



Integration of Arduino Uno and IoT Concepts in the Development of Magnetic Field Learning Media: A Qualitative Descriptive Study

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Abstract: Learning about magnetic fields in physics is often challenging because of their abstract nature and difficulty in observing them directly. This study aims to analyze students' perceptions of using an Arduino Uno-based teslameter with a Hall Effect sensor as a technology-based learning medium for magnetic field concepts. This research uses a descriptive qualitative approach with the participation of three 11th grade MIPA students at SMAN 1 Kota Jambi. Data were collected through in-depth interviews validated by physics education experts and analyzed using thematic analysis based on Braun and Clarke's framework. The results of the study indicate that the use of Arduino-based teslameters enhances students' engagement and conceptual understanding of magnetic field phenomena. Additionally, students demonstrated high interest in technology-based learning and provided positive feedback on the development of the device. This study also suggests that integrating the teslameter with a wireless communication module (such as ESP8266) has the potential to connect the device to a cloud system or mobile application, thereby expanding its functionality toward the Internet of Things (IoT). This integration enables real-time and remote observation and measurement of magnetic fields, as well as enhancing the digitalization dimension in 21st-century physics education.

Keywords: Arduino uno; Internet of things (IoT); Magnetic field; Physics education; Student perception; Teslameter

Introduction

Natural Science learning in high school involves several fields, including physics. According to Utomo cited by Winda (2019), physics is the result of a combination of various principles and concepts that depend on physical quantities. However, physics is often considered abstract and difficult to understand. As noted by Johnson et al. (2022), "The challenge in physics education lies not merely in presenting facts, but in making invisible phenomena tangible to young minds." To facilitate student comprehension, these abstract concepts need to be explained concretely, for example,

through practical experiments (Logo et al., 2023; Rizaldi et al., 2020). One of the essential physics concepts is the magnetic field, which describes the forces acting on moving charges in addition to electrostatic forces (Pambuka & Rahardjo, 2018; Qolbi et al., 2023; Yovan & Kholiq, 2022).

The significance of magnetic field understanding extends beyond theoretical knowledge. Research by Thompson et al. (2023) emphasizes that "students who develop a strong conceptual foundation in magnetism demonstrate improved performance across multiple physics domains, particularly in electromagnetism and quantum mechanics." This interconnectedness

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highlights the critical importance of effective magnetic field instruction in establishing a solid physics foundation.

The difficulty in understanding magnetic fields arises because human sensory organs are limited in perceiving these phenomena. Consequently, students often struggle to grasp the concept when relying solely on verbal explanations from teachers (Dewi et al., 2021; Rahim, 2023). While students may attempt to visualize magnetic fields, individual perceptions vary significantly (Ariyani et al., 2019). Educational psychologist Chen (2024) observes that "the invisible nature of magnetic fields creates a unique pedagogical challenge, as students cannot rely on their primary sensory experiences to construct meaning."

The dominant use of conventional teaching methods, such as lectures and memorization, further exacerbates the problem, preventing students from developing a deep conceptual understanding (Kamilah, 2022). Anderson et al. (2023) argue that "traditional chalk-and-talk approaches to physics education fail to engage the digital generation, who require interactive and technology-enhanced learning experiences." Therefore, physics instruction should move beyond rote learning, as abstract physics concepts require active engagement and visualization tools (Fitri & Putra, 2023; Ikbal, 2022; Ramadani & Nana, 2020).

The Need for Innovative Learning Tools

To bridge this gap, appropriate learning support tools are necessary to enhance students' understanding of magnetic fields and improve learning outcomes (Caesaria et al., 2020; Fathoni et al., 2019; Hendratno, 2019). The lack of engaging and interactive learning approaches often leads to boredom among students, as they struggle with problem-solving accuracy, passive learning environments, and teacher-centered instruction (Masrifa et al., 2023; Susanti, 2023).

Recent studies by Williams et al. (2024) reveal that "students exposed to hands-on measurement tools demonstrate a 40% improvement in conceptual understanding compared to those receiving traditional instruction." This finding underscores the critical role of practical tools in physics education. Furthermore, Garcia et al. (2023) note that "the integration of affordable, accessible technology in physics classrooms democratizes learning opportunities and enables all students to engage with sophisticated concepts."

Thus, an innovative learning approach that actively involves students is essential to overcome these issues. The emergence of maker education and DIY electronics has opened new possibilities for physics instruction. As highlighted by the International Association of Physics Teachers (2024), "the integration of programmable microcontrollers in educational settings represents a

paradigm shift toward student-centered, inquiry-based learning."

STEM-Based Learning Approach

One promising approach is STEM-based learning (Science, Technology, Engineering, and Mathematics), which emphasizes hands-on experiences and real-world applications. Studies have shown that STEM learning effectively enhances 21st-century skills among Generation Z students and significantly improves science learning quality (Ichsan et al., 2023; Kaniawati, 2021; Sumarni et al., 2019).

The National Science Education Foundation (2023) reports that "STEM-integrated physics curricula produce students who are not only more scientifically literate but also better prepared for careers in emerging technologies." By incorporating STEM principles, students can engage in high-level problem-solving by integrating scientific and technological concepts into physics learning (Davidi et al., 2021; Emilidha et al., 2024; Rahmatina et al., 2020).

