Science Education International
30(3), 217-222
https://doi.org/10.33828/sei.v30.i3.8

ORIGINAL ARTICLE

Prevalence of Random and Null-model Student's Responses using Concentration Analysis: An Example from Electromagnetism Concepts

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ABSTRACT

Science concepts, like electromagnetism, involve abstract relations, which are often problematic in students' learning. Electromagnetism concepts are crosscutting concepts across science disciplines. A standardized Conceptual Survey of Electricity and Magnetism, which is a 32-item multiple-choice test, was used to collect data from 117 first-year science students newly enrolled in a university in Ethiopia. Concentration analysis was used to analyze the student's responses to the test. A paired samples t-test was conducted to evaluate the difference between the concentrations of the student's responses to the scientific and alternative conceptions. The results showed that there was no statistically significant difference between the two concentrations of the student's responses ($t = 0.23$, $p = 0.82$). In addition, three-level categorization of student's responses on the test showed that more than four-fifth of the student's responses were in the null non-model state, less than one-fifth of the student's responses were in the mixed bimodal state, and none of the students' response was in the pure state. These results showed that the student's responses to the electromagnetism concepts were nearly all in the null-model and random response states. This study argues that teacher educators need to use concept learning strategies to develop significantly students' conceptual knowledge of electromagnetism.

KEY WORDS: alternative conceptions; concentration analysis; introductory physics; model states; scientific conceptions

INTRODUCTION

Research in physics education is primarily to improve students' understanding of physics concepts (McDermott, 2001). However, students often come to these science classes with only a limited or an inappropriate understanding of science concepts (Duit and Treagust, 2003). For example, electric and magnetic fields are abstract science concepts and are learned at different levels of formal education. These concepts are fundamental in and crosscutting across science and technology disciplines. The concepts of electromagnetism, such as electric potential, electric energy, induced current, induced electromotive force (EMF), and fields, are complex and unfamiliar to many students' everyday experiences (Dega, 2012; Dega et al., 2013a; Dega et al., 2013b).

Students encounter electric and magnetic fields concepts in their formal classroom learning; however, they are often confused with the effects of electric and magnetic fields. Students show misunderstanding and inconsistencies, indicating that they lack a coherent framework of ideas and show alternative conceptions (misconceptions) about electromagnetism concepts such as their ideas that charges are attracted to magnetic poles and are pushed along magnetic field lines (Maloney et al., 2001; Scaife and Heckler, 2010). Students have misconceptions in electromagnetism concepts due to their lack of understanding of Newton's Laws in the contexts of electromagnetism. For example, a larger force is exerted by a larger charge in the Coulomb's interaction between two charges and a uniform electric field implies a uniform velocity of a charge placed in the field (Galili, 1995; Leppävirta, 2012; Maloney et al., 2001; Planinic, 2006).

Assessment studies (Chabay and Sherwood, 2006; Planinic, 2006) have shown that the concepts of electromagnetism are significantly more difficult to understand than the concepts in mechanics. Students' misconceptions in electromagnetism concepts have similar trends across undergraduate and upper high school students in different countries (Planinic, 2006; Saglam and Millar, 2006). This highlights that many students have problems with the concepts of electromagnetism globally, which may cause problems in their physics learning. Hence, it can be assumed that many students have inconsistent understanding of the electromagnetic concepts, and therefore, this needs to be investigated. Therefore, a diagnostic assessment on students' level of understanding in the undergraduate electromagnetism concepts of physics contributes to meaningful learning in science and engineering in all topics and helps students solve physical problems in different contexts.

An assessment is needed to provide information about students' understanding of relevant prior knowledge and misconceptions

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within the domain-specific knowledge. Such an assessment can provide information about their cognitive strengths and weaknesses (Fuchs et al., 2003; Leighton and Gierl, 2007). Such an assessment should be done at the beginning of a semester class to obtain information about the prior learning of student's difficulties and misconceptions. Teachers may use this information to adjust instruction by identifying students' difficulty areas. Thus, a quantitative assessment on students understanding of electromagnetism concepts is needed to identify student difficulties and plan for remedial instruction, which helps to overcome their difficulties.

