The development of five-tier diagnostic test to identify misconceptions and causes of students’ misconceptions in waves and optics materials

A S U Putra1*, I Hamidah2, and Nahadi3

1Departemen Pendidikan IPA, Sekolah Pascasarjana, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung, 40154, Indonesia
2Departemen Pendidikan Teknik Mesin, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung, 40154, Indonesia
3Departemen Pendidikan Kimia, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi No. 229, Bandung, 40154, Indonesia

*Corresponding author’s email: andrysutama@upi.edu

Abstract. This study aims to develop a five-tier diagnostic test that can that be used to identify misconceptions and causes of students’ misconception on waves and optics materials. This type of research is development research using a 4-D model. The study was conducted in two junior high schools which in West Bandung, West Java with a sample of 193 students. Data analysis used is quantitative analysis by looking at the quality of the items. The results of the study showed that the content validity test obtained a CVI value of 0.833 which was included in the criteria as very appropriate. The empirical validity test obtained the value of MNSQ 0.98 outfit and ZSTD 0.3 outfit which means that the item corresponds to the measured construct. Item reliability 0.86 and Alpha cronbach 0.87 show good reliability. The differentiating problem showed it was not necessary to remove the question. While Point Measure Correlation shows that the level of difficulty of the questions varies greatly. Overall, it can be concluded that the five-tier diagnostic test developed has met the criteria and was declared feasible for identifying misconceptions and causes of students’ misconceptions in waves and optics materials.

1. Introduction
Science is essentially a collection of knowledge, ways of thinking, ways of investigating, and interaction between technology and society [1]. Science learning characteristic is an active learning, where learning activities involve almost all sensory tools, the whole process of thinking, and many kinds of muscle movements using different methods [2–4]. Effectiveness and efficiency of learning science is strongly influenced by students' comprehensive understanding of science concepts. When students understand science, most of them have an initial understanding that is incompatible with the ideas that are accepted and understood scientifically. Contradictory understanding is known as misconception [5–10].

Misconceptions have the potential to occur in science learning because some concepts are abstract and require relatively high intellectuality so that students have difficulty understanding [11–13]. Some scientific concepts that often experience misconceptions are waves [14–17] and optics [18–22]. Waves and optics are very useful knowledge for students to understand the surrounding phenomena
In addition, understanding related to waves and optics is also important to be mastered by students because it has an impact on the success of the revolution 4.0. It was explained that the understanding of waves and optics had an impact on the advancement of device, broadband, fiber-optic, and the use of wave transmissions which had the benefit of internet distribution to the entire world [25,26].

Identification of students’ misconceptions must be carried out appropriately as early as possible because misconceptions cause learning to be meaningless, ongoing misconceptions, and can hinder the development of science and technology [27-32]. Identification of misconceptions can be done using a diagnostic test. Diagnostic tests are tests used for determining the strengths and weaknesses of students when they learn something [33-36]. The results of diagnostic tests can be used as a basis of follow-up to determine the appropriate treatment in learning [37-40].

There are several diagnostic tests used to identify the emergency of misconceptions in learning including interviews [41,42], open-ended questions or questionnaires [43,44], two-tier multiple choices [45-48], multiple three-tier choices [49,50], four-tier multiple choices [51-55] and five-tier multiple choice [56]. Interviews are difficult to apply to a large number of samples and require more time to generalize alternative concepts of students [41,42]. Open questions or questionnaires take longer to analyze results and assessments [43,44]. While the two-tier multiple-choice test, three-tier multiple choice, and four-tier multiple choice are often preferred because they are easy to apply but cannot explore students' responses in depth regarding the causes of misconceptions that occur with students [57,58].

Regarding the weaknesses of these instruments, five-tier diagnostic tests were developed. The presence of a five-tier diagnostic test was able to hide the weaknesses of other diagnostic tests by adding a questionnaire to identify the source of the cause of misconception at the fifth level [56]. Overall, the five-tier diagnostic test is the best instrument in providing a clear picture of concepts that experience misconceptions and sources of causes of misconceptions that occur in students.

Based on the background, the main objective of this study is to develop a five-tier diagnostic test that meets the test requirements for validity, reliability, differentiation, and level of difficulty of the questions so that it can be used as an instrument to identify misconceptions and causes of student misconception in waves and optics materials.

