Contrasting-cases problems: learning material to improve students’ conceptual understanding on magnetism

R Cahyaningrum¹, A Hidayat² and Sutopo²

¹ Graduate Program of Physics Education, State University of Malang, 5 Semarang Street Malang, Indonesia
² Department of Physics, Faculty of Mathematics Natural Sciences, State University of Malang, 5 Semarang Street Malang, Indonesia

Abstract. We have developed three sets of contrasting-cases problems as learning material to improve students’ conceptual understanding on magnetism. The contrasting-cases problems consisted of several different problems with the same physic idea. This paper reports the effectiveness of the learning material drawn from a quasi-experiment, one group of pre-test post-test design. The subject consisted of 24 undergraduate students of physics education enrolling electromagnetism course in the State University of Malang. The results showed that the contrasting-cases problems effectively improved students’ understanding with very high d-effect size (2.12). However, some sets of contrasting-cases problems need to be improved.

Keywords: Contrasting-case strategy, Student’ difficulty, Magnetism topic.

1. Introduction
Student’s difficulties in physics are common issues that are often discussed in physics education research for many specific topics such as Newtonian mechanics, impulse-momentum, thermodynamics, electricity, and magnetism [1-3]. Some researchers have revealed common students’ difficulties on magnetism, for example in explaining the magnetic fields’ concept [1, 2, 4], in understanding the electromagnetic inductions [1, 5, 6], and in explaining the physical meaning of Faraday’s law [5-8].

The conceptual students’ difficulties are studied deeply in a misconceptions theory or naïve theory [9]. According to the theory, students who come to physics class cannot be regarded as “empty glasses”, but they have their own conceptions which are usually different from scientific conception. Students’ misconception interferes with scientific conception taught by the teacher or presented in the textbook [9]. Students also have a basic knowledge built on a lot of efforts and repetitions (learning time). The basic knowledge is usually suitable for some occurred phenomena. Therefore, they are difficult to give the new true knowledge [9]. At least, a student who has a wrong knowledge is resistant, so he/she needs much time to change it.

A good conception has to be built by the students themselves. They can build it by studying in the class but it has a limited time. The students will not get the meaningful knowledge when they do not foster themselves. We gave some various problems to deepen the material either inside or outside the class [10-12]. This action improved a good foundation to study a more complex context [13].

On the other hand, the problem which is given to the student must be different and makes them think deeply. Giving a problem with different cases enables the students to find the key features of the material [14]. Contrasting cases are one of the strategies that help the students to build their knowledge independently. The different cases assist the students to distinguish important forms of a phenomenon
Contrasting cases present a wide range of different cases and help them to find the key points of the concept [15].

Contrasting cases are a fundamental strategy which improves basic knowledge. This strategy helps the students to understand a concept by analogy of one case to others [16]. It makes the students ready accepting new concept in the next class [14, 16]. The contrasting cases strategy gives a good impact to student. They learn to find the key feature from the concepts and improve their conceptual understanding [14]. Based on the previous study, we know that using contrasting cases strategy helps students to identify unusual phenomena deeply [6, 17-19]. Therefore, this study aimed to analyze the impact of the exercise with contrasting cases strategy to overcome the students’ difficulties on the magnetism topic.

We have developed three packages of contrasting-cases problems as a learning material to improve students’ understanding on magnetism topic. The first package covered Biot-Savart law and magnetic flux; the second one covered Ampere law, the magnetic force on a charge moving in a homogeneous magnetic field, and a magnetic force on a current-carrying straight-wire; and the last covered torque on a current loop in a homogeneous magnetic field, and electromagnetic induction. Overall there are 26 multiple-choice problems with immediate feedback. We provide feedback for every option. The feedback is designed to either strengthen student understanding [22], revise misconception [23], or overcome students’ difficulties in making sense of a concept [24]. We have implemented the learning material in electromagnetism course, offered to the 3rd students of physics education, State University of Malang. This paper focuses to report the effectiveness of the learning material to improve students’ understanding.