The traditional teaching approaches are ineffective in physics learning (Dykstra et al., 1992; Grayson, 1994; Hake, 1998). Jelicic et al. (2017) showed that high school students that were taught physics by the traditional approaches lack understanding of basic concepts of electromagnetism. Consequently, student's misconceptions in electromagnetism often remain persistent after instruction. The concepts in electromagnetism are complex and involve abstract relations (Chabay and Sherwood, 2006) and can, therefore, be particularly problematic in students' learning. Moreover, studies on the assessment of difficulties in the concepts of electromagnetism have shown that the difficulties have similar trends across countries and universities (Maloney et al., 2001; Planinic, 2006; Saglam and Millar, 2006).

Assessment in science is generally conducted in developed countries with less emphasis at university level than in schools (Soto-Lombana et al., 2005). In line with this, no study has been conducted on the assessment of the university students' response states of electromagnetic concepts. Therefore, a study on the assessment of students' response states in electromagnetic concepts at the introductory undergraduate level is important; otherwise, the misconceptions may ultimately affect students' learning of successive advanced physics concepts. Thus, this study aims to investigate students' response states and distributions of their responses to the scientific and misconceptions and the characteristics level of the student's conceptions. The research questions that are addressed are as follows:

1. How significant is the difference between the student's responses to the scientific conceptions and misconceptions in the concepts of electromagnetism?
2. How are the students response states characterized in the concepts of electromagnetism?

MATERIALS AND METHODS

Quantitative research method was used to collect and analyze data collected from 117 undergraduate physics students in a university in Ethiopia. The data were collected using a standardized conceptual test, Conceptual Survey of Electricity and Magnetism (CSEM), developed by Maloney et al. (2001). This standardized diagnostic test has 32 items to assess student's misconceptions and conceptual knowledge of introductory electromagnetism concepts. The test is a multiple-choice test with a combination of conceptual knowledge as a correct answer and misconceptions as distracters. The CSEM items were designed to probe the students' understanding of the concepts: Electric charge, electric force, electric potential energy, electric field, magnetic field, induced EMF, and induced current. The test has been used to compare the understanding of electromagnetism concepts in courses employing different instructional strategies. It can also measure overall achievement and progress of individual students and relate students' response patterns to misconceptions.

Data Analysis

Concentration analysis method (Bao and Redish, 2001) was used to analyze quantitative data collected by the CSEM. Concentration analysis is a new statistical method used to measure how students' correct and incorrect responses on multiple-choice questions are distributed. It was also used to investigate the degree of relative importance of the alternative states/models of student's responses in the sample. The analysis was used to address the limitations of traditional test analysis, which often relies solely on scores, the number of students giving the correct answer. Traditional test analysis is limited to give information on the distribution of alternative answers given by students. The information on the students' wrong answers cannot be analyzed using traditional test scores analysis alone. However, the essential nature of the concentration analysis is its ability to find patterns in the student's misconceptions and conceptual knowledge. Thus, concentration analysis is believed to fill in the existing gap of analyzing and getting information about the students' correct and incorrect response states.

In concentration analysis, every item of a diagnostic test is represented by three parameters, the concentration score (S), concentration factor (C_f), and concentration deviation (C_d). The concentration score is the fraction of number of students' correct answer to each multiple-choice question. It is expressed as follows:

$$S = \frac{n_c}{N} \tag{1}$$

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 range from 0 to 1.

The concentration factor is the concentration of the student's responses to the different options of each item. It could be expressed as follows:

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

In the equation, m stands for the number of multiple options and n_i is the number of student's responses to the i^{th} option, where i varies from 1 to m and N is the total number of students who wrote the test. The values of concentration factor also range from 0 to 1. In addition, Bao and Redish (2001) introduced concentration deviation (C_d), the concentration of students'

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alternative conceptions. The concentration deviation formula is given as follows:

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

In this case, n_s stands for the number of student's responses to the correct answer and all the notations in this equation are also the same as that of the concentration factor. The values of concentration deviation also range from 0 to 1.

