Lorentz Force Practicum Tool (LoFoPaT): Enhancing Students' Conceptual Understanding in Physics

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Abstract: The Lorentz Force Practicum Tool (LoFoPaT) is a physics learning medium designed to visualize abstract concepts related to the direction of the Lorentz force. This study aims to describe the development of LoFoPaT and its effectiveness in constructing students’ understanding of Lorentz force concepts. The research employed a 4D model (Define, Design, Develop, and Disseminate). During the development stage, the tool was enhanced to generate a larger Lorentz force. Based on assessments by three experts using Mini-Facets Rasch 3.84.0 software, the results indicated that LoFoPaT is valid, though some revisions were suggested. In the dissemination stage, LoFoPaT was implemented with 20 high school students (11 females and 9 males) as research subjects. The Four-tier Instrument on Lorentz Force (FILOF) was used for pre- and post-test questions. The results demonstrated that LoFoPaT is effective in constructing students’ understanding of the Lorentz force at an intermediate level. In conclusion, LoFoPaT can be utilized as a physics learning medium in classrooms to enhance students’ conceptual understanding, particularly in visualizing the direction of the Lorentz force using the right-hand rule.

INTRODUCTION

Kurikulum Merdeka is a curriculum currently being applied in Indonesia, which requires problem-solving and project-oriented learning. However, in this curriculum, a strong understanding of physics concepts is essential. The physics concept plays a crucial role in supporting the resolution of problems to be solved (Phanphech, Tanitteerapan, & Murphy, 2019; Putranta & Supahar, 2019). Hence, physics conceptual understanding is fundamental for students.

At the high school level, students are required to understand physics concepts related to electricity and magnetism. In this sub-concept, students study the Lorentz force (Üre & Çoramık, 2021; Mbonyirivyuze, Yadav, & Amadalo, 2022; Hernandez, Campos, Barniol, & Zavala, 2022). The concept of the Lorentz force is abstract because it cannot be observed directly. When students learn this material, it becomes more challenging if it is only imagined without direct observation (Jelicic, Planinic, & Planinsic, 2017; Shubha & Meera, 2019; Sianipar, Sunaryo, & Astra, 2020; Ürek & Çoramık, 2021).

Based on early observation results at one of the schools in Tuban, East Java, 43% of the 210 students did not understand the concept of the Lorentz force. Additionally, based on the results of problems in previous lessons, students had difficulty determining the direction of the Lorentz force using the right-hand rule, as well as the direction of the
magnetic field and electric current. An example of this situation is shown in Figure 1, where a wire connected to a battery generates an electric current. The electric current in the wire is in a magnetic field, causing the Lorentz force to appear.

Students are still confused about why the copper wire can move up or down and the direction of its motion. When given problems with different conditions, students still cannot determine the direction of the Lorentz force. This difficulty arises because the concept of the Lorentz force is challenging for students to grasp (Fatmaryanti, Suparmi, Sarwanto, & Ashadi, 2018; Shubha & Meera, 2019).

The most frequently encountered difficulty is determining the direction of the Lorentz force. Research by Fatmaryanti et al. (2017) shows that numerous students make "sign errors" when determining the direction of the Lorentz force. The concept that the Lorentz force is perpendicular to the electric current and the magnetic field is not complemented by an understanding of vector multiplication. Direction labeling errors also occur in understanding field direction, magnetic poles, and cross-products (Kustusch, 2016; Saarelainen, Laaksonen, & Hirvonen, 2007).

Additionally, preliminary research results indicate that teaching and learning activities regarding the Lorentz force concept have not been conducted through practical activities, experiments, or hands-on skills. Instead, learning has been done using traditional methods, where students are given theory followed by practice questions (Samsudin, Suhandi, Rusdiana, Kaniawati, & Coştu, 2016; Shubha & Meera, 2019). The lack of practicum activities in class, compounded by the unavailability of laboratory tools in some schools, makes it difficult for students to understand the concept, especially determining the direction of the Lorentz force using the right-hand rule (Cahyono, Prabowo, & Admoko, 2018; Mufida, Sinaga, & Samsudin, 2021; Sianipar et al., 2020). Therefore, a learning tool is needed to address these problems and help construct a conceptual understanding of the Lorentz force for students.

