COGNITIVE DIAGNOSTIC ASSESSMENT OF STUDENTS' RESPONSES: AN EXAMPLE FROM ENERGY AND MOMENTUM CONCEPTS

Bekele Gashe Dega

Department of Physics, College of Natural and Computational Sciences

Ambo University, Ethiopia

bekele.gashe@ambou.edu.et

(Received: 11. 01. 2019, Accepted: 27. 02. 2019)

Abstract

Students' responses to energy & momentum (EM) concepts were investigated. EM concepts are fundamental and crosscutting in physics. A standardized Energy and Momentum Conceptual Survey (EMCS) test were used to collect quantitative data from 108 first year science students enrolled in a university in Ethiopia. Concentration analysis was used to analyze the responses in terms of concentration score, concentration factor, and concentration deviation. A one-sample t-test was conducted and showed no statistically significant difference ($t=0.33$, $p=0.74$) between the average concentration score and the hypothetical random score. A paired-samples t-test was conducted and showed also a no statistically significant difference ($t=1.25$, $p=0.22$) between the concentrations of students' responses to the scientific conceptions and misconceptions. The results showed that newly enrolled university science students have low, random and inconsistent conceptual knowledge of core physics concepts. Concentration analysis is recommended for science teachers to diagnose students' level of understanding before instruction.

Keywords: Concentration analysis; core physics; diagnostic assessment; misconceptions

INTRODUCTION

Research has shown that students come to science classes with pre-instructional knowledge about the concepts to be taught in which many students develop only a limited or an inappropriate understanding of science concepts (Duit & Treagust, 2003). Science concepts, like energy and momentum, are abstract core concepts in science and they are learned at different levels in school and university. These concepts are fundamental in and crosscutting across science and technology disciplines.

The principles of energy and momentum are tools for analysis of processes and events of science (Jin & Anderson, 2012). The conservation principles have a lot of applications in other fields of science and engineering and they are dominantly applied in the analyses of problems in natural events and phenomena. The work-energy and momentum-impulse relations are powerful to coherently and meaningfully understand natural phenomena and they also help students to understand and solve physical problems in different contexts.

However, most first-year university students are confused with the principles of energy and momentum. Students face most of the energy and momentum concepts in their formal classroom learning. They show misunderstandings and inconsistencies indicating that they lack a coherent framework of ideas and show misconceptions about the concepts. Thus, it is found important to cognitively diagnose students' response states to the concepts of energy and momentum.

Cognitive Diagnostic Assessment

Cognitive diagnostic assessment (CDA) is meant to measure students' domain-specific knowledge needed to provide information about their cognitive strengths and weaknesses (Leighton & Gierl, 2007). CDA may be defined as an assessment in which the results provide information about students' understanding of relevant prior knowledge and misconceptions about the material within domain-specific knowledge (Fuchs, Fuchs, Hosp & Hamlett, 2003). CDA assesses what the learner already knows and/or the nature of difficulties that the learner might have, which, if undiagnosed, might limit their engagement in new learning. It is intended to improve the learners' understanding and their level of achievement. Diagnostic assessment is concerned with judgments about the level of student responses before instruction and its result can be used to shape and improve the students' competence by reducing the randomness and inefficiency of arbitrarily chosen supportive approaches (Sadler, 1989). In other words, diagnostic assessment is usually done at the beginning of a semester class to obtain information about students' difficulties and misconceptions in a domain-specific subject. Science teacher educators may use diagnostic assessment to find out what students know and can do prior to instruction. Teachers use diagnostic assessment to make appropriate decisions to support students learning and adjust instruction based on students' difficulty areas (Sadler, 1989). Thus, cognitive diagnostic assessment on students' level of understanding in the core concepts of physics can contribute knowledge to the theory of conceptual change and meaningful learning in science. The conceptual change theory acknowledges that student's existing prior knowledge influences the learning outcomes. Therefore, students' misconceptions must be taken into account in terms of their response states before initiation of teaching for conceptual development. Thus, cognitive diagnostic assessment is needed to identify students' difficulties and plan for remedial instruction which can help to overcome their misconceptions.

The Role of Concentration Analysis

Earlier assessments in science learning have a limitation because they have used classical test theory which is mainly based on scores to assess students' knowledge. Traditional test analysis relies solely on scores which depend on the number of students giving the correct answer. Traditional test analysis is also limited to give information on students' understanding because it ignores significant and important information on the distribution of incorrect answers (misconceptions) given by students. The information on how the students get a question wrong cannot be analyzed using traditional test analysis alone.

