Students’ understanding of electric fields in the context of multiple representation

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Abstract. This study aims to describe physics students' understanding of the concept of electric fields through a multi-representation review in a qualitative way. This research is a qualitative research using test and interview techniques to obtain the data. The research subjects consisted of 6 students from Physics Education department. The test used is an essay test which includes indicators of translation, interpretation and extrapolation on the concept of an electric field. The more in-depth interviews with respondents related to the concept of the electric field were carried out in this study. Based on data analysis, it can be concluded that students' conceptual understanding is in the moderate category. The highest scores obtained are in translation, interpretation, and extrapolation respectively, which show that the level of indicator complexity affects student achievement. This research implies that the poor conceptual understanding of students on extrapolation indicators caused by the lack of creativity in students' thinking in exploring the whole information presented on a particular issue. Thus, a learning method that prioritizes high-level critical thinking skills is extremely needed.

1. Introduction

Physics is closely related to natural phenomena in the universe, such as phenomena on electrically charged objects. In an electrically charged object, various important phenomena occur, such as the transfer of electric charge, electric force, or changes in electric potential energy. Every human being needs electricity to support daily activities. Without realizing it, the need for electrical energy will continue to increase along with the growth in population, technological developments, and education development. There is an awareness of the current mindset that the big challenges for society related to electronic devices and energy-efficient computing related to electricity require better-integrated technology [1]. Success in developing technology cannot be separated from assessment activities in understanding the concept of electricity. Understanding is the basis for students to build insight. Misunderstanding of physics concepts can create gaps between teaching and students' understanding and impact students’ learning outcomes [2].

One of the most essential components in the material on electrical topic that needs to be investigated is the electric field. Many methods can be carried out to learn the concept of electric fields in physics. One of them is through multi-representation. Learning activities that involve multiple representations provide a rich context for students to comprehend a concept [3]. Students' success in solving physics problems is influenced by the ability to represent the algebraic-based physics material [4]. These representation formats are very essential in studying physics, including verbal representations, pictures, graphs and mathematics [5]. Graphical representation can help students to conceptualise abstract mathematical structures in vector calculus when understanding Maxwell’s
equations [6]. It is necessary to introduce learning models and teaching materials with multiple representations to students in order to gain a better understanding. The right representation choice can generate a simpler view of the dynamic mechanism by shifting some of the complexity into the representation itself [7]. Therefore, students' representational abilities make a significant contribution in understanding the concept of an electric field. However, there are also some difficulties encountered when using multiple representation formats in understanding physics concepts.

Students have difficulty representing electric field vectors using representational geometric features and solving electric field problems [8]. Students' understanding of the field concept in electromagnetism shows that most students do not have a coherent conception of electric field characteristics [9]. Many students failed to choose the appropriate coordinate system when writing mathematical expressions for vector fields to solve electric field problems [10]. Students still have difficulties in recognizing the representation of electric field lines compared to vector field plots, algebraic notation, and the density of field lines as the magnitude of the electric field [11].

Research conducted by Gire and Price on understanding the concept of electric field vectors only focuses on using mathematical representations [8]. Bollen et al. have conducted research on students' difficulties in symbolic representation of electric field materials [10]. In addition, Campos et al. have conducted an investigation on students' understanding of the concept of an electric field that focuses on mathematical representation [11].

The above studies only focused on the format of mathematical representations but have not conducted research using verbal representation, pictures and graphics format. Therefore, it is necessary to conduct a study on the understanding of electric field concepts in physics students through a multi-representation review using verbal representation, picture and graphics format.

2. Method
This research was descriptive qualitative. It describes physics students' understanding of the concept of electric fields through a multi-representation review in a qualitative way. The subjects of this study were 6 students of Physics Education department. The data were collected through an essay test given to the respondents. Then, the interview in which two respondents used as the representative of each category of high, moderate, low was carried out. The essay test instrument contains the concept of an electric field which is presented in a multi-representation form. The essay test instrument used in this study consisted of 4 numbers, consisting of 3 aspects of representation: verbal, pictures and graphics. It also uses three indicators of concept understanding: translation, interpretation and extrapolation. After obtaining the data, qualitative data analysis was carried out using three stages: reducing data, presentation of data and drawing conclusions and verification. Descriptive analysis technique was carried out by analysing the match between the answers and the reasons for the respondents' answers which can show the mastery of the concepts possessed by the respondents on the electric field topic.

3. Results and Discussion
3.1 Indicator of Translation
As an example, the answer to RT-01 is presented for the context of the translation indicator in describing the picture as follows:

The electric field lines formed in the figure were attracted to each other because the electric charges are different from each other. It is also seen in the picture that the arrow lines on the positive charge point were oriented outward which means releasing electrons. Then, on the negative electric charge, the arrows on the lines were directed inward (towards the nucleus) which means it is receiving electrons released by a positive electric charge.