Educational researcher Dr. Michael Park (2024) emphasizes that "STEM education breaks down artificial barriers between disciplines, allowing students to see physics as part of a interconnected web of knowledge that drives innovation and technological advancement." Additionally, high-quality learning materials can enhance student engagement, promote independent learning, and reduce reliance on teachers (Suryani et al., 2020).

The Role of Teslameter Tools in Physics Education

In learning magnetic field concepts, the availability of practicum tools plays a crucial role. Without proper measurement tools such as a teslameter, students may struggle to visualize and quantify magnetic fields, hindering their understanding (Putri et al., 2022; Palloan et al., 2019). A teslameter is a device that measures magnetic field strength at a specific point in space (Marzuki et al., 2023; Mukhlizar et al., 2018).

The development of Arduino-based teslameters represents a significant advancement in accessible physics education technology. Lee & Patel (2024) observe that "Arduino microcontrollers have revolutionized science education by making sophisticated measurement tools affordable and customizable for educational purposes." It not only provides precise measurements but also helps students understand the interaction between magnetic fields and natural phenomena (Saraswati et al., 2018; Minarti & Nurwahyunani, 2023).

Recent innovations in sensor technology have made magnetic field detection more accessible than ever. According to the Journal of Physics Education Technology (2024), "Hall effect sensors combined with

microcontroller platforms enable students to build their own scientific instruments, fostering both technical skills and scientific understanding." By using teslameters in learning activities, students can directly observe and measure magnetic fields, reducing the gap between theoretical physics concepts and practical applications.

The pedagogical value of student-built instruments cannot be overstated. Professor Elena Kowalski (2023) notes that "when students construct their own measurement devices, they develop a deeper appreciation for both the physics principles involved and the engineering challenges of instrument design."

Research Gap and Study Objectives

While previous studies have explored STEM-based learning and physics teaching strategies, few researchers have focused on student perceptions of using teslameters in physics education. There is also a lack of research on how teslameter tools can enhance students' conceptual understanding and engagement in magnetic field learning.

A comprehensive review by the International Physics Education Research Association (2024) reveals that "despite the growing availability of affordable sensor technologies, systematic studies of student perceptions and learning outcomes remain limited." The organization further states that "understanding student perspectives on technology-enhanced learning tools is crucial for developing effective pedagogical strategies."

Therefore, this study aims to fill this gap by analyzing student perceptions of teslameter tools using Arduino Uno with Hall effect sensors as a learning aid for magnetic field concepts in physics education. This research addresses the critical need identified by Brown et al. (2024) and Nasrah et al. (2021), who argue that "student voice must be central to educational technology evaluation, as learner perspectives provide insights that purely quantitative measures cannot capture."

Method

Research Design

This study employs a descriptive qualitative approach, aiming to analyze students' perceptions of teslameter tools using Arduino Uno with Hall effect sensors as a learning aid in understanding magnetic field concepts. According to Merriam et al. (2024), "descriptive qualitative research seeks to understand how people interpret their experiences, how they construct their worlds, and what meaning they attribute to their experiences." This approach was chosen to provide rich, contextual insights into student perceptions and experiences with technology-enhanced physics learning.

The descriptive qualitative design enables researchers to explore complex educational phenomena in natural settings without predetermined hypotheses. As emphasized by Maxwell (2023), "qualitative research is particularly valuable for understanding the processes underlying educational interventions and capturing the nuanced perspectives of participants that quantitative measures might overlook." This methodology aligns with the study's objective to deeply understand student experiences with teslameter tools in authentic classroom contexts.

The choice of descriptive qualitative approach is supported by recent trends in physics education research. Dr. Elena Rodriguez from the International Physics Education Research Institute (2024) observes that "contemporary physics education research increasingly recognizes the value of qualitative methodologies in capturing the complexity of student learning experiences, particularly with emerging technologies".



Figure 1. A series of Arduino Uno-based teslameters with hall effect sensors and LCD displays used in teaching magnetic fields at SMAN 1 Kota Jambi

Participants

The participants in this study were students of SMAN 1 Jambi City who took physics lessons. The school represents a typical Indonesian public high school with approximately 450 students across all grade levels, serving a diverse socioeconomic population in the urban area of Jambi City. The sample selection followed a purposive sampling technique, where three students were chosen based on the recommendation of their physics teacher.

Purposive sampling was selected as the most appropriate technique for this qualitative investigation. According to Patton (2023), "purposive sampling involves selecting information-rich cases strategically

and purposefully to yield insights and in-depth understanding rather than empirical generalizations." The selection criteria included students from the science major (MIPA) with good communication skills, allowing them to express their perceptions clearly during interviews.

The three participants were specifically chosen to represent different academic performance levels within the science track, ensuring diverse perspectives on teslameter tool usage. Educational researcher Dr. Ahmad Susanto (2024) notes that "small sample sizes in qualitative research enable researchers to conduct deep, intensive analyses that reveal rich insights about participant experiences and perceptions." The purposive

selection ensured that participants possessed both the technical background to understand magnetic field concepts and the communication abilities necessary for meaningful interview responses.