Constructing student understanding can be facilitated through hands-on activities (Cai, Chiang, Sun, Lin, & Lee, 2017; Kittiravechote, 2020). Using learning tools aligns with constructivist learning, where students actively build their knowledge (Riaz, Marcinkowski, & Faisal, 2020). Therefore, this research developed a Lorentz Force practicum tool (LoFoPaT) as a learning medium to construct high school students' conceptual understanding. The physics learning media, LoFoPaT, was developed using a simple tool. LoFoPaT is useful for visualizing abstract Lorentz-force concepts, particularly determining the direction of the Lorentz force based on the right-hand rule. Traditional Lorentz-force practicum tools in some laboratories only use a thin wire, resulting in a small Lorentz force that is difficult to observe. In this LoFoPaT development, increasing the Lorentz force was achieved by requiring a larger current.

Based on this description, the aim of this research is to describe the development of physics learning media in the form of LoFoPaT, which is used for constructing students' conceptual understanding of the Lorentz force. The utilization of LoFoPaT addresses difficulties in learning physics concepts, particularly determining the direction of...
the Lorentz force based on the right-hand rule. The advantage of LoFoPaT compared to other tools is that it does not require a large voltage to increase the current; instead, adding a coil of wire suffices. Consequently, the resulting current will be substantial. The greater the current, the greater the Lorentz force, making it more visible to the observer.

METHOD

The research design employed a 4D model (Defining, Designing, Developing, and Disseminating), as described in Figure 2. This model was chosen because it aligns with the stages of LoFoPaT development. A detailed explanation of each stage of the 4D model used in this research is provided in the results and discussion section.

The research subjects were high school students from one of the districts of Tuban, East Java, selected using purposive random sampling. This area was chosen for the research because students there still face learning difficulties regarding determining the direction of the Lorentz force. The school is located 7.6 km to 9.1 km from Tuban district. The demographics of the research subjects are shown in Figure 3.

![Figure 2. Research Design of LoFoPaT use 4D Model.](image-url)
The research instrument consisted of five questions in a four-tier format, containing sub-concepts on the direction of the Lorentz force based on the right-hand rule, determining the direction of the magnetic field and the direction of the current, as well as the quantities that affect the magnitude of the Lorentz force. This instrument was developed by adapting the Magnetism Conceptual Survey (MCS) by Li & Singh (2016) and the Electricity and Magnetism Conceptual Assessment (EMCA) by McColgan, Finn, Broder, & Hassel (2017), which were modified to suit the high school level. Thus, this instrument is called the Four-tier Instrument on Lorentz Force (FILOF). The FILOF was used for both the pre-test and post-test. The reliability of FILOF, based on the value of Cronbach's Alpha, is 0.78.

The validation results from the LoFoPaT development were analyzed using the rater test of the Mini-facets Rasch 3.84.0 software. The students’ level of conception is coded and graded according to Table 1. Students’ conception levels are adapted from Aminudin, Kaniawati, Suhendi, Samsudin, Coştu, & Adimayuda (2019).

Table 1. Students’ Level Conception and Score.