RT-01 explained that the electric field lines formed in the picture were attracted to each other because the electric charges on the two sides have different types. RT-01 can accurately describe the direction of the arrow as a sign of the direction of the electric field of the two charges, pointing from a positive charge to a negative charge. However, RT-01 did not describe the number of electric field lines formed between the two charges. This should be included in the answer presented by RT-01 because it is closely related to the electric field strength in terms of the value of the two electrical charges.
The limited explanation given by RT-01 in the interview is due to the respondent's lack of memory recall of the electric field concept and the answers given in the testing session. This phenomenon is in line with the findings of Sutriani and Mansyur that the poor memory of respondents at each stage of problem-solving provides a great opportunity for errors to occur [12].

3.2 Indicator of Interpretation

For example, the answer to RT-02 is presented for the context of the interpretation indicator in interpreting the graph as follows:

In the image, the graph is decreasing. Thus, noticeably that the electric field strength becomes weaker if the distance is increased.

RT-02 only gave the interpretation that the graph was decreasing, so that the electric field strength became weaker if the distance was increased. RT-02 only stated the field strength. He did not clearly state the particular electric field strength. RT-02 also did not interpret the dash line which should be able to provide important information related to the comparison between the electric field strength and the charge distance. When asked about the interpretation of the graph, RT-02 answered:

\[ RT-02: \text{So the graph is decreasing, as the graph becomes further, then, it will decrease. So the electric field strength becomes weaker if the distance is increased} \]

The researcher : How can you tell that the electric field strength is inversely proportional to the distance, which part of the graph do you think contains that information?

RT-02 : That part of the curve.

The researcher : So, what do you think the dash line on the graph mean in this case?

RT-02 : From the value of 0 to this R, the value of the field strength is zero

Based on the interview result above, RT-02 explained that the further away the graph was, the lower it would be. So, the electric field strength would decrease as the distance was also increased. The answer to RT-02 was still the same as the answer when working on written essay questions. During the interview, RT-02 explained the meaning of the dash line on the graph that the value 0 to R had a field strength value of zero. Compared to the answers from by RT-02 when answering written questions, RT-02 gave more answers during interviews.

RR-01 was given two images. The figure (a) shows a positive electric charge, which transfers electric current to negative charge. Meanwhile, figure (b) has a negative electric charge, which receives current from a positive electric charge. RR-01 interpreted figure (a) as a charge that transferred current to a negative charge. It was perceived from the direction of the arrow in the Figure. In Figure (b), RR-01 interpreted that a negative electric charge received current from a positive charge. There is only one point charge in each image, but the RR-01 understands it as two interacting charges. Thus, this is the error made by the respondent.

Respondents' answers were further explored through the interview method. The transcription is described as follows:

\[ \text{The researcher} : \text{What meaning do you catch based on the picture in the question?} \]

\[ RT-01 : \text{So in picture A, it is a positive charge, while in picture B, it is a negative charge. The positive charge direction of the electric force goes outward because it gives a negative charge. Then, for the negative the direction of the arrow is inward because it receives charges or ions.} \]

Based on the interview above, it can be concluded that the interpretation of RS-01 is in line with the results of the answers when working on written essay questions. RR-01 explained that the positive charge seen from the direction of the arrow in the picture pointed to the outward, means that the direction of the electric force is out because it gives a negative charge in the form of charges or ions. While for a negative charge, it only accepted electrons, so that the arrow pointed to the center of the negative charge.
3.3 Extrapolation Indicator

As an example, RS-01’s answer is presented for the context of extrapolating indicators in determining the type of charge and describing electric field lines as stated “The charge at point B is positive, the charge at point C is negative”. RS-01 responded correctly that at B was a positive charge and at C was a negative charge. Unfortunately, the RS-01 could not properly describe the electric field lines formed on the charges at A and D. RS-01 illustrated the electric field lines at A will point to the charge at D and past the charges at B and C. The number of lines and the direction of the electric field lines depicted were also incorrect.

Respondents’ answers were further explored through the interview method with the transcript described as follows:

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The researcher  :  What do you think should be in point B and C?
RT-01            :  The charge at point B is positive while the charge point C is negative
The researcher  :  Can you give an explanation related to the picture of the electric field lines formed at point A and D based on the charges at point B and C that you have described?
RS-01            :  I think the direction of the line from point A to D is mutually attractive because only one point is positive and the other is negative.
The researcher  :  So, do you mean that there is an interaction between charges at point A and D?
RS-01            :  Yes, they interact with each other because they are positive and negative.
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Based on the interview above, it can be concluded that RS-01 believed that there was an interaction between a positive charge at point A and a negative charge at point D. RS-01 ignored the charge in point B and C which should be considered in describing the electric field lines. The answer that RS-01 gave for the charge at point B was a positive charge and at point D was a negative charge. That was in line with the answers given when working on written questions.