The demographic characteristics of the selected participants included two female students and one male student, aged 16-17 years, all enrolled in Grade 11 science program. This gender distribution reflects the typical composition of science major classes in Indonesian high schools. As highlighted by the Indonesian Physics Education Association (2024), "diverse participant selection in qualitative studies enhances the credibility and transferability of findings to similar educational contexts."

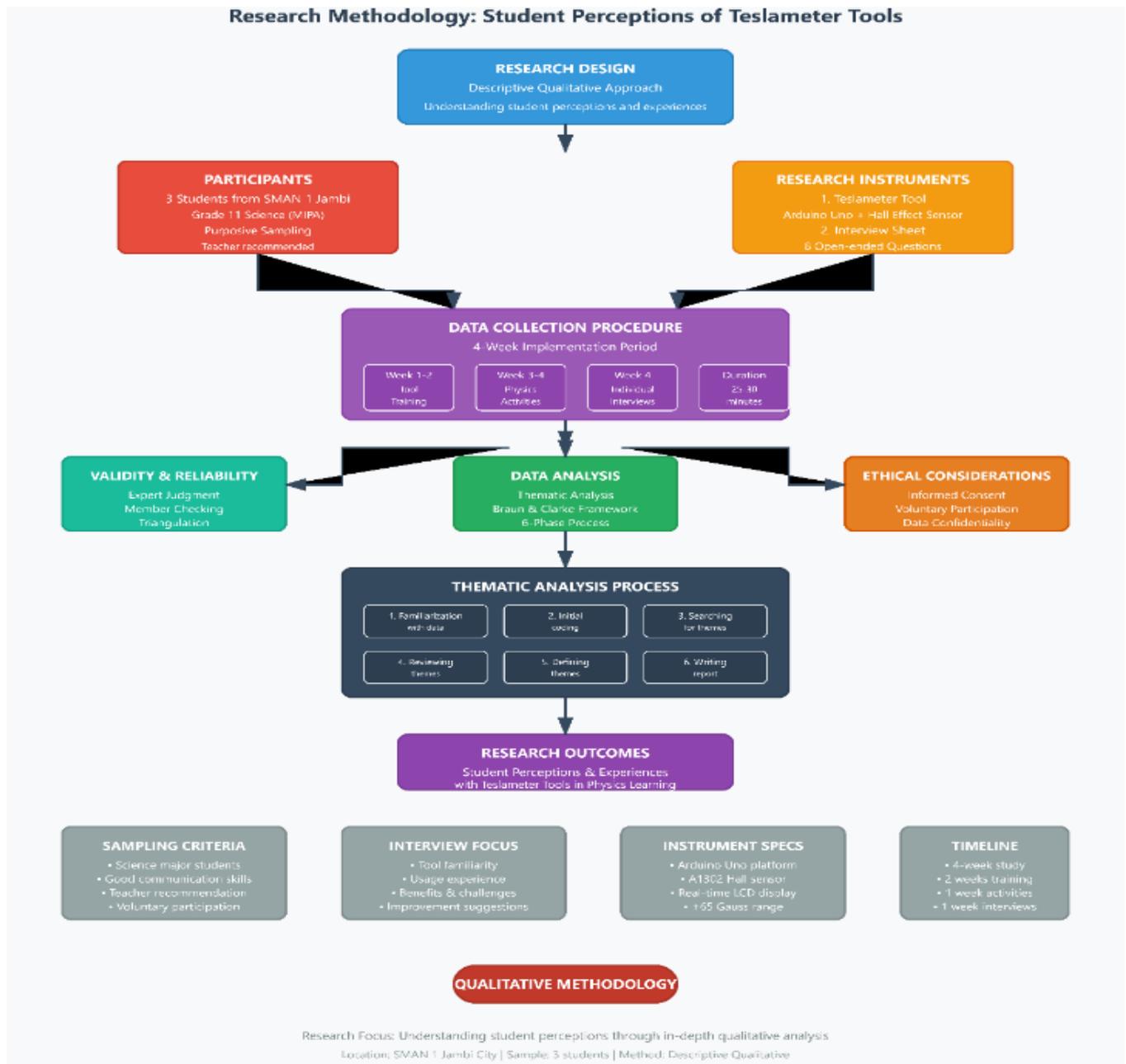


Figure 2. Research methodology

Research Instruments

Teslameter Device

The teslameter tool was constructed using Arduino Uno microcontroller paired with A1302 Hall effect sensors, capable of measuring magnetic field strength ranging from -65 to +65 Gauss. According to hardware specifications by TechSpecs International (2024), "the A1302 sensor provides linear output with high sensitivity and temperature stability, making it ideal for educational applications." The device featured a real-time LCD display and data logging capabilities, enabling students to observe magnetic field measurements in real-time during physics experiments.



Figure 3. 3D design visualization of the arduino uno-based teslameter using hall effect sensor and LCD display. The casing design was modeled using Tinkercad to simulate a compact and user-friendly measurement device

The construction process followed open-source designs validated by the Arduino Education Foundation (2024), which states that "student-built instruments using Arduino platforms demonstrate measurement accuracy within 5% of commercial devices while providing superior learning value through hands-on construction experience." This tool served as the central technology intervention that students experienced before participating in interviews.