Students' model states categorization

An important part of the concentration analysis is the characterization and categorization of students' model states. For its realization, the students' response patterns are formed by combining their response concentration scores with their response concentration factors. Then, three-level coding (Bao and Redish, 2001) is used to categorize students' response states (Table 1).

Bao and Redish (2001) used a simulated data and combined score and concentration factor to plot an *S-C* graph to show the score and concentration results of individual multiple-choice questions. Due to the constraint between the score and concentration factor, data points can only exist in the area between the two boundary lines (Figure 1).

This combination helped to code the concentration score and concentration factor that provide the student response patterns for each conceptual multiple-choice question. For this purpose, the possible students' model states categorization can be done by combining concentration scores with concentration factors and concentration deviation deviations (Table 2).

Consequently, the students' response patterns were formed by combining the response concentration factors with the response scores. The combination helped to code for the score and concentration factor that provided the student response patterns (model states) for each conceptual multiple-choice question.

Therefore, in response to the first research question, the concentration factor and the concentration deviation were compared using paired samples t-test to determine whether the student's responses were consistent or not in the conceptual diagnostics test. In response to the second research question, the students' response patterns were formed by combining their response concentration scores with their response concentration factors and three-levels coding was used to categorize students' response states (Tables 1 and 2).

Table 1: Three-level students' model states categorization

Concentration score (*S*)	Concentration factor (C_f)	Concentration deviation (C_d)	Levels
0≤C<0.4	0≤C<0.2	0≤C<0.2	Low (L)
0.4≤C<0.7	0.2≤C<0.5	0.2≤C<0.5	Medium (M)
0.7≤C≤1.0	0.5≤C≤1.0	0.5≤C≤1.0	High (H)

Table 2: Students' possible model states categorization

Pure state	One model state	HH	One correct model
		LH	One dominant incorrect model
Mixed state	Two models state	LM	Two possible incorrect models
		MM	Two models (correct and incorrect)
Random state	Null-model state	LL	Near random situation

RESULTS

Table 3 presents the distribution of student's responses to the CSEM multiple-choice questions, which includes the concentration score, concentration factor, and concentration deviation with their model states.

In response to the first research question, a paired samples t-test was conducted to evaluate the difference between the concentration factor and concentration deviation of the student's responses which showed that there was no statistically significant difference between the two concentrations of the student's responses (t = 1.23, p = 0.82) (Table 4). This showed that the student's responses to the CSEM were inconsistent and lay nearly in the random response state.

Figure 2, a circular model graph, represents the concentration factors and concentration deviations of the student's responses versus CSEM items. The graph can be used as characteristic explanation and feedback of the student's 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 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 low level and that their difference is insignificant.

In response to the second research question, three-level categorization of student's responses, Table 2, highlights that 81% of the student's responses were in the null-model state,

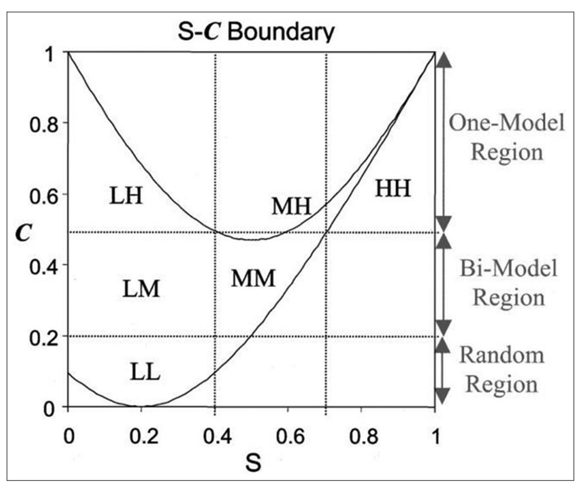

Figure 1: A plot showing model regions adopted from Bao and Redish, 2001

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https://doi.org/10.33828/sei.v30.i3.8

19% of the student's responses were in bimodal state, and none of the students' response was in the pure correct or incorrect one modal state (Table 3 and Figure 3). This means that the students had neither a pure correct nor incorrect model which showed the inconsistency of their conceptions.

