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Research Article

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Obstacles for Physics Teachers in Utilizing Digital Technology-Based Learning Media in the Implementation of the Independent Curriculum

[1]Nanda Safarati*, [2]Marnita, [3]Novianti, Tegar Putra Socrates[4]

[1] Physics Education Study Program, Almuslim University, Bireuen, Aceh, 24261, Indonesia
[2] teacher professional education study program, Almuslim University, Bireuen, Aceh, 24261, Indonesia
[3] mathematics education study program, Almuslim University, Bireuen, Aceh, 24261, Indonesia
[4] Student of Teacher Professional Education Study Program, Almuslim University, Bireuen, Aceh, 24261, Indonesia

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ABSTRACT

This study aims to analyze the obstacles faced by physics teachers in utilizing digital technology-based learning media in the implementation of the Independent Curriculum. This study employed a quantitative research method, with a descriptive type of research. The sampling technique used was convenience sampling, involving 25 high school physics teachers who were non-randomly selected from various regions based on ease of access. Data analysis was conducted using a Likert Scale. The research procedure was carried out systematically through the stages of problem collection and literature review, instrument development and validation, questionnaire distribution using Google Forms, data collection and analysis, and interpretation of the results and drawing conclusions. Based on the results of the research data analysis that has been conducted, it was found that physics teachers generally have a positive perception of the use of digital media in learning and believe that digital media can increase interactivity and help visualize physics concepts. This study shows that the implementation of digital media in physics learning is not only influenced by the technical ability to use technology, but also by the teacher's ability to integrate technology pedagogically according to the characteristics of physics learning and the demands of the Independent Curriculum.

ABSTRAK

Penelitian ini bertujuan untuk menganalisis kendala guru fisika dalam pemanfaatan media pembelajaran berbasis teknologi digital pada implementasi Kurikulum Merdeka. Penelitian menggunakan metode penelitian kuantitatif, dengan jenis penelitian deskriptif. Teknik pengambilan sampel yang digunakan adalah convenience sampling, melibatkan 25 guru fisika SMA yang dipilih secara tidak acak dari berbagai daerah berdasarkan kemudahan akses. Analisis data dilakukan menggunakan skala Likert. Prosedur penelitian dilakukan secara sistematis melalui tahapan identifikasi masalah dan studi literatur, penyusunan serta validasi instrumen, penyebaran kuesioner secara daring menggunakan *google forms*, pengumpulan dan analisis data, hingga interpretasi hasil dan penarikan kesimpulan. Berdasarkan hasil analisis data penelitian yang telah dilakukan, ditemukan bahwa guru fisika secara umum memiliki persepsi positif terhadap penggunaan media digital dalam pembelajaran dan menilai bahwa media digital mampu meningkatkan interaktivitas serta membantu visualisasi konsep fisika. Penelitian ini menunjukkan bahwa implementasi media digital dalam pembelajaran fisika tidak hanya dipengaruhi oleh kemampuan teknis penggunaan teknologi, tetapi juga oleh kemampuan guru dalam mengintegrasikan teknologi secara pedagogis sesuai karakteristik pembelajaran fisika dan tuntutan Kurikulum Merdeka.

*Corresponding Author
Email: safaratinanda@gmail.com

INTRODUCTION

Over the past decades, the development of digital technology during the Industrial Revolution 4.0 era has had a significant impact on education. Technological advances are rapidly reshaping society, and innovations often become outdated before they can be fully integrated into everyday life (Bessas et al., 2025). Digital media technology is playing an increasingly important role in social development, not only as a tool for information dissemination, but also as an indispensable part of human civilization progress and cultural innovation (Chi et al., 2025). The use of digital technology-based learning media is believed to improve the quality of the teaching and learning process, make learning more interactive, and facilitate the achievement of 21st-century competencies such as critical thinking, collaboration, communication, and creativity. Digital skills are crucial to both teachers and students. Digital competency involves navigating and effectively using digital technology for learning and teaching (Claro et al., 2024). Advances in information technology provide an opportunity for teachers can utilize to improve their learning patterns (Riskiawan et al., 2016). Teachers are required to utilize technology in accordance with modern advances, starting from designing, implementing and evaluating learning (Setiawan et al., 2018; Baihaqi et al., 2020;Ramadhina & Rohman, 2022).