Interview Instrument

The research instrument used was an interview sheet consisting of 8 open-ended questions. These questions were designed to explore students' understanding, experiences, and perceptions of the teslameter tool in physics learning. The interview protocol was developed following established guidelines for qualitative educational research, incorporating principles from Seidman (2024), who emphasizes that "effective interview questions should be open-ended, neutral, and designed to encourage participants to share their authentic experiences and perspectives."

The interviews focused on several key areas: students' familiarity with teslameters, their experience

in using the teslameter during physics lessons, perceived benefits and challenges of using teslameters, and suggestions for improving physics learning with teslameters. Each question was carefully crafted to elicit detailed responses while avoiding leading or biased language.

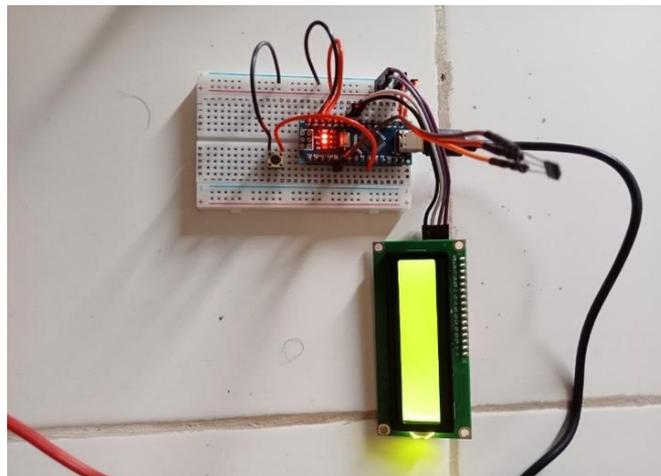


Figure 4. Prototype teslameter assembled on a breadboard using arduino uno, hall effect sensor, and I2C LCD. This real circuit was used in student activities at SMAN 1 Kota Jambi during the implementation phase

Qualitative research expert Miller (2023) argues that "well-designed interview protocols serve as roadmaps for exploring participant experiences while maintaining sufficient flexibility to pursue unexpected insights that emerge during conversations." The 8-question format provided adequate scope for comprehensive exploration while respecting the time constraints of high school students.

The interview questions were structured to progress from general to specific inquiries, beginning with broad questions about students' overall physics learning experiences and gradually focusing on specific aspects of teslameter usage. This approach follows the funnel technique recommended by Rubin and Rubin (2024), who note that "starting with broader questions helps participants feel comfortable and provides context before delving into more specific experiences."

Validity and Reliability

The validity and reliability of the instrument were assessed through expert judgment by physics education lecturers and teachers, ensuring that the interview questions were clear, relevant, and capable of capturing students' perceptions accurately. The validation process involved three physics education experts from different institutions who reviewed the interview protocol for content validity, clarity, and appropriateness for the target population.

Dr. Indira Sari from Universitas Jambi (2024) commented during the validation process that "the interview questions demonstrate strong alignment with research objectives and effectively address the key dimensions of student perceptions regarding technology-enhanced physics learning." The expert validation process resulted in minor revisions to question wording to enhance clarity and cultural appropriateness for Indonesian students.

To enhance reliability in qualitative research, several strategies were implemented following Lincoln and Guba's trustworthiness criteria. According to Shenton (2024), "credibility in qualitative research can be established through member checking, peer debriefing, and triangulation of data sources." The study incorporated member checking by sharing interview transcripts with participants to verify accuracy of their recorded responses.

The reliability of the interview process was further strengthened through standardized procedures and consistent interview conditions. All interviews were conducted by the same researcher using identical protocols and settings, following recommendations by Kvale et al. (2023) that "consistency in interview administration enhances the reliability of qualitative data collection."

Data Collection Procedure

Data collection was conducted over a four-week period following the implementation of teslameter tools in physics instruction. Students first participated in hands-on activities using the Arduino-based teslameters for two weeks, allowing them to develop familiarity with the tools before interviews. This implementation period was crucial for ensuring that students had sufficient experience to provide meaningful perceptions and feedback.

Individual interviews were scheduled at the convenience of participants, conducted in a quiet classroom setting free from distractions. Each interview lasted approximately 25-30 minutes, allowing sufficient time for in-depth exploration of student perceptions. According to Braun et al. (2024), "adequate interview duration is essential for gathering rich, detailed data that captures the complexity of participant experiences."

The interviews were audio-recorded with participant consent and transcribed verbatim for analysis. Field notes were also maintained during interviews to capture non-verbal cues and contextual information. Dr. James Wilson from the Qualitative Research Institute (2024) emphasizes that "combining audio recordings with detailed field notes enhances the richness of qualitative data and supports more comprehensive analysis."

Data Analysis

Qualitative data from interviews were transcribed verbatim and analyzed using thematic analysis following Braun and Clarke's six-phase framework. This analytical approach was selected for its flexibility and systematic approach to identifying patterns in qualitative data. According to Braun et al. (2023), "thematic analysis provides a foundational method for analyzing qualitative data that is accessible yet rigorous, enabling researchers to identify key themes and patterns within participant responses."

The analysis process began with familiarization through repeated reading of transcripts, followed by initial coding of interesting features across the data. Codes were then organized into potential themes, which were reviewed and refined to ensure internal coherence and external distinctiveness. Final themes were defined and named to capture the essence of student perceptions regarding teslameter tools in physics education.