Thus, a need arises to undertake a diagnostic assessment of students' understanding of core and cross-cutting science concepts using a statistical method that can help to assess students' response states in terms of both correct (scientific) and incorrect (misconception) responses. Assessing students' knowledge about how their existing conceptions deviate from or relate to the scientifically accepted ones and helping students to modify their misconceptions accordingly are both parts of assessment and teaching and they have a beneficial impact on students' conceptual knowledge development (Yin et al., 2008). Therefore, a new method such as concentration analysis is believed to fill in the existing gap of analyzing and getting information about the students' correct and incorrect response states.

Concentration analysis (Bao & Redish, 2001) is a recent statistical method used to measure how students' correct and incorrect responses to multiple-choice questions are distributed. This information is an important indication for teacher educators to help them improve their teaching. The essential nature of this analysis is its ability to find patterns to both correct and incorrect students' responses to a multiple-choice test. In concentration analysis, every item of a diagnostic test is mainly represented by three parameters. These are the concentration score (S), concentration factor (C_f) and concentration deviation (C_d).

Concentration score

The concentration score is the fraction of the number of students' correct answer to each multiple-choice question. It is expressed as:

$$S = \frac{n_c}{N}. \qquad \text{eq. (1)}$$

In the equation, n_c stands for the number of correct answers to an item and N is the total number of students who wrote the test. Its values vary from 0 to 1. If students have low conceptual knowledge in a discipline-based science concept, then they may randomly respond to a standardized multiple-choice question of the concept. Thus, their score will be the same as the random response score. Random response score is represented by an extreme case where the students' responses are evenly distributed among all the choices, similar to the results of random guessing (Bao & Redish, 2001). If a multiple-choice single-response question with *m* choices is given to a number of respondents, then the random response score of the respondents will be *1/m*. For example, if a multiple-choice single-response question with five choices (A, B, C, D, and E) is given to students, then their random response score will be 0.20 or 20%. This random response score can be taken as a threshold score which may help science educators to assess the level of their students' conceptual knowledge. It should be noted that if students, with inappropriate preparation on a specified science concept, are tested by a standardized multiple-choice test their average threshold score or random response score will not be zero, but approximately equal to *1/m*. Hence, the first objective of this study is to diagnose if there is a significant difference between the students' average score and the random response score.

Concentration Factor and Concentration Deviation

The concentration factor (Bao & Redish, 2001) is the concentration of the students' responses to the different options of each item. It could be expressed as:

$$C_f = \frac{\sqrt{m}}{\sqrt{m}-1}\left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2}}{N} - \frac{1}{\sqrt{m}}\right). \qquad \text{eq. (2)}$$

In the equation, m stands for the number of multiple options and n_i is the number of students' responses to the ith option, where it varies from 1 to m and N is the total number of students who wrote the test. The values of the concentration factor also vary from 0 to 1. In addition, Bao and Redish introduced concentration deviation (C_d), the concentration of students' alternative conceptions. The concentration deviation formula is given as:

$$C_d = \frac{\sqrt{m-1}}{\sqrt{m-1}-1}\left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2 - n_s^2}}{(N-n_s)} - \frac{1}{\sqrt{m-1}}\right). \qquad \text{eq. (3)}$$

In this case, n_s stands for the number of students' responses to the correct answer and all the notations in this equation are also the same as that of the concentration factor. The second objective of this study was on the statistical comparison of the concentration factor and concentration deviation of science students on a standardized conceptual test which is believed to help science educators to diagnose whether the students' conceptions are coherent or incoherent.

Perspectives on Student's Misconceptions

Teaching for conceptual development of science concepts arose from the 1980s' research on students' misconceptions (Driver, 1989). An essential part of this teaching was to clarify students' existing ideas and to help them construct the scientifically accepted ideas.

Current reviews on the progress of concepts learning research show that there are two prominent but competing theoretical perspectives regarding the structure of students' misconceptions (Özdemir & Clark, 2007). These are a misconception as a theory perspective (e.g., Chi, 2005; Ioannides &Vosniadou, 2002; Wellman &Gelman, 1992) and misconception as elements perspective (e.g., Clark, 2006; diSessa, Gillespie, & Esterly, 2004; Harrison, Grayson, &Treagust, 1999). These two theoretical perspectives imply different pathways for conceptual change to help students restructure their knowledge (Özdemir &Clark, 2007). These perspectives on students' misconceptions put science teachers in an indecisive situation with regards to the realization of concepts learning because of the limitation of the classical test theory which is mainly based on correct answers (scientific conceptions) to assess students' understanding.