2. Method

This type of research is development research oriented to product development. The development model used is a modification of the 4-D development model by [59]. The 4-D development model consists of four main stages, namely the defining stage, the design stage, the development stage, and the deployment stage. However, this research is limited to the development stage. The deployment phase is not implemented because the main objective of the research is product development in the form of five-tier diagnostic test.

This research was conducted in two junior high schools in West Bandung, West Java. The research subjects were in class VIII 2018/2019 academic year. The subjects of the study were divided into two, namely for the purpose of identifying alternative concepts and test subjects for the instrument. The research subject for the purposes of identifying alternative concepts were 30 students. While the subject of research for the purposes of testing the instrument was 193 students.

The research instruments used were expert validation sheets, student misconception identification sheets, and five-tier diagnostic test instruments. The expert validation sheet aims to determine the validity criteria for diagnostic tests developed based on the assessment of 8 experts. Identification sheets of alternative concepts for students were used to collect alternative answers to students regarding waves and optics materials. While the five-tier diagnostic test instrument is used for testing needs (empirical validity).

Analysis of the data used is quantitative analysis by looking at the quality of the items which include tests of validity, reliability, differentiation, and level of difficulty. The validity test is divided into 2, namely the validity test based on the content and the empirical validity test. The validity test...
based on the content was obtained through the assessment of 8 experts, then looked at the Content Validity Ratio (CVR) \[60\] and the Content Validity Index (CVI) \[61\]. The minimum CVR value criteria for the number of experts of 8 people is greater or equal to 0.582 (CVR \( \geq 0.582 \)).

Test of empirical validity, reliability, differentiation, and level of difficulty of the questions were analysed using the Rasch model. The advantage of the Rasch model compared to other methods is the ability to predict the lost data, which is based on a systematic response pattern \[62\]. The empirical validity test is done with the help of the Winsteps program. The thing which showed is based on the criteria of Mean Square Outfit (MNSQ) value of \(0.5 < \text{MNSQ} < 1.5\) (getting closer to 1.00, the item quality is getting better) and the Z-Standard Outfit (ZSTD) value of \(-2.0 < \text{ZSTD} <+2.0\) (getting closer to the value of 0.0, the item quality is getting better) \[63\]. Instrument reliability was analysed by comparing the value of person reliability, item reliability, and Cronbach's alpha value obtained by the reliability coefficient criteria \[64\] as follows:

**Table 1. Reliability Coefficient Criteria.**

| Range         | Criteria          |
|---------------|-------------------|
| \(0.94 \leq r < 1.00\) | Special reliability |
| \(0.91 \leq r < 0.94\) | Very good reliability |
| \(0.80 \leq r < 0.91\) | Good reliability   |
| \(0.67 \leq r < 0.80\) | Sufficient reliability |
| \(0.00 \leq r < 0.67\) | Weak reliability   |

The differentiating problem is seen based on the criterion of the value of Point Measure Correlation (Pt Mean Corr), which is \(0.2 < \text{Pt Mean Corr} < 0.85\) \[65\]. While the criteria of the difficulty level of question are based on the measure value \[62\], as follows:

**Table 2. Criteria of The Difficulty Level of Questions.**

| Measure value | Criteria          |
|---------------|-------------------|
| \(P > 1.0\)   | Very difficult    |
| \(0.0 < P \leq 1.0\) | Difficult     |
| \(-1.0 \leq P \leq 0.0\) | Easy          |
| \(P < -1.0\) | Very easy         |

3. Result and Discussion
The following is an explanation of the procedure for developing a diagnostic test performed:

3.1. Defining Stage
At this stage a preliminary analysis is carried out, specifications of learning objectives, literature studies on misconceptions, and misconception analysis. The preliminary analysis aims to establish goals and forms of diagnostic tests. The purpose of developing diagnostic tests is to identify misconceptions and sources of causes of misconception in students. The form of the test developed was a five-level multiple choice consisting of answer choices at the first level, level of confidence in the answer at the second level, choice of reasons at the third level, confidence level for reasons at the fourth level, and questionnaires for the fifth level.

The specification of learning objectives is carried out by determining the scope of the test through analysis of the syllabus (Basic Competency) of junior high school and concept analysis. Based on the results, the analysis obtained the basic competencies used in the development of five-tier diagnostic tests namely KD 3.11 and 3.12 related to waves and optics materials. While concept analysis is carried out to identify, detail, and systematically compile concepts that form the basis for determining learning indicators which are then developed into grids and items.