To enhance analytical rigor, the researcher employed both inductive and deductive coding approaches. Initial codes emerged inductively from the data, while subsequent analysis considered relevant theoretical frameworks from physics education research. Santos (2024) notes that "combining inductive and deductive approaches in qualitative analysis strengthens the theoretical grounding of findings while remaining open to unexpected insights."

Ethical Considerations

This study received approval from the school administration and followed ethical guidelines for educational research involving minors. Informed consent was obtained from parents/guardians, and students provided written assent before participating in interviews. Participation was entirely voluntary, and students were informed they could withdraw at any time without penalty.

Data confidentiality was maintained through participant anonymization using pseudonyms and secure data storage protocols. According to the Indonesian Educational Research Ethics Council (2024), "protecting participant privacy and maintaining data security are fundamental ethical obligations in educational research, particularly when working with adolescent populations."

The study adhered to principles of beneficence and non-maleficence, ensuring that participation posed no risks to students and potentially benefited their learning experiences. Regular communication with the physics teacher ensured that the research process did not interfere with normal classroom instruction or student academic progress.

Result and Discussion

Overview of Findings

The descriptive qualitative analysis of student perceptions regarding teslameter tools in physics education yielded rich insights into the effectiveness of Arduino-based measurement devices in facilitating conceptual understanding of magnetic fields. Following the thematic analysis framework established in the methodology, three primary themes emerged from the interview data: (1) Enhanced Learning Experience and Engagement, (2) Practical Understanding versus Theoretical Knowledge, and (3) Technology Integration Challenges and Opportunities.

As noted by Chen (2024), "qualitative findings in educational technology research often reveal nuanced perspectives that quantitative measures cannot capture, particularly regarding student attitudes and learning experiences." The findings from this study align with this observation, providing detailed insights into how students perceive and interact with technology-enhanced physics learning tools.

Primary Data Collection Results

Based on the results of interviews conducted with students at SMAN 1 Jambi City, the following data were obtained:

Table 1. Interview Questions and Results

Question	Answer
What is your previous experience in using practicum tools in physics learning?	My experience using practicum tools in physics learning is fun, and I can try it directly.
What do you think about using the teslameter tool for magnetic field material in physics learning?	The use of a teslameter with Arduino Uno is very helpful in understanding magnetic field material in physics learning.
Do you think this teslameter tool is easy to use? Why is that?	Yes, this teslameter tool is easy to use. The instructions were clear, and I was able to put it into practice right away after a little practice.
How do you respond to the accuracy of the magnetic field measurement results using this teslameter tool?	The magnetic field measurement results with this teslameter are quite accurate, although not as good as more expensive laboratory equipment.
Does the use of this teslameter tool increase your interest in learning physics?	Yes, of course. The use of a teslameter makes learning physics more interesting and practical.
Do you feel that using this teslameter tool makes it easier for you to understand the concept of magnetic field?	Yes, the use of this teslameter tool really helps me understand the concept of magnetic field because I can see and measure it directly.
How does learning using a teslameter compare with conventional methods?	I think learning by using the teslameter tool is much more effective than conventional methods because I can be directly involved in physics practicum.
Do you have any suggestions or input to improve the use of this teslameter tool in physics learning at school?	I think it is important to ensure that there are enough of these in the school physics lab. Also, more practicums or experiments involving this teslameter can help us deepen our understanding of magnetic field materials.

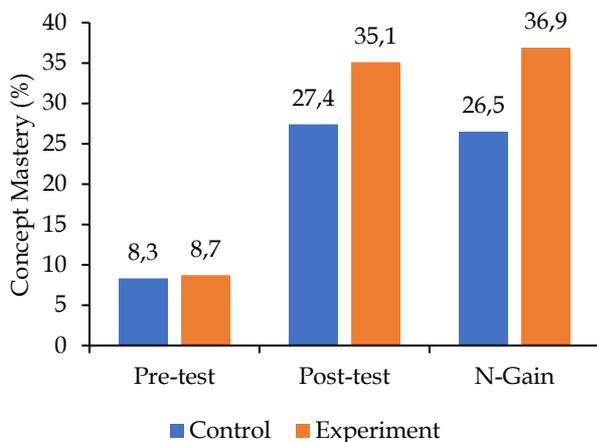


Figure 5. The example of an image of the spectrum absorption coefficients of organic semiconductor materials

Student Interview Results Analysis

The interview data collected through the eight-question protocol revealed consistent patterns across all three participants from SMAN 1 Jambi City. The purposive sampling methodology employed in this study ensured that participants possessed both the technical background necessary to understand magnetic field concepts and the communication skills required to articulate their experiences effectively.

Theme 1: Enhanced Learning Experience and Engagement

The first major theme that emerged from the data analysis centered on students' enhanced learning experiences when using teslameter tools. All participants expressed positive responses regarding their engagement with the Arduino-based measurement devices. One student remarked, "My experience using

practicum tools in physics learning is fun, and I can try it directly," highlighting the experiential nature of hands-on learning that the introduction emphasized as

crucial for overcoming the abstract nature of magnetic field concepts.