Digital technology (e.g physics simulations, virtual laboratories, augmented reality, and learning platforms based on Learning Management Systems) can increase student engagement through interactive activities and gamification, support deeper conceptual understanding, especially in science subjects, and improve problem-solving and critical thinking skills (Laius & Orgusaar, 2025;Hillmayr et al., 2020). Additionally, the use of digital devices can help students overcome cognitive barriers stemming from various misconceptions (Hillmayr et al., 2020). Digital literacy is required for the use of digital technology in learning activities. The development of students' literacy levels and their digital competence is crucial for improving the effectiveness and efficiency of the learning process as well as for the adaptation of students (Shopova, 2014;Harmawati et al., 2024). Digital literacy is a set of skills that involve the use of ICT and is supported by basic competencies in using digital devices to retrieve, assess, store, produce, present and exchange information wirelessly (Saiz et al., 2025). Digital literacy encourages students to explore various learning methods and arouses their interest and engagement, thereby stimulating learning motivation (Zhang, 2025).

In the context of physics learning, digital media can help students understand abstract concepts through visualizations, simulations, and virtual experiments. In line with this, the Indonesian government has implemented the Independent Curriculum (Curriculum Merdeka), which emphasizes project-based learning, differentiation, and the strengthening of student competencies. This curriculum provides ample opportunity for teachers to utilize various learning resources, including digital technology, to make the learning process more relevant to real life. The Independent Curriculum has been implemented since 2021 (Wijayanti & Tirtoni, 2023). An independent curriculum provides freedom for teachers to create educational and enjoyable learning (Ariga, 2022), as well as innovate in teaching methods to increase student engagement and support learning that is more relevant to the needs of the times (Viola et al., 2024). The implementation of the Independent Curriculum aims to overcome the learning crisis (learning loss), although the positive goal of implementing the Independent Curriculum through several activities, this implementation presents challenges and problems for educational units that adopt it (Badriah & Adimayuda, 2024). Whenever there is a change in the curriculum, teachers must be able to adapt to ensure that the implementation of the curriculum can run optimally (Ariga, 2022).

This is in line with Yanti and Fernandes (2021), who stated that the curriculum lies with the teacher. If the teacher cannot understand it deeply, then the educational goals will not be achieved, so the teacher's ability to adapt is important, even though it takes time. In addition, according to Naufal, et al (Ode et al., 2025), even though the independent curriculum is considered simpler and provides more autonomy to schools, its implementation still

faces various challenges for teachers as the spearhead of implementation in the successful implementation in the classroom. Nur, et al (Anggraini, 2025) the implementation of and independent curriculum in terms of technology integration is still a challenge, with increasingly rapid technological developments and requiring digital media to be an important part of the teaching and learning process.

The urgency of using learning media for teachers is as a tool to help convey learning materials, making it easier for teachers to attract their time effectively and attract students' attention in the learning process (Asmita et al., 2022). Physics learning has distinct characteristics compared to other subjects because it includes many abstract concepts, microscopic phenomena, and complex mathematical representations that are difficult to understand if explained solely through lectures or textbooks. Therefore, the use of digital technology-based learning media such as PhET simulations, virtual laboratories, and motion analysis videos is crucial in helping visualize concepts and improving students' conceptual understanding. In implementing the Independent Curriculum, physics teachers are required to provide exploratory, experiment-based learning and utilize digital technology meaningfully (Azzarkasyi, 2024).

However, the use of digital media in physics learning is not solely related to teachers' technical skills in operating technological devices. A more fundamental issue lies in how digital media can represent the nature of physics as an experimental science. Physical phenomena require direct observation, tool manipulation, and real-life experimental processes, which cannot be fully replaced by digital media. On the other hand, some teachers experience difficulties in integrating digital media with physics experimental activities in a balanced manner. Excessive use of virtual simulations has the potential to diminish students' empirical experience of the scientific process, while limited laboratory facilities often make digital media the only learning alternative. This situation creates a pedagogical dilemma for physics teachers: the need to visualize concepts through technology and the importance of maintaining the essence of real-life experiments in physics learning. Therefore, this study is crucial for an in-depth analysis of the obstacles physics teachers face in utilizing digital technology-based learning media in the implementation of the Independent Curriculum.