<table>
<thead>
<tr>
<th>Categories of Students’ Conception</th>
<th>Tier 1 (Option)</th>
<th>Tier 2 (Level Confidence)</th>
<th>Tier 3 (Reason)</th>
<th>Tier 4 (Level Confidence)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Understanding (SU)</td>
<td>C</td>
<td>S</td>
<td>C</td>
<td>S</td>
<td>4</td>
</tr>
<tr>
<td>Partial Understanding Positive (PUP)</td>
<td>C</td>
<td>S</td>
<td>C</td>
<td>NS</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>NS</td>
<td>C</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Partial Understanding Negative (PUN)</td>
<td>C</td>
<td>S</td>
<td>IC</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>S</td>
<td>IC</td>
<td>NS</td>
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<td></td>
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<td>IC</td>
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<tr>
<td></td>
<td>IC</td>
<td>S</td>
<td>C</td>
<td>S</td>
<td>2</td>
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<tr>
<td></td>
<td>IC</td>
<td>S</td>
<td>C</td>
<td>NS</td>
<td></td>
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<th>Tier 4 (Level Confidence)</th>
<th>Score</th>
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</thead>
<tbody>
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<td>C</td>
<td>S</td>
<td>C</td>
<td>S</td>
<td>4</td>
</tr>
<tr>
<td>Partial Understanding Positive (PUP)</td>
<td>C</td>
<td>S</td>
<td>C</td>
<td>NS</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>NS</td>
<td>C</td>
<td>NS</td>
<td></td>
</tr>
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<td>C</td>
<td>S</td>
<td>IC</td>
<td>S</td>
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<td>C</td>
<td>NS</td>
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</tr>
</tbody>
</table>

20 students (age range 17-19 years).
9 males 11 females

Figure 3. School Location and Research Subject Demographics.
Categories of Students’ Conception | Tier | Score
---|---|---
No Understanding (NU) | 1 (Option) | IC S IC NS
No Coding (NC) | 1A | -

Description: Correct (C), Incorret (IC), Sure (S), Not Sure (NS), and Incomplete Answer (IA)

Table 2. Interpretation of N-Change Values.

<table>
<thead>
<tr>
<th>N-Change Score</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.7 &lt; \langle c \rangle \leq 1$</td>
<td>High</td>
</tr>
<tr>
<td>$0.3 &lt; \langle c \rangle \leq 0.7$</td>
<td>Intermediate</td>
</tr>
<tr>
<td>$0 \leq \langle c \rangle \leq 0.3$</td>
<td>Low</td>
</tr>
<tr>
<td>$-1 \leq \langle c \rangle &lt; 0$</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Furthermore, the distribution of students’ conceptions was analyzed using the Rasch Model with MINISTEP 4.7.0.0 software based on the results of the Wright map. The construction of students’ conceptual understanding was analyzed using Normalized-Change $\langle c \rangle$ (Marx & Karen, 2007). The N-Change values were categorized based on Table 2.

RESULT AND DISCUSSION

Defining

This stage involves an initial literature study of several references, followed by curriculum analysis and preliminary studies in several schools. The demands of basic competencies state that learners should be able to apply the concept of magnetic force to various knowledge and technological products and conduct experiments on magnetic forces around electrically flowed wires, presenting their findings. However, the results of the preliminary studies indicated that students had difficulty understanding the Lorentz force concept, particularly in determining the direction of the Lorentz force based on the right-hand rule. This finding aligns with research by Fatmaryanti et al. (2018), Campos, Hernandez, Barniol, & Zavala (2021), Hernandez et al. (2022), and Saarelainen et al. (2007). Consequently, a solution was proposed to create a physics learning medium, namely LoFoPaT.

Designing

LoFoPaT was made with simple materials and tools. The design of LoFoPaT is shown in Figure 4. After the switch is pressed, the indicator that there is an electric current is the light turning on. The presence of a current through the wire in the magnetic field will cause a Lorentz force (magnetic force). The appearance of the Lorentz force is indicated by a wire that deviates forward or backward. The greater the current, magnetic field, and length of the wire, the greater the Lorentz force ($F = B I L$).

![Figure 4. Design of LoFoPaT](image-url)
Developing

LoFoPaT was developed based on problems encountered in the laboratory, where typically only a thin strand of wire is used, resulting in a small Lorentz force that is difficult for observers to see. Consequently, the development stage of LoFoPaT involved adding a wire winding to generate a larger current. The wire winding is shown in Figure 5. The greater the current, the greater the Lorentz force. A larger deviation of the wire indicates a larger Lorentz force, making it observable to the viewer. Additionally, LoFoPaT can utilize a power supply with a DC voltage source instead of a battery.

