	24	6	22	50
LC	2	0	0	0	0	2
LK	4	7	1	11	10	3
MSC	30	43	27	47	57	20
HNC	0	0	0	0	0	0

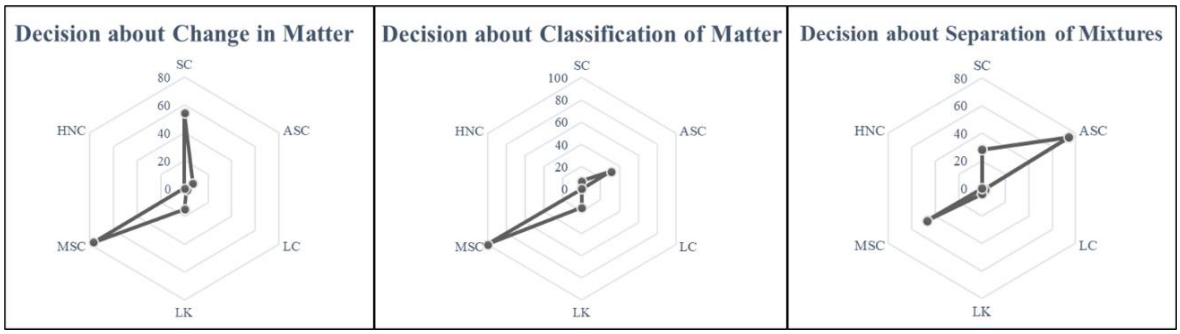

Figure 3. Trends in PBSTs' misconception category on each concept

In both CIM and COM, the category shows a predominant tendency in the misconception profile (MSC); however, on the CIM topic, the condition of the SC shows a better condition. Meanwhile, in SOM, the category pattern leads to ASC. In the SOM, it is related to understanding the microscopic conditions of the arrangement of particles in the mixture and their changes when the conditions are separated. Many of the known understandings found in CIM influence how PBSTs are interpreted on the SOM topic. The relationship between this topic and the misconceptions is also shown in previous research [36] that explored the misconceptions about the concepts of physical and chemical change, as well as homogeneous and heterogeneous mixtures. The condition of misconceptions at the symbolic level in CIM also shows a connection to the SOM topic [37]. The profile of PBSTs based on educational background also shows a predominant pattern of MSC as displayed in Figure 4.

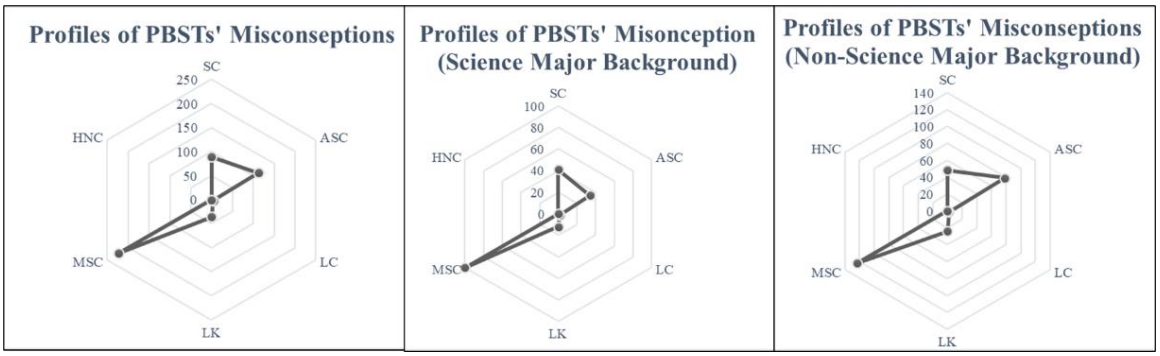

Figure 4. Misconception profiles of PBSTs on the topic of material concepts and their changes

Figure 4 shows that the condition of the misconception of PBSTs still dominates both those who have educational backgrounds in science and non-science majors. The PBSTs' understanding and self-confidence are incompatible with scientific truth. The distribution of the answers (N=3x155) shows the conditions of SC (19.1%; N=89), ASC (24.1%; N=112), LC (0.9%; N=4), LK (7.7%; N=36), MSC (48.2%; N=224), and HCN (0%; N=0). PBSTs need to be trained in re-representing the same concept through various forms, which include descriptive (verbal, graphic, table), experimental, mathematical, figurative (pictorial, analogy, and metaphorical), and/or optional-operational mode representation [38].

This study is still limited to exploration in the PBSTs group without further data mining through focus group discussions. Further exploration through personal or group interviews can be investigated so that solutions to overcome misconceptions can be formulated. It is necessary to make improvements in the learning process and teach the concept of matter and its changes to PBSTs so that there are no further misconceptions in PBSTs' prospective students in understanding this concept in the future.

4. CONCLUSION

The profile of pre-service basic science teachers' misconceptions shows the conceptual mastery condition dominated by the MSC category (misconceptions). Through the six-tier diagnostic tests that have been carried out, it is known how PBSTs understand the phenomena that occur macroscopically, trace the microscopic conditions that occur in the phenomenon, and symbolically describe the conditions that occur at the microscopic level. The condition for understanding PBSTs that most have the scientific conception category is related to changes in substance form (CIM), while those that show the least scientific conception category are related to material classification (COM). The results can map the conditions of mastery of the PBSTs' concept so that strategies can be designed to correct the emerging misconceptions. Thus, teaching strategies, as well as media development to overcome misconceptions in the PBSTs training program are needed by emphasizing the topic of change in the matter (CIM).

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