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# The Development of Two-Tier Diagnostic Test for Evaluating Primary Students' Understanding on Plant Life

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**Abstract**

Students hold some knowledges about physical world which may or may not match with scientific explanation before class. Then, they made a meaning of their new experience base on those existence ideas. In order to understand how students shape their understanding, 20 items of two-tier multiple choices diagnostic instrument was developed to address primary students' understanding of plant life. A mixed methods was conducted involving 642 Year 4 to 6 (total of 21 classes). The responses were analysed to examine the reliability, degree of difficult, and the index of discrimination of the test. The item analysis indicated that the test reach the requirement criterion with acceptable reliability, an average difficulty indices, and acceptable discrimination indices.

***Keywords:*** *Two-tier diagnostic test, Plant life, Alternative conceptions, Elementary science*

## 1. Introduction

During 1980 to 2014, different types of assessments are used in order to measure the levels of students' understandings and identify alternative conceptions (Gurel, Eryilmaz, & McDermott, 2015). For instance, concept map, interview, observation, open-ended questions, multiple-choices test, and multiple-tiers test. Two-tier diagnostic test is one of the most widely used for investigate students' understanding. As Treagust (1988), this test can be defined into two parts. The first tier is a content question refer to students' understanding related to the subject. The second one is the reason tier of the first response. Indeed, the justification was considered to be correct if students' responses in both tiers are corrected (Treagust, 2006). The first tier of the items is authentic and rational multiple choices question with usually two to four choices (Treagust, 2006). Likewise, the second tier of each item contains a set of usually four to five possible reasons particular the first tier answer (Wang, 2004). The format of the second dimension can be a multiple choice or a multiple choice with one optional open ended (Bayrak, 2013). Moreover, the reason tier consists of the correct scientific conception together with common students' conceptions and misconceptions which derive from the literature and the students' responses from the interviews (Treagust, 2006). Thus, two tier multiple choices test provides a sensitive and effective way of assessment and can be served as an effective diagnostic tool (Tamir, 1989).

Plant life seems to be a simple concept in the context of agricultural country like Thailand However, this general view is a complicated topic that involves plant transport, photosynthesis, seed germination and plant growth, and the responses of plant to environmental stimuli (The Institute for the Promotion of Teaching Science and Technology; IPST, 2013). It can be seen that this topic contains a lot of difficult scientific concepts like photosynthesis, water transport in plants, and plant growth and development. Because of the abstraction of these concepts related to molecular and cellular levels of representations (Lazarowitz, 2010). Consequently, when the concepts were applied to the class, they do not make sense to students. Dealing with this issue, the development of a two-tier test for evaluating primary students' understanding of plant

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life may lead to more effective instruction and learning. So, the purpose of the study was to develop a two-tier diagnostic instrument for evaluating Year 4 students' understanding of plant life.

## 2. Materials and Methods

This study is a mixed method with incorporation of qualitative and quantitative methods. The participant of the study was a convenience sample (Merriam, 2009) of 642 Year 4 to Year 6 (total of 21 classes) Thai primary students. There are three stages of the diagnostic instrument development based on Treagust (1995) procedure which was divided into three stages as shown in Figure 1.

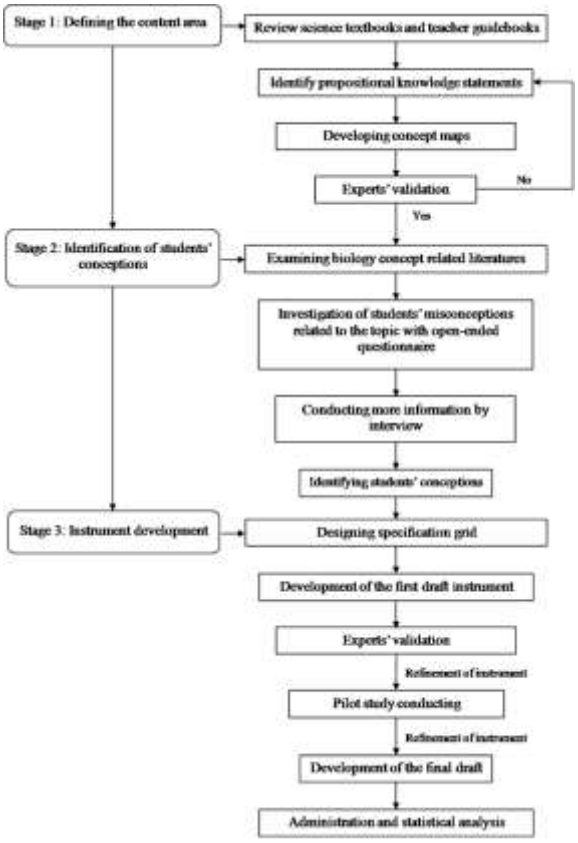


Fig. 1 The flowchart of instrument development.