Figure 5. Increasing of the Windings Number on the Wire.

![Figure 5. Increasing of the Windings Number on the Wire.](image)

Before being implemented in the class, LoFoPaT was validated by experts. Validation was analyzed using rater tests with Mini-Facets Rasch 3.84.0 software. The results of the rater test are shown in Figure 6. Based on Figure 6, the validators consist of three experts, namely Validators A, B, and C (blue box). The validation aspects are encoded with words in the green and yellow boxes. The validation aspects are described in Table 3.

Table 3. Description of Validation Aspects.

<table>
<thead>
<tr>
<th>Validation Aspects</th>
<th>Code on Wright Map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy-to-use tool for students</td>
<td>Easy</td>
</tr>
<tr>
<td>Interesting tools</td>
<td>Interesting</td>
</tr>
<tr>
<td>LoFoPaT can construct students’ concepts</td>
<td>Construct</td>
</tr>
<tr>
<td>LoFoPaT can be used to visualize abstract concepts is</td>
<td>Visualize</td>
</tr>
<tr>
<td>LoFoPaT can be used for demonstration activities</td>
<td>Demonstration</td>
</tr>
<tr>
<td>LoFoPaT can help students to find their knowledge</td>
<td>Knowledge</td>
</tr>
<tr>
<td>LoFoPaT functions as a supporting media for learning physics</td>
<td>Learning</td>
</tr>
</tbody>
</table>

The validation results using the rater test with the Mini-Facets (Minifac) Rasch software are presented in Figure 6. The Wright map results in Figure 6.
show that all validators assessed that LoFoPaT met the validation aspects in the green box, especially validator A. However, according to validators B and C, LoFoPaT needs improvements in the validation aspects marked in the yellow box. These improvements aim to enhance the tool's effectiveness. Validator B suggested increasing the Lorentz force by increasing the magnitude of the magnetic field and provided recommendations for improvements in the "Construct" and "Interesting" aspects. Overall, all validators (A, B, and C) stated that LoFoPaT is valid for use, with suggested improvements in the aspects of Construct and Interesting.

**Disseminating**

This stage involves the implementation of LoFoPaT. The LoFoPaT was applied in one class of high school students. Utilizing LoFoPaT in the classroom can support constructing students’ conceptual understanding of the Lorentz force. The N-Change results of the construction of students’ concepts before and after treatment are shown in Table 4.

<table>
<thead>
<tr>
<th>N-Change</th>
<th>Pre-test Average</th>
<th>Post-test Average</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.52</td>
<td>2.25</td>
<td>11.45</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Construction of Students’ Conceptual Understanding based on N-change Scores.

Based on Table 4, the N-Change value is 0.52. According to the interpretation of Marx & Karen (2007), the overall construction of students' conceptual understanding falls into the intermediate category. The detailed categories of students’ N-Change values are presented in Figure 7.

![Figure 7. The Construction Category of Students’ Conceptual Understanding of the Lorentz Force.](image)

After students were treated with LoFoPaT, Figure 7 shows that 40% of students experienced conception constructions in the high category, 25% in the intermediate category, 30% in the low category, and 5% in the negative category. The presence of this negative category indicates a decrease in conceptual understanding.

LoFoPaT, a physics learning medium, was developed to support students’ conceptual understanding. The construction of conceptual understanding is essential for
meaningful learning in physics. The activities of constructing students’ conceptual understanding begin with exploring students’ prior knowledge and further guide students to discover their concepts. Cai et al. (2017), Riaz et al. (2020), and Shubha & Meera (2015) remarked that constructing conceptual understanding involves student learning activities starting with observing, processing data, and analyzing the final result. The purpose is to instill the concept of Lorentz’s force for long-term retention, rather than it being quickly forgotten.