Magen-Nagar dan Maskit (Mercader, 2020), Classifying obstacles in integrating learning technology can be understood in two main categories, namely individual obstacles related to teachers' personal characteristics, such as limited time, lack of training, low self-confidence in using technology, and limited experience in digital learning and institutional obstacles related to organizational support, such as limited facilities, minimal supporting policies, lack of professional mentoring, and resistance to changes in digital learning culture.

In the context of physics learning, barriers to technology integration cannot be explained solely through technical or institutional aspects. The Technological Pedagogical Content Knowledge (TPACK) framework provides a more comprehensive explanation that the success of technology integration is largely determined by the teacher's ability to simultaneously integrate technological knowledge (Technology), pedagogy (Pedagogy), and content. Therefore, the main challenge for physics teachers lies not only in their ability to use technology (Technological Knowledge/TK), but primarily in the intersection between Content Knowledge (CK) and Pedagogical Knowledge (PK) integrated with technology. Physics teachers are generally familiar with various digital applications, simulations, or technology-based learning media. However, many teachers still experience difficulties in determining how these technologies can be used pedagogically to explain abstract, complex, and mathematical physics concepts. This situation indicates that the obstacles physics teachers experience are not merely technological barriers, but rather obstacles to the full integration of TPACK. Integrating technology into physics learning according to the TPACK framework also faces challenges in teacher readiness regarding technological and pedagogical aspects (Oktasari et al., 2020). Meanwhile, a study on the implementation of the Independent Curriculum in physics learning shows that teacher readiness, media availability, and time allocation are still serious problems (Dewi et al., 2023).

These conditions indicate that most previous studies have indeed raised aspects of technology and digital media in learning, but there is still a research gap that needs to be bridged. Although digital technology has great potential for visualizing abstract

physics concepts, its implementation in learning still faces conceptual challenges. Many digital media are developed with a focus on technology and visualization, but they are not fully aligned with the needs of physics pedagogy and the flexible learning characteristics of the Independent Curriculum. Within the TPACK framework, this problem indicates a disconnect between technology, pedagogy, and content. Teachers may be able to use digital applications or media, but they do not yet understand how these technologies can be used pedagogically to help students develop a deeper understanding of physics concepts. As a result, technology often functions only as a presentation tool, rather than as a means of constructing concepts. This condition is crucial because physics learning requires not only visualization but also the integration of mathematical representations, real-world phenomena, and scientific reasoning. Therefore, there is a conceptual gap in the form of a mismatch between digital media design and the demands of flexible pedagogy in the Independent Curriculum, which can ultimately reduce the effectiveness of physics learning.

Based on these problems, this study aims to analyze the barriers to digital media integration in physics learning through a TPACK perspective. Different from previous studies that generally only highlight technological or facility limitations, this study emphasizes the specificity of the physics study field, particularly the mismatch between digital media design, physics pedagogical needs, and the characteristics of abstract concepts in the Independent Curriculum. Thus, this study is expected to provide a conceptual contribution in strengthening the understanding of TPACK integration in physics learning and become the basis for the development of digital media that is more pedagogical, contextual, and appropriate to the needs of 21st-century physics learning.

METHODS

This study employed a quantitative research method with descriptive statistics. This method was used to describe and analyze physics teachers' responses regarding the obstacles faced when utilizing digital technology-based learning media in the implementation of and independent curriculum. Quantitative method, namely research data in the form of numbers and analysis using statistics (Tumurang, 2024). Descriptive research is research used to describe and answer questions about a current phenomenon or event, whether the phenomenon is in a single variable or correlation, comparison of various variables (Rachman et al., 2024). This research is positioned as a preliminary study that aims to obtain an initial overview of the obstacles faced by physics teachers in utilizing digital technology-based learning media in the implementation of the Independent Curriculum.