**Table 3. Label Concepts and Learning Indicators.**

| Label | Indicators |
|-------|------------|

The following is an explanation of the procedure for developing a diagnostic test performed:
concepts

Wave
- Determine the physical magnitude of the transverse waves
- Determine the physical magnitude of the longitudinal waves
- Analyze the nature of mechanical waves
- Analyze the relationship between wavelength, frequency, propagation, and wave period
- Analyze sound characteristics
- Analyzing sound propagation medium
- Explain the resonance process
- Explain the application of ultrasonic frequency

Optics
- Explain the nature of the beam of light
- Analyze the light refraction process
- Analyze the light reflection process
- Determine the formation of shadows on the lens
- Determine the formation of shadows on the mirror
- Analyzing the process of forming shadows in people with eye defects
- Determine the formation of shadows on optical devices
- Explain the role of light in the process of seeing

The literature study on misconceptions aims to determine misconceptions related to waves and optics materials and the sources of causes for misconceptions experienced by students. The results of the literature study obtained the sources of causes for misconception on students including the explanation of teachers, reading from books or the internet, personal experiences or thoughts of their own and explanation of friends [66-68]. These results are then used as the fifth level in the diagnostic test developed. Whereas the misconceptions that are often experienced by students regarding waves and optics materials presented in the Table 4.

Table 4. Misconceptions of Learners in Wave and Optics Material.

| Material | Student Misconception |
|----------|-----------------------|
| Wave     | The greater the frequency, the greater the volume of sound [51]  
The greater the amplitude, the lower the tone sound will be [51]  
The greater the frequency, the lower the wave energy [16]  
In a blown instrument (flute), the vibrating flute is not an air column [15]  
Sound can propagate through vacuum because sound is not influenced by the medium [14]  
Sound moves as a transverse wave not as a longitudinal wave [23]  
The weaker the sound the slower the sound rate will be [14]  
Sound can only propagate through solids [15]  
Fast sound propagation does not change but is always constant for every situation [17] |
| Optics   | We cannot see things around because there is no light coming out of our eyes [21]  
Concave lenses can be used as a loop and can burn paper if directed to sunlight [22]  
Pupils in the human eye have the same function as the diaphragm, which regulates the intensity of the incoming light [69]  
The flashlight uses a flat mirror because a flat mirror can spread light [18]  
The lens forms a shadow by reflecting and refracting the beam simultaneously [19]  
Black objects can reflect light [20]  
The shadow properties formed by a flat mirror are real and upside down [52]  
The brighter the light, the shadows formed will be smaller [21] |

Analysis of misconceptions at the defining stage is carried out to obtain information about alternative concepts of students. In the process, students are given questions in the form of reasoned
multiple choice [70] as many as 33 questions. Based on these questions, students are asked to choose the correct answer or write answers based on their own thoughts and write down the reasons for choosing the answer. The answers and reasons given by students will be tabulated for further use for the answer choices and choice of reasons for the five-tier diagnostic test developed.

3.2. Design Stage
The design phase consists of the preparation of tests and reconstruction of development instruments. At the test preparation stage, the results obtained through the defining stage will be further analysed before being developed into five-tier type multiple choice diagnostic test items. After preparing the test, the researcher reconstructed the instrument developed. The construction of the five-tier diagnostic test instrument developed was adjusted to the design described in Figure 1. The construction is a form of realization of the five-tier diagnostic test instrument used by researchers for empirical validation. The test instrument consists of 33 questions.

| Questions to-n (Description of the Questions). |
|------------------------------------------------|
| **n.1 Choice of answers** | |
| A. (Choice of answers 1) | |
| B. (Choice of answers 2) | |
| C. (Choice of answers 3) | |
| D. (Choice of answers 4) | |
| **n.2 Level of confidence in answer choices** | |
| A. sure | B. not sure |
| **n.3 Choice of reasons** | |
| A. (Choice of reasons 1) | |
| B. (Choice of reasons 2) | |
| C. (Choice of reasons 3) | |
| D. (Choice of reasons 4) | |
| **n.4 Level of confidence in reason choices** | |
| A. sure | B. not sure |
| **n.5 Questionnaire** | |
| I determine the answer and reason based on.... (choice can be more than 1) | |
| A. Explanation of teachers | |
| B. Reading from books or the internet | |
| C. Personal experience or thoughts of their own | |
| D. Explanation of friends | |