DISCUSSION

The results of this study show that these participating students have difficulty understanding the basic concepts of electromagnetism and reveal that they lacked a coherent in-depth understanding of the concepts. This study's finding concurs with similar previous studies (Planinic, 2006; Dega et al., 2013a). These results show that the previous students learning had no significant impact on their conceptual development of electromagnetism concepts.

Table 3: Scores, concentrations, and levels of student's responses

Item	S	C_f	C_d	Response state
1	0.23	0.06	0.09	LL
2	0.10	0.09	0.09	LL
3	0.33	0.13	0.19	LL
4	0.41	0.20	0.16	MM
5	0.46	0.23	0.27	MM
6	0.18	0.09	0.14	LL
7	0.15	0.04	0.04	LL
8	0.21	0.05	0.08	LL
9	0.18	0.11	0.16	LL
10	0.13	0.02	0.01	LL
11	0.08	0.11	0.08	LL
12	0.54	0.26	0.03	MM
13	0.28	0.05	0.05	LL
14	0.18	0.00	0.00	LL
15	0.08	0.11	0.08	LL
16	0.18	0.09	0.13	LL
17	0.26	0.06	0.10	LL
18	0.41	0.21	0.24	MM
19	0.05	0.21	0.16	LM
20	0.03	0.10	0.03	LL
21	0.41	0.22	0.13	MM
22	0.13	0.09	0.10	LL
23	0.23	0.13	0.20	LL
24	0.15	0.15	0.19	LL
25	0.21	0.02	0.03	LL
26	0.10	0.05	0.03	LL
27	0.26	0.04	0.05	LL
28	0.10	0.09	0.09	LL
29	0.33	0.07	0.06	LL
30	0.18	0.09	0.14	LL
31	0.03	0.11	0.04	LL
32	0.13	0.10	0.12	LL
Mean	0.21	0.11	0.10	

At present, the difficulty of students' conceptual understanding of the concepts in physics is a global problem. The Program for International Student Assessment (PISA), which measures the success of secondary education students of a range of countries, reported that the education systems of many countries were based on the memorization of facts and principles in science and cannot prepare students for integrating scientific concepts and principles to real-life situations (OCED, 2010). The PISA examination investigated if students were well prepared for future challenges and continued learning in their future lives. However, the score of many students in different countries around the world was low and they had poor conceptual understanding of the basic physics concepts (Bulunuz et al., 2014).

Similarly, the scores of university students in physics conceptual survey tests were low and <50% before and after instruction. For example, in the USA, students in algebra-based and calculus-based introductory physics levels scored 25% and 31%, respectively, in the CSEM (Maloney et al., 2001). Similarly, Pollock (2008) noted that university students in calculus-based physics course level scored 32% on the CSEM and 26% on the Basic Electricity and Magnetism Assessment. More importantly for the present study, in a quasi-experimental study of Ethiopian students in a calculus-based physics course scored 25% on a pre-test similar conceptual survey test (Dega et al., 2013b).