2. Method
The subjects of this study consisted of 24 undergraduate physics education students at State University of Malang enrolling Electromagnetism Course. The sequences of this research consisted of pre-test, intervention, and post-test. The pre-test was administered one week just after the students learned magnetism through the lecture section, and the post-test was administered after the students completed the intervention. Pre-test and post-test used the same instrument consisting of 20 multiple-choice items. In addition, to choose the correct answer, the students need to write their explanation or mathematical manipulation they use to solve the problems. The instrument has a good internal reliability with a Cronbach alpha coefficient of 0.75.

The intervention was carried out for 3 weeks after pre-test. We provided the students with three packages of contrasting-cases problems that cover 7 topics on electromagnetism. The first package covered Biot-Savart law and magnetic flux; the second one covered Ampere law, the magnetic force on a charge moving in a homogenous magnetic field, and a magnetic force on a current-carrying straight-wire; and the last covered torque on the current loop in a homogeneous magnetic field, and electromagnetic induction. Overall, there were 26 problems.

We used a quantitative approach to justify the effectiveness of the intervention. The quantitative data consisted of pre-test and post-test scores drown from the students’ responses on multiple-choices-test. We used d-effect size to justify the effectiveness of the intervention [24]. We also discussed the strength and weakness of the learning material based on the student responses to the test.

3. Results and Discussion
Based on the quantitative analysis we concluded that the contrasting-cases intervention could improve the students’ understanding of basic ideas in magnetism. The students’ scores significantly improved from pre-test to post-test ($t = 8.347$; $df = 23$; $p = 0.000$), with d-effect size of 2.12, which was in a very high category. A number of the students choosing the correct answer also increased for almost all items (figure 1).
Figure 1. The numbers of students choosing correct answer in pre-test and post-test for each item

Based on the data presented in figure 1, for many items, the numbers of students correctly answering the problem significantly increased from pre-test to post-test. The item number 8 was the highest one. The problem is about magnetic force on moving charge in a homogeneous magnetic field. On the other hand, there is an item that was from pre-test to post-test decreased (number 6). The item number 6 is about Ampere law. Therefore, it is interesting to understand more deeply the phenomena.

3.1 The Strength of the Learning Material

The students’ responses to the item test number 8 would be useful to describe the strength of the learning material. Problem 8 is an item to which the numbers of the students’ correct answer significantly increased from pre-test to post-test. This problem accesses the students’ understanding of the motion of electron when entering the homogeneous magnetic field (figure 2). The students’ responses to the problem are summarized in table 1.

**Problem number 8**

An electron moving at light velocity enters the center of a uniform magnetic field of 0.04 T (see figure below). The electron has a mass of $9 \times 10^{-31}$ kg and a charge of $-1,6 \times 10^{-19}$ C. The electron when entering these magnetic field will...

A. be deflected upward with 4 cm trajectory radius  
B. keep moving in the right direction at constant speed  
C. be deflected downward to form a semicircle with a radius of 4 cm  
D. move on a circular orbit and be trapped in a magnetic field with a radius of 2 cm
Table 1. Cross Tabulation of Students’ Answers on Problem 8

|          | Pretest | Post-test | Total |
|----------|---------|-----------|-------|
|          | A       | B         | C*    | D     |       |
| A        | 0       | 0         | 10    | 0     | 10    |
| B        | 0       | 0         | 2     | 0     | 2     |
| C        | 0       | 0         | 5     | 1     | 6     |
| D        | 0       | 0         | 3     | 0     | 3     |
| abstain  | 0       | 0         | 3     | 0     | 3     |
| Total    | 0       | 0         | 23    | 1     | 24    |

*) Right Answer Option

On pre-test, 10 students claimed that the electrons would be deflected upward when entering a region with a magnetic field (option A), 2 students thought that the electrons would continue to move without being deflected when entering the magnetic field (option B), and 6 students claimed that the electrons would move in a circular orbit (option D). Only 6 students correctly answered the problems. On the other hand, 23 of 24 students obtained the correct answer on the post-test.