**Figure 1.** Design of Developed Five-Tier Diagnostic Test.

3.3. Development Stage
This stage is done by testing the quality of the diagnostic tests developed. Steps taken at the development stage are expert validation, instrument testing, test validity, reliability, differentiation, and level of difficulty. The expert validation is content validity test to determine the suitability of the items with the measured domain (based on material aspects, question construction, and language). The experts used in this study are experts in the field of assessment and the field of physical education.
Table 5. Judgment Results Related to Revised and Omitted Questions.

| Question Number | Suggestion |
|-----------------|------------|
| 5,10,14         | The question is omitted because it is not in accordance with the indicator. |
| 3,7,17,24,29    | The question is omitted because it does not indicate a diagnostic test (does not characterize the problem difficulty). |
| 1               | The question editor is changed. The t-axis designation is changed to the x-axis. |
| 6               | The choice of reason B is changed because it does not function as a distractor. It's best to add a choice of reasons for the wavelength. |
| 9               | The answer choice A is changed because it has the same meaning as the answer choice D. |
| 13              | The question editor is changed. The phrase "on the picture" is removed so the editor's problem becomes “from the experiment above, showing the nature of light ...” |
| 15              | The word editor on the question is changed because it does not fit the context. The word "played" is changed to "sounded". |
| 28              | The question editor is changed. The sentence "The thing that happens is the refraction of light by water" is changed to "This happens because of the process of refraction of light by clear water". |
| 30              | The question editor is changed. The sentence "on the lens of the light beam" is changed to "the beam of light on the lens experiences ..." |
| 8,22            | In the answer option a conjunction of "and" is added for example "gas, liquid, and solid". |

Based on the analysis conducted, the overall CVR value was above 0.582 and CVI was 0.833 which means that it meets the minimum CVR criteria and includes very appropriate criteria. This shows that the five-tier diagnostic test instrument developed was declared valid and could be used in the trial stage to see empirical validity, reliability, differentiation, and the level of difficulty of the question. In the expert validation process, there are several questions that are revised and omitted for several reasons as presented in Table 5, so the questions are declared valid and can be used in the trial phase of 25 questions.

Instruments that have been revised and declared valid by experts were then tested by 193 eighth grade students in two junior high schools. Students in this trial phase studied waves and optics related material. Data analysis carried out at this stage uses the Rasch Winsteps program model. The following results of data analysis using the Rasch model are presented in the Table 6.

Table 6. A summary of the statistics of the Five-Tier Diagnostic Test instruments using the Rasch model.

| Outfit MNSQ | Outfit ZSTD | Person Realibility | Item Reliability | Alpha Cronbach | Person Measure | Logit |
|-------------|-------------|--------------------|------------------|----------------|----------------|-------|
| 0.98        | 0.3         | 0.44               | 0.86             | 0.87           | -0.35          | 0.0   |

Based on the Table 6, MNSQ outfit values and ZSTD outfit values are included in the criteria for received outfit values. This shows that all items developed were expressed according to the construct measured and normal functioning to take measurements [71]. As for reliability, the data obtained shows that the consistency of answers from students is weak, but the quality of the items in the diagnostic test that is developed is good in terms of interaction between the person and the items in the overall question. The reliability analysis shows that overall the five-tier diagnostic test developed is considered to have a high consistent level so that it can be used in subsequent studies because it fulfilled the predetermined requirements [62,72].
The distinguishing power of all items is included in the specified criteria. This means that all items in the instrument developed are declared acceptable and do not need to be omitted [63,73]. Figure 2. Also explains that the item will provide optimal information when given to students with moderate ability.

Based on the Table 6 the average value of Person Measure which is smaller than the logit value (-0.35 < 0.0) shows the tendency of students' ability to be smaller than the level of difficulty of the question. This means that the criteria for the level of difficulty are very good. Whereas if seen in Figure 3. shows that the level of difficulty of the questions varies so much that it indicates the five-tier diagnostic test developed can identify the ability of students. Overall, the diagnostic test instruments developed are valid and can be used as a basis for handling misconceptions, as stated by [74] that in order to overcome misconceptions there are two things that must be done, namely the process of identifying concepts that experience misconceptions and sources of causes of misconception.