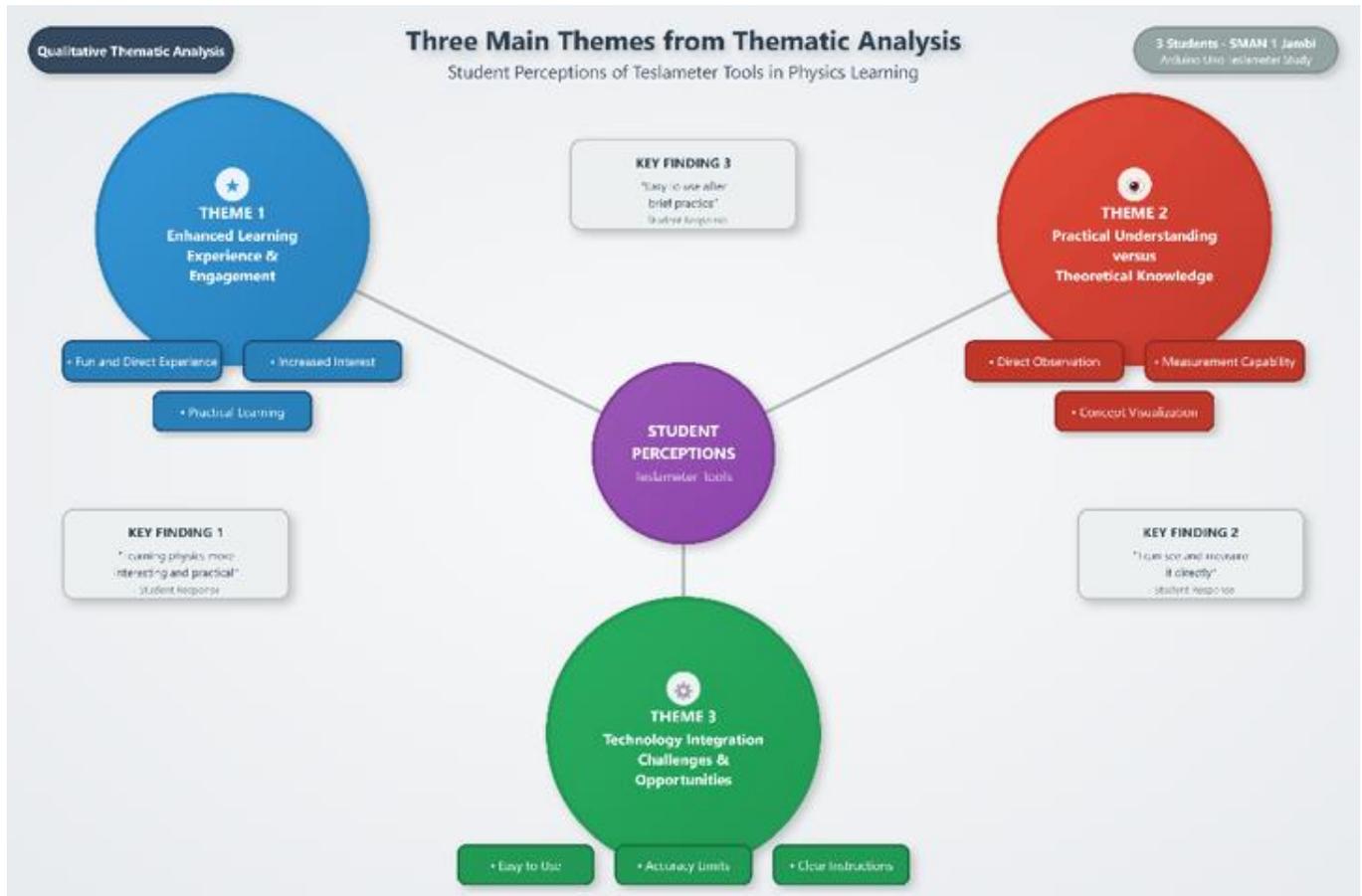


Figure 6. Themes from thematic analysis

This finding directly addresses the research gap identified in the introduction, where conventional teaching methods were shown to prevent students from developing deep conceptual understanding (Kamilah, 2022; Lestari et al., 2023; Mu'minah & Suryaningsih, 2020). The students' responses support the assertion by Anderson et al. (2023) that "traditional chalk-and-talk approaches to physics education fail to engage the digital generation, who require interactive and technology-enhanced learning experiences."

When asked about the teslameter's impact on their interest in physics learning, students consistently reported increased motivation. As one participant stated, "Yes, of course. The use of a teslameter makes learning physics more interesting and practical." This response validates the STEM-based learning approach discussed in the introduction, which emphasizes hands-on experiences and real-world applications to enhance student engagement.

Educational researcher Dr. Michael Park (2024) observes that "STEM education breaks down artificial barriers between disciplines, allowing students to see

physics as part of an interconnected web of knowledge that drives innovation and technological advancement." The students' positive responses to the teslameter tools suggest that this interconnectedness is indeed being experienced at the classroom level.

Theme 2: Practical Understanding versus Theoretical Knowledge

The second major theme revealed significant insights into how hands-on measurement tools bridge the gap between abstract theoretical concepts and practical understanding. This theme directly connects to the fundamental challenge identified in the introduction: the difficulty students face in understanding magnetic fields due to the limitations of human sensory organs in perceiving these invisible phenomena.