Stage 1 related to defining the content area by identifying the propositional content knowledge statements of the topic and developing a concept map. Stage 2 involved the identification of students' conceptions from literature and students' responses. Stage 3 concerned about design and quality standard of the test.

### 2.1 Defining the content area

According to the examining of curriculum documents, the propositional knowledge statements were identified. In addition, the topic can be defined into four concepts boundaries the content area of plant life including transport in plants, photosynthesis, seed germination and plant growth, and the responses of plant to environmental stimuli. Indeed, four concept maps referred to the topic area were developed. Then the relationship between the propositional knowledge statements and the concept maps was checked. Finally, in order to ensure that the concept maps and propositional knowledge statements related to the topic area, content validity was addressed by two Year 4 expert science teachers, two science educators, and three biology lecturers.

### 2.2 Identification of students' conceptions

This stage emphasised on an identifying of students' conceptions. Firstly, the related literatures were examined to determine students' misunderstandings. Accordingly, not only alternative conception articles but also students' notebooks and logbooks were reviewed. Secondly, 67 students of Year 5 and 6 who had learned this topic were asked by four open-ended questions. The questionnaires concerned with plant transport, photosynthesis, seed germination and plant growth, and the responses of plant to environmental stimuli as shown in Figure 2. Finally, for more information and deeper perspective of students' understandings semi-structure interviews were conducted. Indeed, 22 students were asked to add up more information and to make the unclear answers to be more clarify. These students were selected because there were several ambiguities in their answers. The interviews were enduring 15 to 30 minutes and were recorded and transcribed verbatim. Then, students' conceptions were identified by structured protocols.

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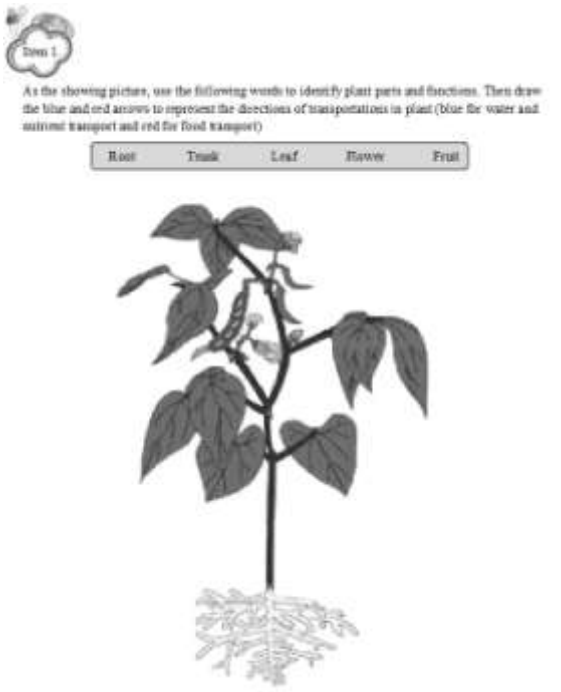


Fig. 2 The example of open-ended question related to the concept of transport in plant.

## 2.3 The development of two-tier multiple choice diagnostic instrument

This stage focused on design and standard quality of the two-tier diagnostic test. The defining of the content area from stage 1 and students' conceptions information from stage 2 were used to develop the first draft of the test. Moreover, based on specification grid, 20 two-tier multiple-choice items were created. Each item of the instrument consisted of two sections. The first part was designed to address students' knowledge about transport in plants, photosynthesis, seed germination and plant growth, and the responses of plant to environmental stimuli. The second tier, students were asked for the reasons of the first tier responses. This shows the propositional statements and the concept maps affected the first section while students' conception from questionnaire responses and interviews influenced both parts. Indeed, there are four choices for the first tier, while the second tier consisted of one expected scientifically acceptable reason, six nonscientific concepts, and one open-ended for free responses.