Misconceptions in Energy and Momentum

Studies on misconceptions in science concepts have shown multifaceted misconceptions in the concepts of energy and momentum (Ding, Chabay, & Sherwood, 2013; Van Heuvelen & Zou, 2001). University students fail to recognize the implications of a particular choice of the system during problem-solving (Lindsey, Heron & Shaffer, 2012). In some cases, students do not believe that particular groupings of objects can even be considered to be a system. These misconceptions pose barriers to students' conceptual learning of the energy conservation principle. Lindsey et al., (2012) showed that misconceptions of the concept of energy, like failure to apply energy conservation in a variety of contexts, are not restricted to physics novices but extend to advanced learners. It was also found that learners have considerable misconceptions with the basic concept of energy and its related ideas and their application to everyday situations.

Students also had misconceptions in using the conservation of energy and momentum principles appropriately in many situations (Singh &Rosengrant, 2003). Studies (Lawson & McDermott, 1987; Singh & Rosengrant, 2003) showed that questions involving work-energy and impulse-momentum theorems are typically perceived to be more difficult than those involving their special cases, momentum, and energy. Students who were able to solve numerical problems showed a lack of understanding of fundamental concepts and were not able to solve qualitative conceptual problems (Goldring and Osborne, 1994). This means that though students may manipulate complex formulae and may do through involved exercises, they often do not understand fundamental conceptual principles.

It was found that university students have considerable misconceptions with the basic concept of energy and momentum and their application and implication to everyday situations (Jewett, 2008b; Lindsey, Heron & Shaffer, 2012). Lindsey et al., (2012) showed that the misconceptions the students have described are not restricted to physics novices but extended to advanced learners. Dega and Govender (2016) studied levels of students understanding of energy and momentum by emphasizing on the score and concentration factor. However, their study was limited that they did not consider the concentration of the misconceptions (concentration deviation) in the students' responses. Thus, a cognitive diagnostic assessment on a newly enrolled university science students' domain-specific knowledge of energy and momentum is found important to be undertaken by considering the concentration of students' misconceptions into account in their response states using the concentration analysis. The study will inform on the response states of the students' conceptions whether their responses are random or form a pattern, coherent or incoherent. Thus, this study is believed to be useful to get information on students' conceptual knowledge level which would help teachers as a pivotal point to design and use appropriate supportive approaches for conceptual meaningful learning. Thus, the research questions are as follows:

1. *How significant is the deviation of students' average score from the theoretical random response score in the energy and momentum concepts?*
2. *How significant is the difference between the concentration of students' responses to the scientific conceptions and misconceptions in the concepts of energy and momentum?*

METHODOLOGY

The quantitative research method was used to collect and analyze data from108 science students in a university in Ethiopia. A standardized conceptual test of Energy and Momentum Conceptual Survey (EMCS) developed by Singh and Rosengrant (2003) was employed to collect data, before commencing of the semester's courses. The diagnostic test has 25 items to assess students' misconceptions and conceptual knowledge (scientific conceptions) in energy and momentum. The test is a multiple-choice with a combination of conceptual knowledge as a correct answer and misconceptions as distracters. The test has been used to compare the understanding of energy and momentum concepts in courses employing different instructional strategies. It can also measure the overall achievement and progress of individual students and relate students' response patterns to misconceptions and measure the effectiveness of a particular learning approach in the concepts. A pilot test was conducted and the face and content validity of the EMCS test was verified by experts of the field. In addition, the reliability of the test was checked using the Kuder Richardson-21 estimation which was 0.88.

Concentration analysis developed by Bao and Redish (2001) was used to analyze data collected by EMCS to investigate the concentration of misconceptions in students' responses to the multiple-choice tests. It was also used to investigate the degree of the relative importance of the alternative states of students' responses in the sample. This means that the concentration of misconceptions and conceptual knowledge were analyzed in terms of concentration score [0, 1], concentration factor [0, 1] and concentration deviation [0, 1]. Concentration deviation (the concentration of misconceptions), as in Bao and Redish, was analyzed to investigate the concentration of students' responses to the misconceptions.

Therefore, in response to the first research question, the concentration score of the students' responses was calculated to investigate the students' conceptual understanding level in energy and momentum concepts. A one-sample t-test was used to investigate whether the students' responses to EMCS are random or they form a pattern. In response to the second research question, the concentration factor and the concentration deviation were compared using a paired samples t-test to determine whether the students' responses to EMCS were coherent or incoherent.