The increase in the numbers of students that correctly answered the problem implied that the students learning through solving relevant contrasting-cases problems have improved their understanding. Therefore, it is useful to review contrasting-cases problems the students use as learning material.

The contrasting-cases problems that are relevant to this context are problems 4.1, 4.2, 4.3, and 4.4 (figure 3 to 6). The problems are about “the magnetic force on moving charged particles in a homogeneous magnetic field.”

The Problem of Contrasting Cases 4.1
If a charged particle is in a magnetic field then what will happen is ….
A. Particles experience to the magnetic force caused by the movement of the particle
B. Particles get a magnetic force that makes them get kinetic energy
C. Particles experience to the magnetic force having maximum value as moving in the direction of the magnetic field
D. Because of a magnetic field, a magnetic force exerts to particle either when it is at rest or in motion.

Figure 3. The Problem of Contrasting Cases 4.1, Magnetic Force on Moving Particles in a Homogeneous Magnetic Field

Contrasting-cases problem 4.1 (figure 3) asks the students to identify the behaviour of charged particles (either positive or negative) in a homogeneous magnetic field. The students were expected to distinguish the behaviour of charged particles at the rest or while moving. When the charged particles are at the rest, there is no magnetic force. Conversely, when the charged particles move, the particle will be influenced by the magnetic force, which is formulated by \( \vec{F} = q\vec{v} \times \vec{B} \). The magnetic force will be maximum when the direction of particles’ motion is perpendicular to the magnetic field. The correct answer to the problem is the particles experience a magnetic force if they are moving in the magnetic field.
Figure 4. The Problem of Contrasting Cases 4.2, Magnetic Force on Moving Particles in a Homogeneous Magnetic Field

Problem 4.2 (figure 4) asks the students to analyze the movement of negatively charged particles (electrons) upon entering a homogeneous magnetic field. Cartesian coordinates were added to make it easier to analyze the direction of motion within the graph. The direction of electron motion is given in option B, which is deflected toward the y-axis.

The Problem of Contrasting Cases 4.3

Three subatomic particles A, B, and C are fired with the same initial velocity into the magnetic field from the left. If the path of the three particles is shown in the figure, sequentially the particles A, B, and C are…

A. Neutron, Proton, and Electron
B. Proton, Electron, and Neutron
C. Electron, Proton, and Neutron
D. Electron, Neutron and Proton
E. Proton, Neutron and Electron

Figure 5. The Problem of Contrasting Cases 4.3, Magnetic Force on Moving Particles in a Homogeneous Magnetic Field.

The problem 4.3 (figure 5) asks the students to identify the type of charged particles based on their moving direction in the magnetic field. The purpose of this problem is to strengthen the students' understanding of the concept of charged particles motion (protons and electrons) and neutron particles in a homogeneous magnetic field. The proton and electron particles will be deflected as they move inside the magnetic field. Neutron particles will not be deflected as they move inside the magnetic field. The correct answer is stated in option C.
4.4, Magnetic Force on Moving Particles in a Homogeneous Magnetic Field.

Problem 4.4 (figure 6) asks the students to link the magnetism concept to the mechanics concept that has been studied in the previous semester. The problems discuss what will happen when a charged particle moves into a magnetic field. The moving charged particles in magnetic field will be deflected to certain angle and have a certain angular velocity too. If the electric charge particles decrease by the time, then how does it affect the linear velocity and the angular velocity. There are 2 analysis to get the linear velocity and the angular velocity namely:

- Linear Speed: The analysis was done according to Newton’s 2nd Law, that force is proportional to its linear acceleration (\( F \sim a \)). Since the magnetic force is perpendicular to its linear velocity (\( \vec{F}_B \perp \vec{v}_0 \)) then \( \vec{a}_B \perp \vec{v}_0 \) (acceleration (\( \vec{a}_B \))) only changes the direction of velocity (\( \vec{v}_0 \)) without changing its magnitude. Therefore, the linear velocity is constant, the acceleration only changes the direction, without changing the magnitude.