The sampling technique used was convenience sampling, involving 25 high school physics teachers who were randomly selected from various regions. Prior to conducting the study, the researcher explained the research ethics procedures and obtained the participants' informed and voluntary consent. Furthermore, the identities of all respondents were anonymized to maintain the confidentiality and security of participant data in accordance with research ethics standards.

Convenience sampling is sampling based on the availability of elements and ease of obtaining them (Etikan et al., 2016; Hendrajaya & Lestari, 2022). The research procedure was carried out systematically through the stages of problem identification and literature study, preparation and validation of instruments, distribution of online questionnaires using google forms, data collection and analysis, to interpretation of results and drawing conclusions.

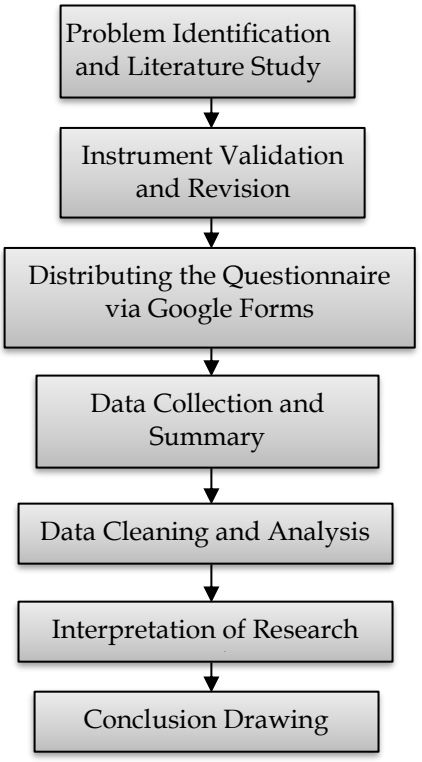

Figure 1. Research Flow

The data were analyzed using a Likert scale.

Table 1. Likert Scale Scoring

Category	Score
Strongly Agree	5
Agree	4
Disagree Less	3
Don't agree	2
Strongly Disagree	1

Source: Alamsyah et al., (2024)

The completion of the questionnaire was voluntary. The research questionnaire includes multiple-choice questions on a Likert scale and open-ended questions, focusing on the challenges faced by physics teachers in general. There are 8 components of questions that the researcher wants to study and are divided into 25 questions that have been given, which have been validated. This study focuses on the challenges experienced by teachers, particularly physics teachers, in using technology-based learning media.

RESULT & DISCUSSION

Site Results

The researcher asked eight components of the questions in the questionnaire. These eight components were reflected in the 25 questions provided. Twenty-five respondents responded to the questionnaire based on the data collection results. Of these, 28% had a master's degree and 72% had a bachelor's degree.

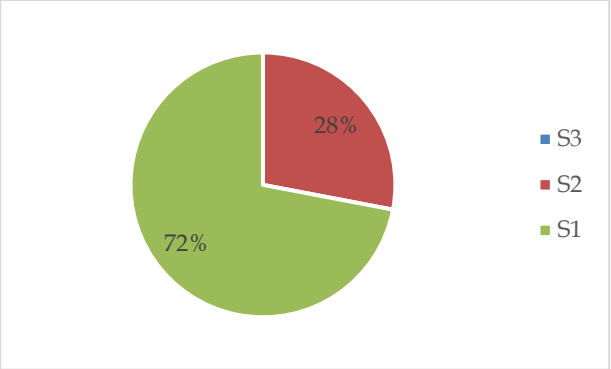

Figure 2. Percentage of initial data analysis of respondents

Furthermore, based on the length of teaching experience of respondents obtained through data collection, which ranges from two years to 33 years, and the grade levels taught, which range from grade VII of junior high school to grade XII of senior high school. The eight components studied by researchers related to the obstacles of physics teachers in utilizing digital technology-based learning media in the implementation of and independent curriculum, namely teacher competence in digital technology, availability of facilities and infrastructure, teacher attitudes and perceptions, relevance to the independent curriculum, school environmental support, technical obstacles and student readiness, benefits and effectiveness, and professional development needs. The results of the questionnaire response analysis for the first components related to teacher competence in digital technology, which consists of three aspects of question responses, are shown in Table 2.