RESULTS

The EMCS items were mainly designed to probe the students' understanding of the concepts: conservation of energy, work was done by the gravitational force, work done by non-conservative forces, momentum conservation in an elastic and inelastic collision, a system for momentum and kinetic energy conservation and applications of the impulse-momentum theorem.

In response to the first research question, the concentration score (S) was calculated using equation 1 and represented in Table 1. The table presents the distribution of students' responses to the multiple-choice questions which include the concentration score, concentration factor, and concentration deviation.

***Table 1**. Concentration score, concentration factor and concentration deviation*

Item	S	C_f	C_d	Item	S	C_f	C_d
1	0.14	0.02	0.01	**14**	0.32	0.04	0.01
2	0.11	0.10	0.10	**15**	0.13	0.22	0.26
3	0.26	0.03	0.03	**16**	0.28	0.12	0.20
4	0.11	0.17	0.19	**17**	0.15	0.07	0.08
5	0.42	0.17	0.17	**18**	0.46	0.17	0.04
6	0.14	0.11	0.14	**19**	0.13	0.04	0.03
7	0.08	0.35	0.38	**20**	0.11	0.15	0.17
8	0.17	0.10	0.14	**21**	0.39	0.10	0.04
9	0.06	0.13	0.10	**22**	0.11	0.07	0.06
10	0.14	0.18	0.22	**23**	0.31	0.04	0.04
11	0.19	0.14	0.20	**24**	0.07	0.26	0.26
12	0.38	0.17	0.26	**25**	0.18	0.04	0.06
13	0.36	0.17	0.27	**Mean**	**0.21**	**0.13**	**0.14**

The one sample t-test was conducted to compare the average concentration score to the theoretical random response score. The result (t=0.33, p=0.74) showed that there was no statistically significant difference between the students' average concentration score and the theoretical random response score (Table 2). This shows that the students' conceptual knowledge in the core concepts of physics is low and their responses are in the random response state.

***Table 2**. One-Sample Test*

	Test Value = 0.20					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
S	0.33	24	0.74	0.008	-0.042	0.058

In response to the second research question, a paired samples t-test result showed that there was no statistically significant difference (t=1.25, p=0.22) between the concentration factor and concentration deviation of the students' responses (Table 3). This shows that the students' responses to the EMCS are inconsistent and lay nearly in the random response state.

***Table 3**.Paired Samples Test*

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair C_f - C_d	-0.01	0.05	0.01	-0.03	0.01	-1.25	24	0.22

A Circular Model Graph for Incoherent Response State

Figure 1 is a circular model graph used to represent and illustrate the concentration factors and concentration deviations of the students' responses versus EMCS items. In this model graph, the items (1 to 25) are represented on the outer circle while the concentrations [0 to 1] are represented in the vertical axis. The vertical axis was labeled in reverse order, the minimum (0) on the outer surface and the maximum (1) at the center of the circular graph. The graph surface represents a random response level with no in-depth understanding while the center of the circular graph represents an in-depth viable understanding of the concepts.

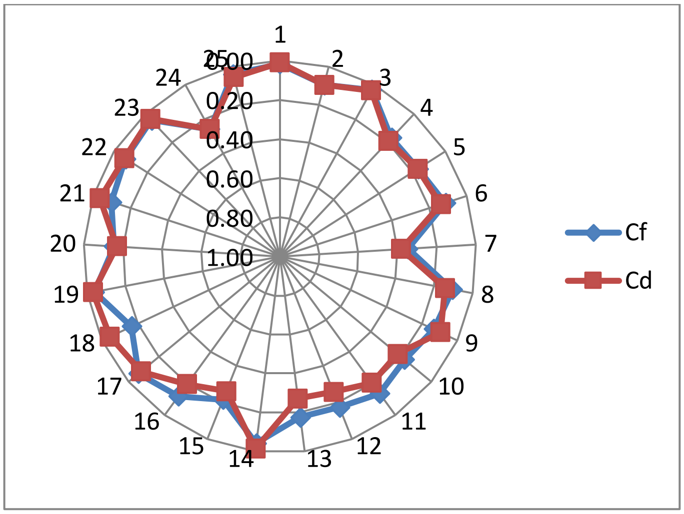

Figure 1. *Concentration factor (C_f) and concentration deviation (C_d) versus EMCS items*

The graph can be used as a characteristic diagnostic explanation of the students' responses distribution. The first characteristic is the position of the two closed paths (loops) with respect to the center or the outer. The other is the relative gap between two loops or their concurrence with each other. Thus, first, the positions of the two loops were found between zero and 0.20 which are nearer to the outer circle than the center. Second, the two loops were nearly in coincidence with each other at the positions. This means that the two concentrations were at a low level and that their difference is insignificant.