The methods of teaching physics in school and university in Ethiopia are mostly lecture based, physical and mathematical problem-solving, and demonstration. However, ways of treating student's misconceptions and conceptual change strategies are not mentioned in the physics curriculum (Dega, 2012). In addition, the students who have higher science achievement in school and strong academic background are not enthusiastic about joining physics program in university (Semela, 2010). Students perceived physics as a subject that is too abstract and theoretical and as such that they cannot see the application in their day-to-day life (Semela, 2010). As a result, most high-scoring students do not wish to undertake physics, and this results in low-scoring students studying physics. The

Table 4: Paired samples test (electromagnetism concepts)

Pair	Paired differences					t	df	Sig. (two tailed)
	Mean	Standard deviation	Standard error mean	95% confidence interval of the difference				
				Lower	Upper			
Pair 1 C_f-C_d	0.0022	0.054	0.0096	0.022	0.017	0.23	31	0.82

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https://doi.org/10.33828/sei.v30.i3.8

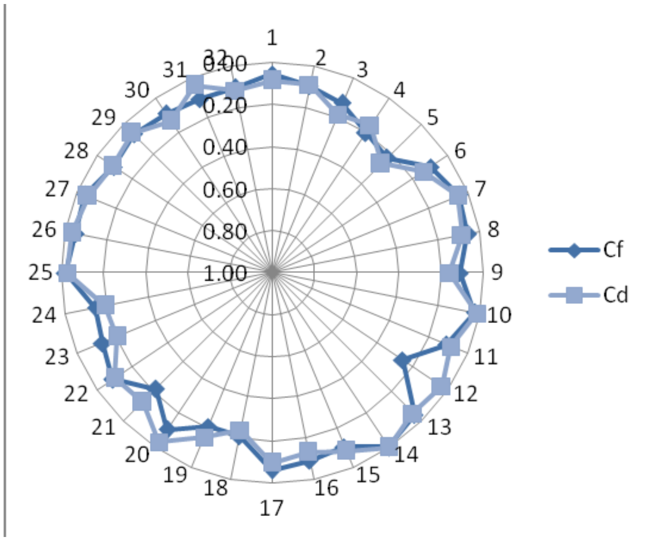

Figure 2: Concentration factor (C_f) and concentration deviation (C_d) versus EMCS items

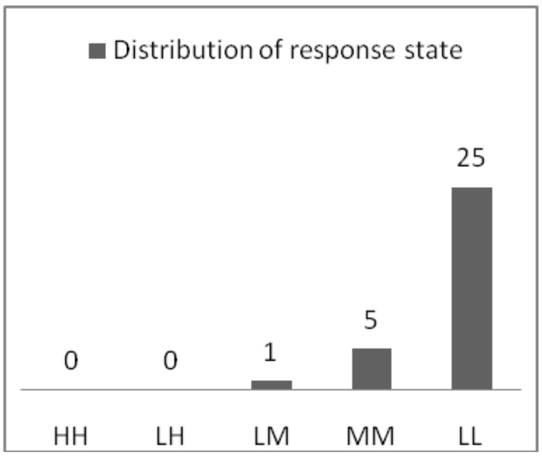

Figure 3: Categorization of students' response model states

enforcement is mainly due to the current high demand for physics teachers in schools. Therefore, the majority of students assigned to study physics are considered to lack interest, be low achievers, and lack academic success (Getenet, 2006).

Misconceptions are very stable and cannot be removed by traditional teacher-centered learning or by the transmission model of learning because conceptual change is a complex process that needs insight and intervention (Planinic, 2007). Concepts learning cannot be effectively done through transmission model of learning between students and the teacher (Baser and Gerban, 2007; Hake, 1998). Thus, schools and universities are advised to apply concepts learning strategies.

CONCLUSION

This study was aimed to investigate 117 first-year students' response states in electromagnetism concepts in a university in Ethiopia. A paired samples t-test ($t = 1.23$, $p = 0.82$) showed that there was no statistically significant difference between the concentration factor and concentration deviation of the student's responses. It was also revealed that the student's responses to CSEM test were nearly random and have no pure state. Thus, based on the results, it can be concluded that the student's responses were inappropriate and counterproductive to the scientific conceptions of electromagnetism. In addition, it may be concluded that the students' previous learning was not supported by concepts learning strategies in science. Hence, it is recommended that schools and universities should encourage science teachers so that they need to apply research-based conceptual change 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 toward the use of the current findings in discipline-based education research, like Physics Education Research (Singer and Smith, 2013).