The items of the first version of the test were validated by three biology lecturers and two science educators. Next, the pilot study was conducted involving 93 Year 5 and 6 students who had experienced on the topic of plant life. After that, the instrument was refined by removing non selected choices and remained the wide range responses of the second tier of each item. Then, the final draft of the two-tier diagnostic instrument was developed. The final version of the test contained 20 items. Each item consisted of four choices of the first tier and four choices of the second tier including one expected scientific reason and three unaccepted conceptions as showed in Figure 3.

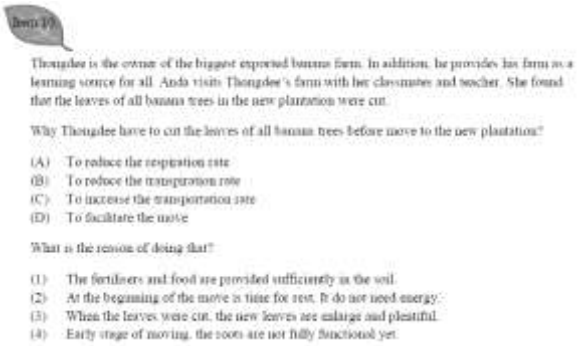


Fig. 3 The examples of the two-tier multiple-choice diagnostic instrument.

## 3. Results and Discussion

The final draft of two-tier multiple-choice diagnostic instrument was administered to 279 Year 4 students who experienced to the topic. The students were from nine Year 4 classes (total of 11 classes). The justification was considered to be correct when the response to each item both content and reason sections were correctly answered. On the contrary, there was no score for any item in case of either tier was incorrectly responded. Furthermore, the responses were analysed using SPSS software to examine the psychometric characteristics: reliability, difficulty indices, and discrimination indices.

As the administration for 279 cases, the reliability coefficient Cronbach alpha was 0.79. The reliability value is acceptable (Cronbach, 1951). With a consideration on the difficulty, the range of the difficulty indices of all items were from 0.46 to 0.69. According to Patel and Mahajan (2013) and Metha and Mokhasi (2014), the difficulty indices of the test were on average. This means the items of the test were not too easy and not too hard. It means the difficulty is acceptable. Meanwhile, the discrimination indices of the items of the test were from 0.47 to 0.61. As Ebel and Frisbie (1991), the value of the index of discrimination is 0.30 or above, it is considered to be desirable. It can be seen that the discrimination indices of the instrument was considered to be acceptable. The statistical analysis showed that all 20 items reach the requirement criterion for item analysis.

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Although the standard quality of the test is acceptable, students' alternative conceptions should not be ignored as well. There are a lot of misunderstandings around the concept of plant life related to all topics as showed in Table 1. The instrument consists of 20 items related to the topic of plant life. Item 3, 4, 8, 9, and 10 concerned with the concept of transportation in plant. Likewise, the concept of photosynthesis was demonstrated in item 1, 2, 5, 6, and 7. Furthermore, item 11, 12, 13, 14, 15, and 16 involved the concept of seed germination and plant growth, and the concept of responses of plant to environmental stimuli was available in item 17, 18, 19, and 20. The table shows the percentage of students' responses to the two-tier diagnostic test. Additionally, the number of students' response to the content tier and the reason tier with referred to students' understandings and alternative conceptions could be illustrated in the table as well.

Table 1: Percentage of students' responses to the two-tier multiple-choice diagnostic instrument (N=279).

| Percentage of responses | | | | | | |
|---|---|---|---|---|---|---|
| Item no. | 1st tier | 2nd tier | | | | Total |
| | | 1 | 2 | 3 | 4 | |
| 1 | A | 8.2 | 0.4 | 0.7 | 55.6* | 65 |
| | B | 4.3 | 7.9 | 3.9 | 2.2 | 18 |
| | C | 2.9 | 6.1 | 1.8 | 2.5 | 13 |
| | D | 0.7 | 1.8 | 0.4 | 0.7 | 4 |
| | Total | 16 | 16 | 7 | 61 | 100 |

Table 1: Percentage of students' responses to the two-tier multiple-choice diagnostic instrument (N=279) (Cont.).