DISCUSSION

The results showed that students have difficulty to understand the basic concepts of energy and momentum. It was also revealed that they lacked a coherent in-depth understanding of energy and momentum concepts which was concurring with similar previous studies in physics education (Dega et al., 2013; Dega & Govender, 2016; Singh & Rosengrant, 2003). Singh and Rosengrant (2003) found that students have difficulty to understand the basic principles and they lack a coherent understanding related to energy and momentum.

Currently, the difficulties of students' conceptual understanding of concepts in physics become a worldwide problem. The Program for International Student Assessment (PISA), meant to measure the success of secondary education students of nearly all countries, reported that the education systems of many countries are based on the memorization of facts and principles in science and cannot prepare students for integrating scientific concepts and principles to real-life situations (PISA, 2009). The PISA examination tries to find out if students are well prepared for future challenges and continue learning in their future lives. However, the score of many students in different countries of the world is low and they have a poor conceptual understanding of basic physics concepts (Bulunuz, Bulunuz, & Peker, 2014).

The methods of teaching physics in school and university in Ethiopia are predominantly lecture-based, physical and mathematical problem-solving. However, ways of treating students' misconceptions and means of designing and using concepts learning strategies are given fewer emphases in the physics curriculum (Dega, 2012). In addition, the students who have higher science achievement in school and strong academic background are not enthusiastic to join natural science program in university (Semela, 2010). The majority of students assigned to study physics are revealed to lack interest, below achievers and lack academic success (Getenet, 2006). It was observed that most high scoring students do not wish to join natural science/physics, and this makes less scoring students to be forced to study in physics.

Misconceptions are very stable and cannot be removed by traditional teacher-centered transmission model of learning because concept learning is a complex process that needs insight and intervention (Planinsic, 2007). It means that concept learning cannot be effectively done through transmission model of learning between students and the teacher. Thus, science teacher educators are advised to apply conceptual development strategies which actively engage students in learning of cross-cutting science concepts, like energy and momentum.

CONCLUSION

This study investigated 108 first-year students' response states in energy and momentum concepts in a university in Ethiopia. The results revealed that the students' responses to the EMCS test were nearly random and inconsistent. This means that the students' responses were inappropriate and counterproductive to the scientific conceptions of energy and momentum. Based on the results, it can be concluded that the students' previous learning was not supported by concepts learning approaches in science. Hence, it is recommended that schools and universities should encourage science teachers so that they need to apply concepts learning approaches which involve students' interactive-engagement of learning. In addition, teacher training institutions and universities are advised to develop science pre- and in-service teachers' capacity towards the use of the current findings in Discipline-Based Education Research (DBER), like Physics Education Research (PER) (Singer, Nielsen & Schweingruber, 2012).

The result of this study can be used as an evaluation of students' conceptual understanding in energy and momentum concepts which can effectively scrutinize and influence the conceptual development of students' perceptions. This means it can be used as a diagnostic conceptual assessment of the students in the core concepts of physics. The result of such kind of study also can be used as feedback to university students that can help them take control of their own learning. In other words, it specifically can make tertiary students to become self-regulated learners (Nicol & Macfarlane-Dick, 2006).

REFERENCES

Bao, L., &Redish, E. F. (2001). Concentration Analysis: A Quantitative Assessment of Student States. *Phys. Edu. Res., American Journal of Physics*, 69 (7), S45-53.

Bulunuz, N., Bulunuz, M. & Peker, H. (2014). Effects of formative assessment probes integrated in extracurricular hands-on science: middle school students' understanding. *Journal of Baltic Science Education*, 13(2), 243-258.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences*, *14*(2), 161-199.

Clark, D. B. (2006). Longitudinal conceptual change in students' understanding of thermal equilibrium: An examination of the process of conceptual restructuring. *Cognition and Instruction*, *24*(4), 467-563.

Dega, B. G. (2012). Conceptual change through cognitive perturbation using simulations in electricity and magnetism: a case study in Ambo University, Ethiopia (Doctoral dissertation).