Table 2. Analysis of teacher competency response questionnaire in digital technology

No	Aspects of Response	Response Results (%)				
		5	4	3	2	1
Teacher Competence in Digital Technology						
1	I feel I have sufficient skills in using digital technology-based learning media	36	52	12	0	0
2	I have difficulty mastering the features of technology-based learning applications	0	12	32	40	16
3	I need additional training to improve my digital media usage competency	48	32	20	0	0
Amount		**84**	**96**	**64**	**40**	**16**
Average Percentage		**28**	**32**	**21**	**3**	**5**

Based on the Teacher Competency Table in Digital Technology, the majority of teachers demonstrated a positive perception of their ability to use digital technology-based learning media. This is evident from the predominance of responses in the agree and strongly agree categories regarding the ability to use digital media in learning. Furthermore, the need for additional training remains quite high, indicating that teachers are aware of the need to

continuously improve their technological competency. On the other hand, some respondents still experienced difficulty mastering the features of technology-based learning applications. This finding suggests that although teachers' basic competency in using digital media is quite good, mastery of technical skills and advanced training are still needed to support the optimal implementation of digital learning.

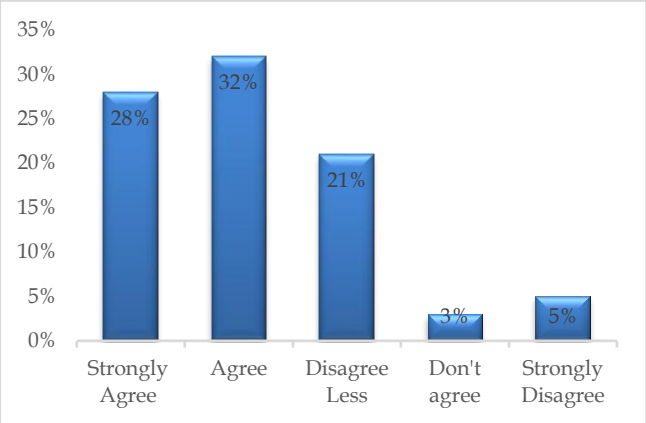

Figure 2. Average percentage of teacher competency aspects in digital technology

Furthermore, the second response aspect, related to the availability of facilities and infrastructure, had three response aspects. Table 3 presents the results of the questionnaire response analysis.

Table 3. Analysis of questionnaire responses to the availability of facilities and infrastructure

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Availability of Facilities and Infrastructure						
1	ICT facilities (laptops, projectors, internet networks) in schools support the implementation of digital learning media	48	28	16	8	0
2	Technical obstacles (e.g. power outages, slow internet) often disrupt the implementation of digital learning	24	48	12	8	8
3	My school has a clear policy in supporting the use of digital media	28	68	4	0	0
Amount		**100**	**144**	**32**	**16**	**8**
Average Percentage		**33**	**48**	**11**	**5**	**3**

Based on the analysis of the availability of facilities and infrastructure, most respondents indicated that ICT facilities in schools generally support the implementation of digital learning media. Furthermore, school policy support for the use of digital media also appears quite strong, indicating institutional attention to the implementation of technology-based learning. However, technical barriers such as internet network and power outages remain a frequent obstacle in the digital learning process. These findings indicate that despite relatively good support from school facilities and policies, technical infrastructure optimization still needs to be improved to ensure the use of digital media in physics learning is more effective.