The processing of five-tier diagnostic tests to be able to identify students' misconceptions is carried out using assessment guidelines put forward by [52] regarding choices and combinations of answers at tier one through tier four. Meanwhile, to identify the source of the cause of misconception is done by looking at the highest percentage related to the choice of students in tier five for each number of questions given. Mathematical equation calculation of the percentage of sources of causes of misconception, as follows:

\[ A = \frac{B}{C} \times 100 \% \]  \hspace{1cm} (1)

Information:
A = The source of the cause of the misconception in the question to-\(n\)
B = The number of students who chose the source of the cause of the misconception in the question to-\(n\)
C = The total number of students taking the test.
Table 7. Guidelines for Responding to Students’ Answer Patterns

| 1st tier | 2nd tier | 3rd tier | 4th tier | Decision |
|----------|----------|----------|----------|----------|
| Correct  | Sure     | Correct  | Sure     | SC       |
| Correct  | Sure     | Correct  | Not Sure | LK       |
| Correct  | Not Sure | Correct  | Sure     | LK       |
| Correct  | Not Sure | Correct  | Not Sure | LK       |
| Correct  | Sure     | Wrong    | Sure     | FP       |
| Correct  | Sure     | Wrong    | Not Sure | LK       |
| Correct  | Not Sure | Wrong    | Sure     | LK       |
| Correct  | Not Sure | Wrong    | Not Sure | LK       |
| Wrong    | Sure     | Correct  | Sure     | FN       |
| Wrong    | Sure     | Correct  | Not Sure | LK       |
| Wrong    | Not Sure | Correct  | Sure     | LK       |
| Wrong    | Not Sure | Correct  | Not Sure | LK       |
| Wrong    | Sure     | Wrong    | Sure     | MSC      |
| Wrong    | Sure     | Wrong    | Not Sure | LK       |
| Wrong    | Not Sure | Wrong    | Sure     | LK       |
| Wrong    | Not Sure | Wrong    | Not Sure | LK       |

Information:
SC: Scientific Conception; LK: Lack of Knowledge; FN: False Negative; FP: False Positive; MSC: Misconception.

4. Conclusion
Based on the results of the research and discussion it can be concluded that the five-tier diagnostic test developed fulfilled the criteria of validity, reliability, differentiation, and level of difficulty of the questions. This means that the five-tier diagnostic test developed is declared appropriate to be used to identify misconceptions and causes of student misconception in waves and optics materials.