- Angular speed: When particles move circularly at the particles work angle speed (\( \omega \)). The angular velocity equation of the particle is \( \omega = \frac{v}{r} = \frac{qB}{m} \). The angular velocity of charged particles is proportional to the charge \( q \) and the magnetic field \( B \), and inversely proportional to the mass. So as the charge decreases over time, the linear velocity is constant, but the angular velocity is decreasing (option A).

The number of different cases in this context leads to the students’ a robust understanding. All problems refer to the same main idea that is the concept of magnetic force in moving charged particles in a homogeneous magnetic field. This result is supported by Salehi’s research which found that contrasting cases in physics help student to manage the complexity of the material with small cases to reach a major form [17].

3.2 The Weakness of the Learning Material
The only problem that has decreased the true score of pre-test and post-test is number 6, that decreased 4 points. It could represent the weakness of this material. This problem accesses the students’ understanding of the physical meaning of Ampere law, \( \nabla \times \vec{B} = \mu_0 J \) (figure 7).

### The Problem of Contrasting Cases 4.4
An electrically charged particle moves into the magnetic field. During the motion, the electrical charge of the particles decreases linearly with time. The decrease effects of particles electrical charge on the linear speed and angular speed are respectively….

A. Constant and Reduced  
B. Constant and Increases  
C. Reduced and Constant  
D. Increases and Constant  
E. Increases and Reduced  
F. Reduced and Increases

### Figure 6. The Problem of Contrasting Cases 4.4, Magnetic Force on Moving Particles in a Homogeneous Magnetic Field.

**Problem number 6**
The Ampere law is formulated as \( \nabla \times \vec{B} = \mu_0 J \). The physical meaning of this Ampere law is …

A. On a straight wire flowing electric current with an upward direction will produce a rotating magnetic field.
B. Static magnetic field can produce electrical current
C. Electric current is generated by divergence of magnetic field
D. The flow of electric current on a circular wire cannot produce a magnetic field

**Figure 7. Pre-test and Post-test Problem No 7**
The students’ answers in pre-test and post-test are tabulated in table 2. Based on this table, some students had changed the answer. The students had answered correctly at the pre-test and they changed to choose the wrong option, and vice versa. The student who thought that the electric current will be produced by rotating magnetic field, changed it. In the post-test, 1 student said that the electric current could be produced by a static magnetic field (option B) and 4 student thought that the electric current was generated by the divergence of a magnetic field.

Meanwhile, there were some students who still chose the wrong answer. In the pre-test and post-test, 3 students thought that the divergence magnetic field generated the electric current and 1 student claimed that the flow of electric current on a circular wire could not produce a magnetic field. Those conditions describe that the students did not understand the concept of divergence and rotation. The students also had a misconception about the concept of magnetic field on the straight-wire and circular electrical wire.

Table 2. Cross Tabulation of Students’ Answers on Problem No 6

|        | A  | B  | C  | D  | Total |
|--------|----|----|----|----|-------|
| Pre-test |    |    |    |    |       |
| A      | 13 | 1  | 4  | 0  | 18    |
| B      | 0  | 0  | 0  | 0  | 0     |
| C      | 2  | 0  | 3  | 1  | 6     |
| D      | 0  | 0  | 0  | 0  | 0     |
| Total  | 15 | 1  | 7  | 1  | 24    |

*) correct answer option

On the other hand, there were some students who chose the correct answer. There were 13 students were consistent choosing the true option in the pre-test and post-test. They thought that the rotational magnetic field generated an electric current (option A). Two students who claimed that the electric current generated by the divergence magnetic field (option C) changed their answer to choose the correct one.