| Percentage of responses | | | | | | |
|---|---|---|---|---|---|---|
| Item no. | 1st tier | 2nd tier | | | | Total |
| | | 1 | 2 | 3 | 4 | |
| 2 | A | 6.1 | 0.7 | 4.3 | 0.4 | 12 |
| | B | 0.7 | 54.1* | 0.7 | 0.4 | 56 |
| | C | 5.7 | 2.2 | 19.4 | 0.4 | 28 |
| | D | 0.7 | 0.4 | 0.4 | 3.6 | 5 |
| | Total | 13 | 57 | 25 | 5 | 100 |
| 3 | A | 13.6 | 4.3 | 1.1 | 1.1 | 20 |
| | B | 7.9 | 9.7 | 0.7 | 50.9* | 69 |
| | C | 6.1 | 1.1 | 0.4 | 0.4 | 8 |
| | D | 1.4 | 0.7 | 0.4 | 0.4 | 3 |
| | Total | 29 | 16 | 3 | 53 | 100 |
| 4 | A | 22.6 | 0.7 | 1.8 | 10.8 | 36 |
| | B | 7.5 | 47.0* | 0.7 | 3.9 | 59 |
| | C | 1.4 | 0.4 | 0.7 | 0.7 | 3 |
| | D | 0.4 | 0.4 | 0.7 | 0.4 | 2 |
| | Total | 32 | 49 | 4 | 16 | 100 |
| 5 | A | 5.4 | 0.7 | 62.7* | 0.4 | 69 |
| | B | 18.3 | 5 | 1.1 | 0.4 | 25 |
| | C | 1.8 | 1.8 | - | 0.4 | 4 |
| | D | 0.7 | 1.1 | 0.4 | - | 2 |
| | Total | 26 | 9 | 64 | 1 | 100 |
| 6 | A | 0.7 | 8.6 | 0.4 | 3.9 | 14 |
| | B | 1.4 | 7.2 | 12.9 | 1.1 | 23 |
| | C | 46.6* | 0.4 | 0.4 | 0.7 | 48 |
| | D | 1.8 | 1.1 | 1.8 | 11.1 | 16 |
| | Total | 51 | 17 | 16 | 17 | 100 |
| 7 | A | 3.6 | 0.4 | 1.4 | 4.3 | 10 |
| | B | 1.4 | 0.4 | 2.5 | 9 | 13 |
| | C | 0.7 | 0.7 | 1.1 | 22.6 | 25 |
| | D | 0.7 | 48.0* | 0.4 | 2.9 | 52 |
| | Total | 6 | 50 | 5 | 39 | 100 |
| 8 | A | 59.9* | 2.2 | 1.1 | 2.9 | 66 |
| | B | 0.7 | 9.0 | 9.0 | 7.2 | 26 |
| | C | - | 1.8 | 1.8 | 1.1 | 5 |
| | D | 0.7 | 1.1 | - | 1.8 | 4 |
| | Total | 61 | 14 | 12 | 13 | 100 |
| 9 | A | 22.6 | 0.7 | 0.4 | 0.4 | 24 |
| | B | 3.2 | 50.9* | 11.5 | 1.1 | 67 |
| | C | 1.1 | 0.7 | 2.5 | 0.4 | 5 |
| | D | 2.2 | 1.1 | 0.7 | 0.7 | 5 |
| | Total | 29 | 53 | 15 | 3 | 100 |
| 10 | A | 5.0 | 8.6 | 2.9 | 2.2 | 19 |
| | B | 2.9 | 2.2 | 6.8 | 50.9* | 63 |
| | C | 7.9 | 0.4 | 0.4 | 0.7 | 9 |
| | D | 2.5 | 1.4 | 4.3 | 1.1 | 9 |
| | Total | 18 | 13 | 14 | 55 | 100 |
| 11 | A | 4.7 | 66.7* | - | 0.7 | 72 |
| | B | 8.2 | 1.8 | 4.3 | 9.0 | 23 |
| | C | 0.7 | 1.1 | 0.7 | 1.1 | 4 |
| | D | 0.4 | - | 0.4 | 0.4 | 1 |
| | Total | 14 | 70 | 5 | 11 | 100 |
| 12 | A | 0.7 | 0.4 | 0.4 | 58.8* | 60 |
| | B | 9.3 | 0.7 | 0.4 | 0.7 | 11 |
| | C | 0.4 | 15.1 | 2.2 | 1.8 | 19 |
| | D | 1.1 | 0.7 | 6.1 | 1.4 | 9 |
| | Total | 11 | 17 | 9 | 63 | 100 |