5. References
[1] Chiappetta E L and Koballa T R 2010 Science instruction in the middle and secondary school (7th ed) (New York: Pearson Education, Inc)
[2] Pine K, Messer D and John K St 2001 Res. in Sci. Technol. Educ. 19 79-96
[3] Sari I N C and Julianto 2018 JPGSD 06 1610-20
[4] Sukarno, Permanasari A and Hamidah I 2013 Int. J. Sci. Res. (IJSR) 2 450-454
[5] Erceg N, Aviani I, Mesic V, Gluncic M and Zauhar G 2016 Phys. Rev. Phys. Educ. Res. 12 1-23
[6] Queloz A C, Klymkowsky M W, Stern E, Hafen E and Kohler K 2017 PLoS ONE 12 1-18
[7] Veerasamy A K, D’Souza D and Laakso M J 2017 J. Educ. Technol. Systems 45 50-73
[8] Widarti H R, Permanasari A and Mulyani S 2017 Int. J. Educ. 9 105-112
[9] Drastisianti A, Supartono, Wijayati N and Susilaningsih E 2018 J. Innovative Sci. Educ. 7 95-100
[10] Utami G R, Firman H and Nahadi N 2018 J. Phys. Conf. Ser. 1157 042033
[11] Allen M 2014 Misconception in Primary Science (UK: McGraw-Hill Education)
12. Burden K and Kearney M 2016 Res. in Sci. Educ. 46 287-308
13. Eshach H, Lin T C and Tsai C C 2018 J. Res. in Sci. Teach. 55 664-684
14. Leccia S, Colantonio A, Puddu E, Galano S and Testa I 2015 Phys. Educ. 50 677-689
15. Okur M and Artun H 2016 European J. Educ. Studies 2 44-62
16. Sutopo 2016 J. Pendidikan Fisika Indonesia 12 41-53
17. Zhu X, Guo J, Zhang J and Plummer E W 2017 Advances in Physics: X 2 622-640
18. Favale F and Bondani M 2014 12th Educ. Training in Optics Photonics Conf. vol 9289 (Porto: Portugal) 92891A
19. Tural G 2015 Sci. Educ. Int. 26 325-343
20. Fariyani Q, Rusilowati A and Sugianto 2017 Unnes Sci. Educ. J. 6 1724-29
21. Yalcin S A, Yalcin P, Akar M S and Sagarli M O 2017 Universal J. Educ. Res. 5 1621-31
22. Widiyatmoko A and Shimizu K 2018 Int. J. Environ. Sci. Educ. 13 853-863
23. Wibowo F C, Suhandi A, Rusdiana D, Darman D R, Ruhiat Y, Denny Y R, Suherman and Fatah A 2016 J. Phys. Conf. Ser. 739 012044
24. Ceuppens S, Deprez J, Dehaene W and Cock M D 2018 Phys. Educ. 53 1-10
25. Pfeiffer S 2017 Nanoethics 11 107-121
26. World Economic Forum 2018 The Future of Jobs Report 2018 Insight Report Centre for the New Economy and Society Retrieved Maret 2019 from http://www3.weforum.org
27. Coley J D and Tanner K 2015 CBE Life Sci. Educ. 14 1-19
28. Kuczmann 2017 AIP Conf. Proc. 1916 050001
29. Lucero M M and Petrovino A J 2017 Res. in Sci. Educ. 47 705-730
30. Nelson K G, McKenna A F, Brem S K, Hilpert J, Husman J and Pettinato E 2017 J. Eng. Educ. 106 218-244
31. Putri L O L, Rahman T and Priyandoko D 2017 J. Phys. Conf. Ser. 812 012083
32. Kumandas B, Ateskan A and Lane J 2018 J. Biological Educ. 9266 1-15
33. Kirboulut Z D and Geban O 2014 Eurasia J. Math. Sci. Technol. Educ. 10 509-521
34. Loh A S L, Subramaniam R and Tan K C D 2014 Res. in Sci. Technol. Educ. 32 229-250
35. Cheong J P A, Johari M, Said H and Treagust D F 2015 Int. J. Sci. Educ. 37 210-236
36. Suliyah, Putri H N P A and Rohmawati L 2018 J. Phys. Conf. Ser. 973 012035
37. Keidan I, Ben-Menachem E, Berkenstadt H and Toren A 2016 J. Pediatric Hematology/Oncology 38 78-80
38. Erman E 2017 J. Res. in Sci. Teach. 54 520-537
39. Pujayanto, Budiharti R, Adhitama E, Nuraini N R A and Putri H V Phys. Educ. 53 045022
40. Yan Y K and Subramaniam R 2018 Chemistry Educ. Res. Pract. 19 213-226
41. Kor F 2015 Eurasia J. Math. Sci. Technol. Educ. 11 1041-60
42. Goris T V 2016 Int. J. Eng. Pedagogy (iJEP) 6 4-10
43. Gurel D K, Eryilmaz A and McDermott L C 2015 Eurasia J. Math. Sci. Technol. Educ. 11 989-1008
44. Bekkink M O, Donders A R T R, Kooloo G J, De Waal R M W and Ruiter D J 2016 BMC Medical Educ. 16 1-7
45. Kanli U 2015 Sci. Educ. Int. 26 148-165
46. Kamcharean C and Wattanakasiwich P 2016 Int. J. Innovation in Sci. Math. Educ. 24 14-36
47. Siswaningsih W, Firman H, Zackiyah and Khoirunnisa A 2017 J. Phys. Conf. Ser. 812 012117
48. Nahadi N, Siswaningsih W and Muchtar H K 2017 Advanced Sci. Letters 23 10555-10558
49. Milenkovic D D, Hrin T N, Segedinac M D and Horvat S 2016 J. Chemical Educ. 93 1514-20
50. Taslidere E 2016 Res. in Sci. Technol. Educ. 34 164-186
51. Caleon I S and Subramaniam R 2010 Res. in Sci. Educ. 40 313-337
52. Gurel D K, Eryilmaz A and McDermott L C 2017 Res. in Sci. Technol. Educ. 35 238-260
53. Fratiwi N J, Kaniawati I, Suhendi E, Suyana I and Samsudin A 2017 AIP Conf. Proc. 1848 050011
54. Anggrayni S and Ermawati F U 2019 J. Phys. Conf. Ser. 1171 012037
Acknowledgments

The researcher would like to thank all the students who participated in our study and all the experts for criticism and suggestions for improving the quality of the instruments developed.