REFERENCES

Bao, L., & Redish, E.F. (2001). Concentration analysis: A quantitative assessment of student states. *Physics Education Research, American Journal of Physics*, 69(7), S45-53.

Baser, M., & Geban, O. (2007). Effect of instruction based on conceptual change activities on students' understandings of static electricity concepts. *Research in Science and Technological Education*, 25(2), 243-267.

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.

Chabay, R., & Sherwood, B. (2006). Restructuring the introductory electricity and magnetism course. *American Journal of Physics*, 74(4), 329-336.

Dega, B.G. (2012). *Conceptual Change through Cognitive Perturbation using Simulations in Electricity and Magnetism: A case study in Ambo University, Ethiopia* (Doctoral dissertation): University of South Africa.

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

Dega, B.G., Kriek, J., & Mogese, T.F. (2013b). Students' conceptual change in electricity and magnetism using simulations: A comparison of cognitive perturbation and cognitive conflict. *Journal of Research in Science Teaching*, 50(6), 677-698.

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

Dykstra, D.I., Boyle, C.F., & Monach, I.A. (1992). Studying conceptual change in learning physics. *Science Education*, 76(6), 615-652.

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.

Galili, I. (1995). Mechanics background influences students' conceptions in electromagnetism. *International Journal of Science Education*, 17(3), 371-387.

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

Grayson, D.J. (1994). Concept Substitution: An instructional strategy for Promoting conceptual change. *Research in Science Education*, 24, 102-111.

Hake, R.R. (1998). Interactive-engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

Jelicic, K., Planinic, M., & Planinsic, G. (2017). Analyzing high school students' reasoning about electromagnetic induction. *Physical Review Physics Education Research*, 13(1), 1-18.

Leighton, J.P., & Gierl, M.J. (2007). Why cognitive diagnostic assessment?

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30(3), 217-222
https://doi.org/10.33828/sei.v30.i3.8

In: Leighton, J.P., & Gierl, M.J. (Eds.), *Cognitive Diagnostic Assessment for Education: Theory and Applications*. New York: Cambridge University Press. p3-18.

Leppävirta, J. (2012). The effect of naïve ideas on students' reasoning about electricity and magnetism. *Research in Science Education*, 42(4), 753-767.

Maloney, D.P., O'Kuma, T.L., Hieggelke, C.J., & Heuvelen, A.V. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics*, S69(7), 12-23.

McDermott, L.C. (2001). Oersted medal lecture 2001: Physics education research: The key to student learning. *American Journal of Physics*, 69(11), 1127-1137.

Organisation for Economic Co-Operation and Development (OCED). (2010). *PISA 2009 Results: What Students know and can do: Student Performance in Reading, Mathematics and Science*. Vol. 1. Paris: PISA, OECD Publishing.

Planinic, M. (2006). Assessment of difficulties of some conceptual areas from electricity and magnetism using the Conceptual survey of Electricity and magnetism. *American Journal of Physics*, 73(12), 1143-1148.

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

Pollock, S.J. (2008). *Comparing Student Learning with Multiple Research-based Conceptual Surveys: CSEM and BEMA*. Vol. 1064. AIP Conference Proceedings. p171-174.

Saglam, M., & Millar, R. (2006). Upper high school students' understanding of electromagnetism. *International Journal of Science Education*, 28(5), 543-566.

Scaife, T.M., & Heckler, A.F. (2010). Student understanding of the direction of the magnetic force on a charged particle. *American Journal of Physics*, 78(8), S69-S76.

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

Singer, S., & Smith, K.A. (2013). Discipline-based education research: Understanding and improving learning in undergraduate science and engineering. *Journal of Engineering Education*, 102(4), 468-471.

Soto-Lombana, C., Otero, J., & Sanjosé, V. (2005). A review of conceptual change research in science education. *Journal of Science Education*, 6(1), 5-8.