Table 1: Percentage of students' responses to the two-tier multiple-choice diagnostic instrument (N=279) (Cont.).

| Percentage of responses | | | | | | |
|---|---|---|---|---|---|---|
| Item no. | 1st tier | 2nd tier | | | | Total |
| | | 1 | 2 | 3 | 4 | |
| 13 | A | 5.0 | 0.7 | 0.4 | 0.4 | 6 |
| | B | 1.4 | 3.9 | 0.7 | 3.9 | 10 |
| | C | 1.1 | 1.1 | 61.6* | 2.9 | 67 |
| | D | 0.4 | 5.7 | 1.8 | 9.0 | 17 |
| | Total | 8 | 11 | 65 | 16 | 100 |
| 14 | A | 2.5 | 1.1 | 0.7 | 0.4 | 5 |
| | B | 13.6 | 4.7 | 6.8 | 1.4 | 27 |
| | C | 4.7 | 0.7 | 0.7 | 2.2 | 8 |
| | D | 2.9 | 0.4 | 49.1* | 8.2 | 61 |
| | Total | 24 | 7 | 57 | 12 | 100 |
| 15 | A | 1.1 | 8.2 | 0.7 | 0.4 | 10 |
| | B | 2.5 | 0.7 | 7.9 | 5.7 | 17 |
| | C | 4.7 | 0.7 | 1.4 | 1.8 | 9 |
| | D | 1.8 | 5.0 | 5.4 | 52.0* | 64 |
| | Total | 10 | 15 | 15 | 60 | 100 |
| 16 | A | 0.4 | 2.2 | 16.5 | 0.4 | 19 |
| | B | 0.7 | 0.4 | 2.5 | 3.2 | 7 |
| | C | 0.4 | 59.5* | 4.3 | 2.2 | 66 |
| | D | 4.7 | 0.4 | 0.7 | 1.8 | 8 |
| | Total | 6 | 62 | 24 | 8 | 100 |
| 17 | A | 0.4 | 0.7 | 7.2 | 4.3 | 13 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | B | 0.7 | 0.4 | 5.7 | 5.7 | 13 |
| | C | 0.7 | 55.6* | 0.7 | 0.7 | 58 |
| | D | 10.4 | 3.6 | 1.8 | 1.4 | 17 |
| | Total | 12 | 60 | 15 | 12 | 100 |
| 18 | A | 49.5* | 3.6 | 3.2 | 1.8 | 58 |
| | B | 0.4 | 17.6 | 0.4 | 0.7 | 19 |
| | C | 1.1 | 2.9 | 2.5 | 6.1 | 13 |
| | D | 0.4 | 0.7 | 5.4 | 3.9 | 10 |
| | Total | 51 | 25 | 11 | 13 | 100 |
| 19 | A | 0.4 | 0.7 | 1.4 | 6.5 | 9 |
| | B | 1.8 | 7.9 | 0.4 | 4.7 | 15 |
| | C | 7.5 | 2.2 | 0.4 | 55.6* | 66 |
| | D | 0.7 | 1.4 | 7.2 | 1.4 | 11 |
| | Total | 10 | 12 | 9 | 68 | 100 |
| 20 | A | 0.7 | 63.4* | 3.9 | 0.4 | 68 |
| | B | 5.7 | 2.2 | 7.2 | 3.2 | 18 |
| | C | 0.7 | 0.7 | 1.4 | 1.1 | 4 |
| | D | 3.6 | 0.4 | 0.7 | 4.7 | 9 |
| | Total | 11 | 67 | 13 | 9 | 100 |

*Note:* * *refers to the corrected answer.*
\- *refers to no response to this categories.*

The percentage of students' responses in Table 1 illustrated students' alternative conceptions available in both content and reason sections. Item 10, for example, investigates the concept of transport in plant. The result revealed that the majority of students with 50.9% selected the corrected category. However, for the first tier, 19% of students selected that 'In order to reduce the respiration rate, the leaves of banana were cut before move to the new plantation'. It showed that students hold misunderstanding on the concept of function of leaf and confusion between respiration and transpiration. Furthermore, focusing on the reason part, it found that 18% of students provided the reason for 'cutting the leaves of banana before move to the new plantation' as 'The fertilisers and food are provided sufficiently in the soil'. This statement indicated that students' alternative conceptions related to the topic of nutrition of plant and function of leaf. It can be seen that many alternative conceptions do not change as a result of instruction.