The distribution of students’ conceptions from the pre-test and post-test were analyzed based on the Wright maps Rasch Model using MINISTEP 4.7.0.0 software. The results are shown in Figure 10. In Figure 8, the questions are coded N1, N2, N3, N4, and N5. Student identities are coded with a number and the student’s gender, namely male (M) and female (F).

Based on the pre-test results in Figure 8(a), seven male students (15M, 17M, 19M, 08M, 13M, 09M, and 04M) and ten female students (02F, 06F, 10F, 11F, 12F, 14F, 20F, 07F, 16F, and 18F) were unable to solve all the questions, indicating low conceptual potential. Students coded 05M, 01M, and 03F could solve questions N1, N2, and N5 correctly. However, none of the 20 students could answer questions N3 and N4 correctly.

Figure 8. The Distribution of Students’ Conceptions.
After the treatment using LoFoPaT, the post-test results showed significant improvement. Based on the post-test results in Figure 8(b), five male students (01M, 08M, 04M, 05M, and 09M) and four female students (14F, 02F, 07F, and 03F) were able to answer all questions correctly. These results demonstrate the construction of understanding the Lorentz force concept through learning activities using LoFoPaT. For example, students 02F, 14F, 08M, 04M, and 07F moved from the lower to the upper class, as evidenced by their logit scale changing from a minus to a positive scale, enabling them to answer all the questions correctly. Students 06F, 16F, and 11F answered four questions correctly, while student 15M answered three questions correctly. Correspondingly, students in the upper grades during the pre-test (03F, 01M, and 09M) were able to complete all questions correctly.

Based on the results of the student conceptions distribution in Figure 8, some male and female students experienced conceptual construction. In the stage of implementing the tools in the class, based on Table 5, the overall construction of students’ understanding was successful in the intermediate category, specifically for students coded 01M, 08M, 04M, 05M, and 09M, as well as 14F, 02F, 07F, and 03F.

The results of concept construction can also be observed through experimental activities. Some examples of students’ work are documented on worksheets, as shown in Figure 9. Based on the results of students’ observations using LoFoPaT, students can determine the direction of the current, the direction of the magnetic field, and the direction of the Lorentz force. Additionally, students can describe these using the right-hand rule of vectors. This finding aligns with research by Kittiravechote (2020), demonstrating that LoFoPaT can effectively visualize abstract concepts.

Figure 9. The Results of the Students’ Work Illustrate the Direction of the Lorentz Force based on Observations.
Apart from determining the direction of the Lorentz force, students can also understand the relationship between the strength of the electric current, magnetic fields, and the Lorentz force. This relationship is illustrated in Figure 10. Based on Figure 10, students have comprehended the factors that influence the magnitude of the Lorentz force. These findings are supported by worksheets that hone psychomotor skills in addition to cognitive skills.

Furthermore, learning processes that involve students in activities such as observing, finding data, and analyzing can make students more active thinkers. Students are engaged in measuring, experimenting, executing, and recording their findings (Kittiravechote, 2020; Lemmer, Kriek, & Erasmus, 2020). These findings align with research indicating that physics learning media facilitate hands-on activities (Jelicic et al., 2017; Donhauser et al., 2020). This activity supports the construction of students’ understanding of the Lorentz force concept, thereby fostering the development of their conceptual understanding.

Figure 10. Student Analysis of the Relationship between Quantities that Influence the Magnitude of the Lorentz Force in Experimental Activities.