Dega, B. G., & Govender, N. (2016). Assessment of Students' Scientific and Alternative Responses in Energy and Momentum Concepts using Concentration Analysis. *African Journal of Research in Mathematics, Science and Technology Education, 20*(3), 201-213.

Dega, B. G., Kriek, J., & Mogese, T. F. (2013). Categorization of alternative conceptions in electricity and magnetism: The case of Ethiopian undergraduate students. *Research in Science Education, 43*(5): 1891-1915.

Ding, L., Chabay, R., & Sherwood, B. (2013). How do students in an innovative principle-based mechanics course understand energy concepts? *Journal of research in science teaching, 50*(6), 722-747. doi: 10.1002/tea.21097

diSessa, A.A., Gillespie, N., & Esterly, J. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science*, 28(6), 843-900.

Driver, R. (1989).Students' conceptions and the learning of science. *International Journal of Science Education*, 11(5), 481–490.

Duit, R. and Treagust, D.F. (2003) Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25(6), 671–688.

Fuchs, L. S., Fuchs, D., Hosp, M. K., & Hamlett, C. L. (2003). The potential for diagnostic analysis within curriculum-based measurement. *Assessment for Effective Intervention*, *28*(3&4), 13-22.

Getenet, T. (2006). Causes of high attrition among physics PPC students. *The Ethiopian Journal of Education*, *26*(1), 53-66.

Goldring H & Osborne J (1994). Students' difficulties with energy and related concepts, *Physics Education*, *29*(1), 26-32.

Harrison, A. G., Grayson, D. J., & Treagust, D. F. (1999).Investigating a grade 11 student's evolving conceptions of heat and temperature. *Journal of Research in Science Teaching*, *36*(1), 55-87.

Ioannides, C., & Vosniadou, S. (2002). The changing meaning of force. *Cognitive Science Quarterly*, *2*(1), 5-61.

Jewett Jr, J. W. (2008). Energy and the confused student II: Systems. *The Physics Teacher*, *46*(3), 81-86.

Jin, H., & Anderson, C. W. (2012).A learning progression for energy in socio-ecological systems. *Journal of Research in Science Teaching*, *49*(9), 1149-1180.

Lawson, R. A., & McDermott, L. C. (1987). Student understanding of the work-energy and impulse-momentum theorems. *American Journal of Physics*, *55*(9), 811-817.

Leighton, J. P., & Gierl, M. J. (2007). Why cognitive diagnostic assessment? In J. P. Leighton & M. J. Gierl (Eds), *Cognitive Diagnostic Assessment for Education: Theory and Applications* (pp. 3-18). New York: Cambridge University Press.

Lindsey, B. A., Heron, P. R., & Shaffer, P. S. (2012). Student understanding of energy: Difficulties related to systems. *American Journal of Physics*, 80(2), 154-163.

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: a model and seven principles of good feedback practice. *Studies in higher education*, *31*(2), 199-218.

PISA (2009). *What students know and can do: Student performance in reading, mathematics and science (Volume I)*. [Online] Retrieved from http://www.oecd.org/pisa/pisa2009keyfindings.htm.

Planinsic, M. (2007). Conceptual change requires insight and intervention. *Physics Education*, *42* (2), 222-223.

Özdemir, G., & Clark, D. B. (2007).An overview of conceptual change theories. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(4), 351-361.

Sadler, D. R. (1989).Formative assessment and the design of instructional systems. *Instructional science*, *18*(2), 119-144.

Semela, T. (2010).Who is joining physics and why? Factors influencing the choice of physics among Ethiopian university students. *International Journal of Environmental & Science Education*, *5*(3), 319-340.

Singer, S. R., Nielsen, N. R., &Schweingruber, H. A. (Eds.). (2012). *Discipline-based education research*. National Academies Press.

Singh, C., & Rosengrant, D. (2003).Multiple-choice test of energy and momentum concepts. *American Journal of Physics*, *71*(6), 607-617.

Van Heuvelen, A., & Zou, X. (2001). Multiple representations of work - energy processes. *American Journal of Physics*, *69*(2), 184-194.

Wellman, H. M., &Gelman, S. (1992). Cognitive development: Foundational theories of core domains. *Annual Review of Psychology*, *43*(1), 337–375.

Yin, Y., Shavelson, R. J., Ayala, C. C., Ruiz-Primo, M. A., Brandon, P. R., Furtak, E. M., & Young, D. B. (2008). On the impact of formative assessment on student motivation, achievement, and conceptual change. *Applied Measurement in Education*, *21*(4), 335-359.