## 4. Conclusions

This study attempted to develop a two-tier multiple choices diagnostic test to assess students' understanding on the topic of plant life including transport in plants, photosynthesis, seed germination and plant growth, and plant responses to their environment of Year 4. The development process related to the analysis of resources, designing and refinement of the test, data collection, and measurement of standard quality of the test. The participants of the study were 642 of primary students who are from twenty-one classes of Year 4 to Year 6. While Year 5 and 6 students participated on the stage of the construction of the test, Year 4 students involved with the administration of test. The final version of the two-tier multiple choices diagnostic instrument contained 20 items. Each item consisted of four choices of the first tier and four choices of the second tier including one scientific conception and three unacceptable reasons. The validation of the test was evaluated by three biology lecturers and two science educators. The statistical result implied that the two-tier multiple-choice diagnostic instrument reaches the requirement criterion for item analysis and it is acceptable.

The finding illustrates that students hold varies misconceptions in all topics of plant life especially, photosynthesis and transportation in plant. These alternative conceptions were arisen by the difficulty and complexity of the concepts, language, existing conceptual understandings, daily-life experiences, and missing interpretation of representations. This confirms that student come to school with plenty knowledge about physical world based on their daily experiences. Therefore, there are several implications of this study on both pedagogical practice and research. Firstly, this two-tier diagnostic instrument could be used at the beginning, during, or after class. By using this instrument before class, students' understanding and any prior knowledge refer to the particular topic being studied were identified. Teacher could use this information for planning and designing lessons or develops suitable teaching approaches to reduce the existing misunderstandings. Vice versa, the use of this diagnostic instrument in class as a formative assessment tool will also enable teachers to justify students' understanding. So teacher can move alternative concepts immediately in class (Pine, Messer, & St. John, 2001). Moreover, if the instrument be introduced after class, the effectiveness of teaching and learning can be measured.

Secondly, as a reason of students' alternative conceptions cannot be ignored, teacher needs to emphasis more on students' misunderstanding. Despite, using this two-tier diagnostic test only as summative assessment is not meaningful as it should. Because of there is no opportunity to integrate students' understanding of the phenomena into the teaching process. Moreover, dealing with alternative conceptions, teacher should aware that teacher can hold non-scientific ideas as well. For example, all science teachers of the classes on this study agree that "plant absorbs water from the soil by root and from the air via stoma" is a clearly misconception. The focus on this statement of teachers is only a traditional function of root and leaf, however, the key words of the statement is 'stoma'. In fact, water

uptake via roots to the leaves is a traditional; recently, numerous evidences indicate that many plants take up water reversely from leaf and/or bark surfaces (Burgess & Dawson, 2004). Thus, the findings of this study could accommodate teachers to plan and implement the plant life conception measurement in order to reduce the students' misunderstandings.

Thirdly, the complexity of the concept can cause of students' alternative conceptions, so, teaching instruction should release this barrier. However, a scientific concept may not be learned if alternative conception already exists in students' mind (Committee on Undergraduate Science Education, 1997). So, moving students beyond this dilemma, students have to confront their beliefs together with related paradoxes and limitations after that reconstruct the understanding to form scientific conceptions. In this case, there are many non-experienced peripheral concepts related to concept of photosynthesis and transport. Consequently, teacher should guide prerequisite concepts for students as the bridging between students' exiting ideas and the understanding of the concept being learning (Tsui & Treagust, 2013).

Finally, the causes of alternative conceptions are very interesting. Teacher needs more information on these to make explicit understanding for students. Paying attention on the causes of alternative conceptions are very interesting for the further research on students' conception, pedagogical practice, teaching and learning science, evaluation and assessment, or socio-cultural. For example, representations seem to be the instruction supported tools; in contrast, it can cause of alternative understanding as well. That could be the further research as a result of this study.

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