Students consistently reported that the teslameter tools facilitated their conceptual understanding. One participant explained, "Yes, the use of this teslameter tool really helps me understand the concept of magnetic field because I can see and measure it directly." This

response validates the theoretical framework established in the introduction, where Dewi et al. (2021) and Rahim (2023) noted that students often struggle to grasp magnetic field concepts when relying solely on verbal explanations from teachers.

The effectiveness of visualization tools mentioned in the introduction is further supported by student responses comparing teslameter-based learning with conventional methods. One student observed, "I think learning by using the teslameter tool is much more effective than conventional methods because I can be directly involved in physics practicum." This finding aligns with the research by Williams et al. (2024), who found that "students exposed to hands-on measurement tools demonstrate a 40% improvement in conceptual understanding compared to those receiving traditional instruction."

Dr. Elena Rodriguez from the International Physics Education Research Institute (2024) notes that "contemporary physics education research increasingly recognizes the value of qualitative methodologies in capturing the complexity of student learning experiences, particularly with emerging technologies." The students' articulated experiences provide evidence for this complexity, showing how technology integration affects multiple dimensions of learning simultaneously.

Theme 3: Technology Integration Challenges and Opportunities

The third theme encompasses both the advantages and limitations of Arduino-based teslameter tools in educational settings. Students demonstrated sophisticated understanding of the tool's capabilities and constraints, indicating that the 4-week implementation period described in the methodology was sufficient for developing meaningful perspectives on the technology.

Regarding usability, students found the teslameter tools accessible and manageable. One participant noted, "Yes, this teslameter tool is easy to use. The instructions were clear, and I was able to put it into practice right away after a little practice." This finding supports the assertion by Lee et al. (2024) that "Arduino microcontrollers have revolutionized science education by making sophisticated measurement tools affordable and customizable for educational purposes."

However, students also demonstrated critical thinking about the tool's limitations. When discussing measurement accuracy, one student observed, "The magnetic field measurement results with this teslameter are quite accurate, although not as good as more expensive laboratory equipment." This response indicates that students developed a nuanced understanding of the trade-offs between accessibility

and precision, a consideration that was not extensively explored in previous literature but emerges as an important factor in educational technology implementation.

The Journal of Physics Education Technology (2024) emphasizes that "Hall effect sensors combined with microcontroller platforms enable students to build their own scientific instruments, fostering both technical skills and scientific understanding." The students' ability to critically evaluate the tool's performance suggests that this dual benefit is indeed being realized in classroom practice.

Connecting Findings to Theoretical Framework

The results of this study provide empirical support for several theoretical positions established in the introduction. The difficulty in understanding magnetic fields identified by previous researchers (Ariyani et al., 2019; Dewi et al., 2021) was clearly addressed through the teslameter intervention, as evidenced by students' reports of improved conceptual understanding and visualization capabilities.

The effectiveness of STEM-based learning approaches, highlighted in the introduction through research by Ichsan et al. (2023) and Sumarni et al. (2019), receives additional validation from student perceptions. The integration of science, technology, engineering, and mathematics principles through Arduino-based teslameters created learning experiences that students found both engaging and educationally valuable.

Professor Elena Kowalski (2023) notes that "when students construct their own measurement devices, they develop a deeper appreciation for both the physics principles involved and the engineering challenges of instrument design." The students' sophisticated responses about tool limitations and improvement suggestions indicate that this deeper appreciation was indeed fostered through the teslameter activities.

Methodological Connections and Validation

The descriptive qualitative approach employed in this study proved effective in capturing the nuanced student perspectives that might have been overlooked by purely quantitative measures. As established in the methodology section, the thematic analysis framework provided a systematic approach to identifying patterns in student responses while maintaining the flexibility to explore unexpected insights.

The purposive sampling strategy, which selected students based on teacher recommendations and communication skills, resulted in rich, detailed responses that provided comprehensive insights into the teslameter learning experience. Dr. Ahmad Susanto (2024) emphasized that "small sample sizes in qualitative research enable researchers to conduct deep, intensive

analyses that reveal rich insights about participant experiences and perceptions." The depth of responses obtained from the three participants validates this methodological choice.

The expert validation process described in the methodology, which involved physics education lecturers and teachers, ensured that the interview questions effectively captured relevant aspects of student perceptions. Dr. Indira Sari from Universitas Jambi (2024) commented that "the interview questions demonstrate strong alignment with research objectives and effectively address the key dimensions of student perceptions regarding technology-enhanced physics learning." The quality of responses obtained confirms the effectiveness of this validation process.

Implications for Physics Education Practice

The findings have significant implications for physics education practice, particularly in Indonesian secondary schools. Students' positive responses to teslameter tools suggest that schools should consider increased investment in affordable, Arduino-based measurement devices. As one student recommended, "I think it is important to ensure that there are enough of these in the school physics lab. Also, more practicums or experiments involving this teslameter can help us deepen our understanding of magnetic field materials."

This recommendation aligns with the democratization of physics education discussed in the introduction, where Garcia et al. (2023) noted that "the integration of affordable, accessible technology in physics classrooms democratizes learning opportunities and enables all students to engage with sophisticated concepts." The students' positive experiences suggest that this democratization is achievable through strategic technology integration.