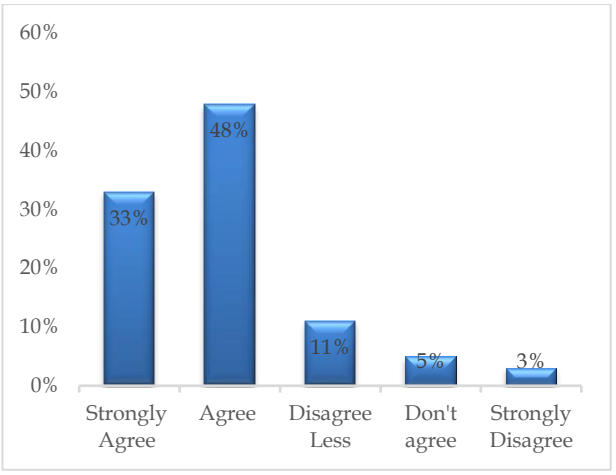

Figure 3. Average percentage of the availability of facilities and infrastructure aspects

In addition to examining teacher competency in digital learning and the availability of infrastructure, researchers have also analyzed teacher attitudes and perceptions regarding digital media, as this is a crucial component in understanding teachers' attitudes and perspectives regarding the digital media they use. The results of the questionnaire response analysis regarding teacher attitudes and perceptions are presented in Table 4.

Table 4. Analysis of teacher attitude and perception response questionnaire

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Teacher Attitudes and Perceptions						
1	I believe the use of digital media can help improve students' understanding of physics concepts.	48	48	4	0	0
2	I am worried that digital media will take up too much time in the learning process.	4	4	24	44	24
3	I feel confident when integrating digital media in teaching physics.	24	56	20	0	0
Amount		**76**	**108**	**48**	**44**	**24**
Average Percentage		**25**	**36**	**16**	**15**	**8**

Based on the analysis of teachers' attitudes and perceptions, the majority of respondents expressed a positive view of the use of digital media in physics learning. Teachers believe that digital media can help improve students' conceptual understanding and feel confident in integrating technology into the learning process. However, some respondents felt that the use of digital media can be time-consuming. These findings indicate that while teachers' attitudes toward the use of digital media tend to be positive, the efficiency of technology use in learning remains a concern that needs to be addressed in its implementation.

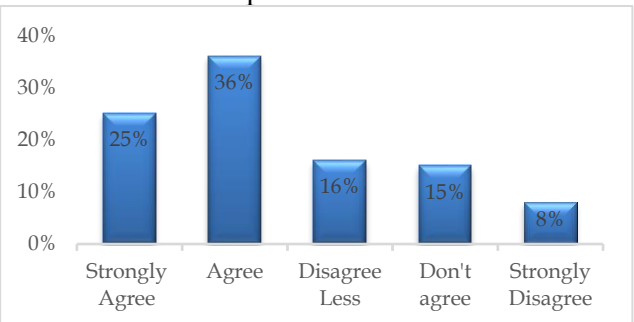

Figure 4. Average percentage of teacher attitude and perception aspects

Furthermore, a study of the relevance of digital media to the independence curriculum is also needed. This will help to clarify the alignment between the existing curriculum and the learning media used by teachers. Table 5 presents the results of this analysis.

Table 5. Analysis of questionnaire responses on the relevance of digital media to the independence curriculum

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Teacher Attitudes and Perceptions						
1	The digital media that I use is in accordance with the learning outcomes of the Independent Curriculum	28	52	20	0	0
2	I have difficulty adapting digital media to the needs of project-based learning (PjBL)	0	12	48	28	12
3	The use of digital media makes it easier for me to differentiate learning.	36	64	0	0	0
Amount		**64**	**128**	**68**	**28**	**12**
Average Percentage		**21**	**43**	**23**	**9**	**4**

Based on the analysis of the relevance of digital media to the Independent Curriculum, the majority of teachers assessed that the digital media used was appropriate for learning outcomes and capable of supporting the learning differentiation process. This finding indicates that digital media is considered relevant in supporting the implementation of the Independent Curriculum, which is oriented towards student learning needs. However, some respondents still experienced difficulties in adapting digital media to project-based learning (PjBL). This indicates that the integration of digital media into more complex learning activities still requires strengthening, both through training and the development of media that is more adaptive to the Independent Curriculum learning model.