Nevertheless, the results of the post-test also revealed that some students still had low conceptual understanding as they could not answer any of the questions. As shown in Figure 8, students who are categorized as still having low conceptual understanding include two male students (17M, 19M) and three female students (10F, 18F, and 12F). These five students did not experience conceptual construction during learning. Based on the results of the implementation of LoFoPaT, it was found that students with moderate and low conceptual understanding faced challenges. Özdemir & Coramik (2018), Shubha & Meera (2015), Deprez, Gijsen, Deprez, & De Cock (2019), and Scaife & Heckler (2010) suggest that difficulties arise because students do not
understand the physical meaning of the unit vector and the relationship between the unit vector and the vector product. Additionally, students’ spatial thinking skills are also influential (Nguyen & Meltzer, 2005; Kustusch, 2016; Kaliampous, Pantidos, Kalogiannakis, & Ravanis, 2021).

Furthermore, the findings indicate that the implementation did not involve specific learning strategies, models, or approaches, which could sustain more structured and directed learning activities (Phanphech et al., 2019). Learning activities that use physics media typically yield the best outcomes (Riaz et al., 2020). Therefore, a recommendation for further implementation is that teachers or other researchers should consider using different learning models, strategies, or approaches.

Additionally, two students (7M and 18F) still experienced misconceptions after the treatment. Misconceptions appeared in question number 2 (N2), where students thought that the wire's movement was caused by a magnet, not the Lorentz force. Several studies have indicated that this material is difficult and confusing for students, especially regarding the Lorentz force acting on charged particles (Eaton, Frank, Johnson, & Willoughby, 2019; Zuza, De Cock, van Kampen, Kelly, & Guisasola, 2020; Deprez et al., 2019; Campos et al., 2021; Maries, Brundage, & Singh, 2022; Jelicic et al., 2017). Misconceptions can occur due to several factors, such as alternative conceptions that arise during learning or outside the classroom (Mufida, Kaniawati, Samsudin, & Suhendi, 2022; Husnah, Suhandi, & Samsudin, 2020; Diani et al., 2018).

To address misconceptions, a model, strategy, or learning approach that includes conceptual changes as proposed by Posner, Strike, Hewson, & Gertzog (1982) is needed. Students diagnosed with misconceptions must be given special treatment that involves learning activities containing cognitive conflict (Samsudin, Suhandi, Rusdiana, Kaniawati, Fratiwi, Zulfikar, & Costu, 2019; Mbonyiryiivuze et al., 2022). Based on these findings, further research recommendations suggest that LoFoPaT media can be applied alongside specific learning approaches for students' misconceptions, such as the ECIRR model (Prastiwi, Kholiq, & Setyarih, 2018), conceptual change model (Addido, Burrows, & Slater, 2022), or the use of worksheets with conceptual change, refutation text (Dersch, Renkl, & Eitel, 2022), conceptual change laboratory (Suhandi, Surtiana, Husnah, Setiawan, Siahaan, Samsudin, & Costu 2020), etc.

Overall, LoFoPaT has been successfully developed and can be implemented to construct an understanding of the Lorentz force concept at an intermediate level. Previous research by Donhauser et al. (2020) and Cai et al. (2017) developed augmented reality (AR) tools, while Shubha & Meera (2019) used simulations in learning. These studies have shown that their methods can increase cognitive activity and conceptual understanding. However, none of them involved hands-on activities related to learning the Lorentz force concept. Thus, the advantage of LoFoPaT is that it serves as a physics learning medium for conducting real experiments and visualizing abstract concepts.

CONCLUSION
This research concludes that the Lorentz Force Practicum Tool (LoFoPaT) can be successfully developed using a 4D model, and in the development stage, it demonstrates validity. Consequently, LoFoPaT proves...
to be an effective physics learning medium for visualizing abstract concepts, particularly aiding in the visualization of the Lorentz force direction based on the right-hand rule. Moreover, students have shown improvement in their hands-on skills through experimental activities facilitated by LoFoPaT. However, despite these successes, there are still shortcomings observed in the research. Some students continue to exhibit low conceptual understanding, and misconceptions persist among certain students. Therefore, recommendations for further research include exploring additional models, strategies, or learning approaches to maximize the effectiveness of LoFoPaT in constructing students’ conceptual understanding of the Lorentz force.

REFERENCES