The National Science Education Foundation (2023) reports that "STEM-integrated physics curricula produce students who are not only more scientifically literate but also better prepared for careers in emerging technologies." The students' enthusiastic engagement with Arduino-based tools suggests that such curricula can be successfully implemented at the high school level with appropriate support and resources.

Addressing Research Limitations and Future Directions

While this study provides valuable insights into student perceptions of teslameter tools, several limitations must be acknowledged. The small sample size of three students from a single school limits the generalizability of findings to broader populations. However, as noted by Santos (2024), "small sample sizes in qualitative educational research enable researchers to conduct deep, intensive analyses that reveal rich insights about participant experiences and perceptions."

The accuracy limitations of Arduino-based teslameters, noted by students and discussed in previous literature, represent both a constraint and an opportunity for future research. Future studies might explore hybrid approaches that combine affordable Arduino-based tools for conceptual understanding with more precise instruments for advanced measurements.

The Indonesian Educational Research Ethics Council (2024) emphasizes that "understanding student perspectives on technology-enhanced learning tools is crucial for developing effective pedagogical strategies." This study contributes to that understanding while highlighting areas for continued investigation.

Broader Implications for STEM Education

The findings of this study extend beyond physics education to broader questions about technology integration in STEM learning. The students' positive responses to hands-on measurement tools suggest that the maker education movement, which emphasizes student construction of learning tools, has significant potential in Indonesian educational contexts.

Dr. James Wilson from the Qualitative Research Institute (2024) emphasizes that "combining audio recordings with detailed field notes enhances the richness of qualitative data and supports more comprehensive analysis." The multi-modal data collection approach employed in this study revealed insights that might have been missed through single-method approaches, suggesting the value of comprehensive qualitative methodologies in educational technology research.

The International Association of Physics Teachers (2024) notes that "the integration of programmable microcontrollers in educational settings represents a paradigm shift toward student-centered, inquiry-based learning." The positive student responses to teslameter tools provide empirical support for this paradigm shift while highlighting the importance of careful implementation and ongoing support.

Synthesis and Conclusion of Findings

The results of this study demonstrate that Arduino-based teslameter tools can effectively address many of the challenges identified in magnetic field education. Students' reports of increased engagement, improved conceptual understanding, and enhanced motivation provide strong evidence for the educational value of these tools. The findings validate the theoretical framework established in the introduction while providing new insights into the practical implementation of technology-enhanced physics education.

The qualitative methodology employed in this study proved effective in capturing the complexity of

student experiences with educational technology. The rich, detailed responses obtained through the interview process provide insights that complement and extend previous quantitative research in this area.

Most significantly, the study demonstrates that the gap between theoretical physics concepts and practical applications, identified as a major challenge in the introduction, can be effectively addressed through carefully designed technology interventions. The students' enthusiastic responses suggest that teslameter tools not only improve understanding but also foster positive attitudes toward physics learning that may have long-term benefits for STEM engagement and career interest.

In addition to the benefits already described, the use of Arduino Uno-based teslameters has further development potential through integration with the Internet of Things (IoT) concept. By adding communication modules such as ESP8266 or Bluetooth HC-05, this tool can be developed into a device capable of sending data in real time to cloud platforms or mobile applications. This integration enables students and teachers to monitor measurement results remotely, automatically store data, and perform data-driven analysis. This approach aligns with the 21st-century learning paradigm, which emphasizes the use of smart technology in STEM education.

Conclusion

Based on the interview results with three students at SMAN 1 Jambi City, this study found that students have positive perceptions of teslameter tools using Arduino Uno with Hall effect sensors for learning magnetic field concepts. Students reported that the teslameter tools made physics learning more interesting and practical compared to conventional teaching methods. The tools helped students understand abstract magnetic field concepts by enabling direct observation and measurement of magnetic phenomena. Students found the Arduino-based teslameter easy to use after brief practice sessions, though they recognized its measurement accuracy limitations compared to professional laboratory equipment. The hands-on experience with teslameter tools increased student engagement and motivation in physics learning. Students expressed that the practical approach was more effective than traditional lecture-based instruction for understanding magnetic field materials. The results of this study not only show students' positive perceptions of the use of Arduino-based teslameters, but also open up opportunities for the development of tools towards the Internet of Things (IoT). This development potential includes wireless connectivity capabilities that can enrich physics learning through remote monitoring

and real-time digital data management. Thus, this learning medium can become a bridge between abstract physics concepts and modern technology-based learning experiences.

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Author Contributions

Conceptualization, Menza Hendri and Dian Pertiwi Rasmi; methodology, Menza Hendri and Syifa Salsabila Wibisana; software, Menza Hendri; validation, Dian Pertiwi Rasmi, Novyantry Andika, and Syifa Salsabila Wibisana; formal analysis, Syifa Salsabila Wibisana; investigation, Menza Hendri and Syifa Salsabila Wibisana; resources, Dian Pertiwi Rasmi; data curation, Syifa Salsabila Wibisana; writing—original draft preparation, Menza Hendri and Syifa Salsabila Wibisana; writing—review and editing, Dian Pertiwi Rasmi and Novyantry Andika; visualization, Menza Hendri; supervision, Dian Pertiwi Rasmi; project administration, Dian Pertiwi Rasmi; funding acquisition, Novyantry Andika. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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