3.4 Students’ Understanding on Electric Field

There were several essential information as a finding in this study, including the respondent’s understanding that if there are different charges, in this case, are positive and negative charges that interact with each other, the electric field lines formed will attract each other. The direction of the electric field lines formed starts from a positive charge towards a negative charge. Respondents understand that the further the distance between the charges, the weaker the electric field strength of the two charges. This was in line with the findings of Jelicic, Planinic, and Planinsic in their research that students consider the farther away from the center of charge, the effect of electromagnetic induction from the generated electric field will be weaker [13]. However, some findings contradict the electric field theory. RR-02 thought that the increasing distance from the charge center, the stronger the electric field would be. Reinforcing the findings of Mustakim et al, that respondents made conclusions by discussing conflicting data with the problems encountered [14]. In addition, the next finding in this study was that respondents understood the arrow image as electric field lines. In line with the findings of Bollen et al, in their research results, students were not aware of the difference between electric field lines and vectors. They did not fully understand the representation of electric fields [15].

The next interesting finding was in extrapolation indicators. Respondents only focused on the direction of the electric field lines directing from a positive charge to a negative charge. So, the electric field lines would pass through the two charges between the positive and negative charges. Confirming Campos’ findings that students did not understand the density of electric field lines and converted it into the algebraic form [11], this study also found some respondents who did not pay attention to the density of electric field lines when asked to describe electric field lines. Based on the study results, it showed that the understanding of the concept of electric fields in the translational aspect was quite good. This was proved by the acquisition score for the translation aspect, obtaining the highest score compared to other aspects. Respondents can described the pictures in verbal form quite well. As research conducted by Cao and Brizuella obtained, students understood concepts more easily through representation [16].
In line with the research conducted by Eynde et al, the respondents in that research had a good conceptual understanding of the translational aspects of the concepts of algebra and calculus [17]. However, in that research, there were still some respondents who could not translate between graphical and symbolic representations of mathematical relationships. The findings of this study were different from the research findings obtained by Wu and Liu that students' conceptual understanding of the translation aspect was mostly poor. It was obviously explained through some of the respondents' answers in their research that many were still failed in representing tables and figures and tend to be wrong in representing tables in verbal form [18].

Based on the study results, it was found that students' understanding of the interpretation aspect as depicted from the test results and interview quotes showed that most of the respondents were quite good at interpreting the questions in the form of image and graphic representations into verbal form. Although some respondents did not interpret the answers completely, their responses regarding the relation between the electric field strength and the distance of its electric field were sometimes incomplete. There were even the answers that erroneously distinguished between electric field vectors and electric field lines for questions in the form of image representation.

In line with a study conducted by Cnevic et al, some students did not achieve maximum results in interpreting schematic representations [19]. Students tend not to understand the theory of light waves well, so they could not write complete answers. During the learning process, students tend to be interested in visual things only. Based on the study result, it was found that the students' understanding of the electric field concept in the extrapolation aspect, as seen from the test results and interview, was still poor. Most of the students were unable to estimate the type of charge in the picture. Therefore, the respondents could not conclude the direction of the electric field formed in the figure. It was seen that some students made a mistake in determining the type of charge. There was still a sprinkle of errors when describing electric field lines. In addition, many students ignore the number of electric field lines depicted. The inability of students to understand the problem is the main cause of student failure in solving a problem [20].

In line with the findings of Pladninic et al, most of the respondents in their research could not predict the symbols or slope patterns of the graphs presented in the questions, causing most of the respondents to give wrong answers [21]. Contrary to the research results obtained by Susac et al, it showed that most students possessed a good understanding of extrapolation aspects. This can be seen from the number of students who generally succeed in estimating the shape of the graph from other contexts in the form of mathematics on kinematics topic [22].

Overall, the results of this study indicated that if sorted from the lowest three aspects of understanding, the following conclusions are obtained respectively (1). Extrapolation, (2). Interpretation, (3). translation. It showed that there were different levels among each aspect of understanding in the electric field concept.

4. Conclusion
Based on the description above, conceptual understanding can be inferred as the ability to grasp information regarding the concept and other related information, then, can restate the concept into a more in-depth interpretation. Based on the results of the study, it was found that the conceptual understanding of the electric field in the extrapolation indicator was at the lowest level compared to the translation and interpretation indicators. The students’ poor conceptual understanding on extrapolation indicators is caused by the lack of creativity in students’ thinking in exploring the overall information presented on a particular problem. Thus, a learning method that prioritises high-level critical thinking skills is extremely needed.

It is expected that students should explore their translation, interpretation, and extrapolation skills in each practice session, especially, in representing the form of questions. Not only through representations in the form of images, but also in the form of graphics and verbal. Thus, it will increase students' understanding of the concept of electric fields.

Future researchers are expected to conduct further research on students' conceptual understanding of electric fields and how to overcome the problem. Since it is essential to master conceptual learning, thus it can impact students' ability to solve problems.
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