Based on the presentation, we know that the students who chose the correct answer in post-test are decreasing. This condition describes the weakness of the learning material. The result is possible because of the limited problem on contrasting cases. There are two problems which represent Ampere’s law concept. The contrasting cases that are relevant to this context are problems 3.1 and 3.2 (figure 8 and 9).

The Problem of Contrasting Cases 3.1

The magnetic field can be formulated mathematically based on both the Biot-Savart law, i.e

\[ \mathbf{B} = \frac{\mu_0 I}{4\pi} \frac{d\mathbf{s} \times \mathbf{r}}{r^2} \]

and the Ampere law, i.e \( \oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I \). In general the meaning of \( d\mathbf{s} \) is… .

A. The very small wire element that carries current \( I \)
B. Wire length vector carrying current \( I \)
C. None of the above statements are true about \( d\mathbf{s} \)

Figure 8. The Problem of Contrasting Cases 3.1, Ampere Law

Problem 3.1 accesses the explanation about Ampere law physical meaning. As previously studied, to determine the magnetic field can be derived through two models of formulation, Biot Savart law and Ampere law. There is a variable \( (d\mathbf{s}) \) in both laws but has a different meaning. At this point, the students distinguished the physical meaning of this variable. The \( d\mathbf{s} \) variable in the Biot-Savart law means a small section (segment) of the wire fed by an electric current. While in Ampere law, the \( d\mathbf{s} \) variable explains the small segment of the magnetic field encircling the wire which is freely determined. This
direction is determined by the right hand’s rule (the thumb as the electric current and the other finger as the magnetic field).

The Problem of Contrasting Cases 3.1

Notice the drawing of some closed trajectories around the electrical wire. According to Ampere law, the order of magnitude of the magnetic field $\vec{B}$ from the smallest to the largest is ....

A. $B_a < B_b < B_c < B_d$  
B. $B_b < B_a < B_c < B_d$  
C. $B_c < B_d < B_a < B_b$  
D. $B_d < B_c < B_b < B_a$

![Picture number 3.1](image)

**Figure 9.** The Problem of Contrasting Cases 3.2, Ampere Law

Problem 3.2 asks the students to rank the magnetic field on a straight wire based on 4 closed trajectories. The problem is adapted from Serway 2nd edition [26]. Based on the description of the ampere law $(\oint \vec{B} \cdot d\vec{s} = \mu_0 I)$, then we know the magnetic field in the straight-wire electric current is $\vec{B} = \frac{\mu_0 I}{2\pi r}$. The magnetic field is generated on the magnetic trajectory that surrounds the wire. The greater radius of the magnetic field trajectory makes the smaller magnetic field. The most appropriate answer to the problem is option B, ie $B_b < B_a < B_c < B_d$.

Based on the number 6, we know that the students decreased the correct number from pre-test to post-test. It means the students still had difficulties with the ampere law’s concept. They did not understand the concept correctly, so their answer easily changed. It is possible because there are 2 problems in this context. The problems did not represent the ampere law’s concept comprehensively. A little problem with contrasting cases strategy did not help the students to find the main features of the concept yet. Therefore, to support a good concept understanding, we have to present many contrasting cases in the same idea [16].

According to all discussions, we conclude that giving problems with contrasting cases strategy can improve students’ conceptual understanding. Each context must contain more than 3 problems to help the students to understand and strengthen their concept. The problems are supplemented with immediate feedback to sharpen the concepts and improve the wrong conception [23]. It is in accordance with Kuo (2016) and Chin (2016) saying that comparing several contrasting cases could improve students’ mastery of physics materials [11, 14].

4. Conclusion

The exercise with contrasting cases strategy helped the students to increase their score from pre-test to post-test. This statement also indicated that the students’ difficulties reduced from pre-test to post-test. The results and the analysis suggest that giving the exercise in contrasting cases supports the improvement of pre-test and post-test scores. The form of contrasting cases was designed by a context of knowledge with several different problems. This problem is supplemented with feedback to reinforce the concepts and improve the wrong conceptions. The effectiveness of the exercises were very high with d-effect size reached 2.12 included in the very large category. In addition, the statistical test explained that there was a significant correlation between pre-test and post-test. However, the number of problems of contrasting must also be considered because it influences the pre-test and post-test. We suggest the next research to give a lot of problems with contrasting cases.
strategy to the student. It aims that students can find the key features of a concept and help to overcome their difficulties.

5. References
[1] Guisasola J, Almudi JM, and Zaza K 2013 (International Journal of Science Education) 35 pp 26 92–717
[2] Saarelainen M, Laaksonen A, and Hirvonen PE 2007 (European Journal of Physics) 28 pp 51–60
[3] Saifulah AM, Sutopo S, and Wisodo H 2017 (Jurnal Pendidikan IPA Indonesia) 30 pp 6
[4] Mauk HV and Hingley D 2005 (American Journal of Physics) 73 pp 1164–71
[5] Thong WM and Gunstone R 2007 (Research in Science Education Springer Nature) 38 pp 31–44
[6] Zaza K, Guisasola J, Michelini M, and Santi L 2012 (Europe Journals of Physics) 33 pp 397
[7] Zaza K, Almudi J-M, Leniz A, and Guisasola J 2014 (American Physical Society (APS)) 30 10
[8] Albe V, Venturini P, and Lascours J (Journal of Science Education and Technology) 10 197–203
[9] Docktor JL and Mestre JP 2014 (American Physical Society (APS)) 1610
[10] Oliveira PC and Oliveira CG 2013 (European Journal of Engineering Education) 38 417–24
[11] Rahmawati I, Sutopo S, and Zulaikah S 2017 (Jurnal Pendidikan IPA Indonesia) 30 6
[12] Hassouny EHE, Kaddari F, Elachqar A, and Alami A 2014 (Procedia - Social and Behavioral Sciences) 116 4617–21
[13] Sadaghiani HR 2011 (Review Special Topics - Physics Education Research American Physical Society (APS)) 24 7
[14] Chin DB, Chi M, and Schwartz DL 2016 (Instructional Science Springer Nature) 44 pp 177–95
[15] Kuo E and Wieman CE 2015 (Physical Review Special Topics - Physics Education Research American Physical Society (APS)) 17 11
[16] Kuo E and Wieman CE 2016 (Physical Review Physics Education Research American Physical Society (APS)) 5 12
[17] Salehi S, Keil M, Kuo E, and Wieman CE 2015 How to structure an unstructured activity: Generating physics rules from simulation or contrasting cases (Physics Education Research Conference Proceedings American Association of Physics Teachers PACS) 01 40 01 50 ht
[18] Schwartz DL, Chase CC, Oppezzo MA, and Chin DB 2011 (Journal of Educational Psychology American Psychological Association (APA)) 103 pp 759–75
[19] Shemwell JT, Chase CC, and Schwartz DL 2014 (Journal of Research in Science Teaching Wiley) 52 pp 58–83
[20] Cresswell J, Clark 2008 Designing and Conducting Mixed Method Research (United States of America: Sage Publication Inc)
[21] Kim E and Pak S-J 2002 American Journal of Physics American Association of Physics Teachers (AAPT) 70 pp 759–65
[22] Butler AC and Roediger HL 2008 (Memory & Cognition Springer Nature) 36 pp 604–16
[23] Frank BW and Scherr RE 2012 (Physical Review Special Topics - Physics Education Research American Physical Society (APS)) 13 pp 8
[24] Laskowski LJ 2018 (Nursing Ovid Technologies (Wolters Kluwer Health)) 48 p 6
[25] Morgan GA 2004 SPSS For Introductory Physics, Use and Interpretation, Second edition (Mahwah, New Jersey London : Lawrence Erlbaum Associates, Publishers)
[26] Serway RA and Jewet JW 2014 Fisika untuk Sains dan Teknik (Jakarta: Salemba Teknika)