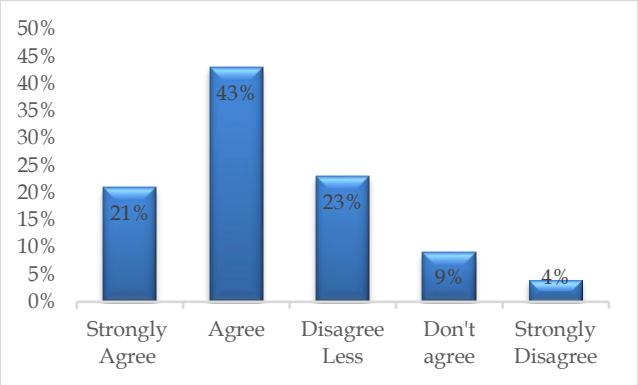

Figure 5. Average percentage of aspects of digital media relevance to the independent curriculum

In addition to the relevance of digital media to the curriculum, school environmental support is also a considered for identifying potential obstacles. The analysis results related to school environmental support are presented in Table 6.

Table 6. Analysis of school environmental support response questionnaire

No	Aspects of Response	Response Results (%) 5	4	3	2	1
School Environmental Support						
1	Principals and colleagues support the use of digital learning media	44	52	4	0	0
2	The school provides a discussion forum/learning community for teachers to share experiences using digital media	16	72	4	8	0
3	I often get motivation or direction from the school regarding the use of digital media	16	64	16	4	0
Amount		**76**	**188**	**24**	**12**	**0**
Average Percentage		**25**	**63**	**8**	**4**	**0**

Based on the analysis of the school environment support aspect, the majority of respondents indicated that the principal and colleagues provided positive support for the use of digital learning media. Furthermore, the school was also deemed quite active in providing discussion forums or learning communities to share experiences using digital media. Support in the form of motivation and guidance from the school was also quite good. These findings indicate that the school environment plays a crucial role in encouraging the implementation of digital media in physics learning. This collaborative support can be a supporting factor for teachers in improving their competence and confidence in utilizing learning technology.

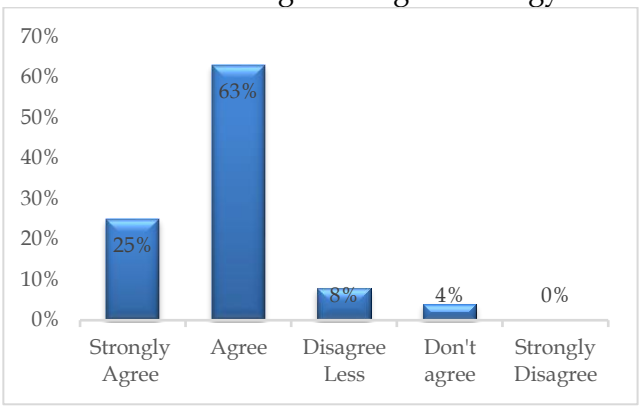

Figure 6. Average percentage of school environmental support aspects

Technical barriers and student readiness must also need to be considered to prevent them from becoming obstacles in the learning process. Technical barriers can originate internally or externally from the respondents, but student readiness to learn the concepts presented in the material also needs to be considered when implementing technology-based learning media. The results of the analysis of the technical barriers and student readiness are presented in Table 7.

Table 7. Analysis of questionnaire responses to technical obstacles and student readiness

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Technical Barriers and Student Readiness						
1	My students have adequate gadgets/laptops to support digital learning	4	56	24	8	8
2	Students have difficulty understanding physics material when it is delivered via digital media	0	4	44	44	8
3	Technical obstacles from students (quota, devices, network) often	16	56	16	12	0

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Technical Barriers and Student Readiness						
	disrupt the learning process					
Amount		**20**	**116**	**84**	**64**	**16**
Average Percentage		**7**	**39**	**28**	**21**	**5**

Based on the analysis of technical barriers and student readiness, most respondents assessed that students had adequate devices to support digital learning. However, teachers still encountered obstacles in the learning process, particularly related to students' difficulty understanding physics material through digital media. Furthermore, technical barriers such as limited internet quota, devices, and network connections often disrupted the learning process. These findings indicate that students' device readiness has not yet fully translated into optimal readiness to understand digital learning materials, necessitating more interactive learning strategies and improved infrastructure support.

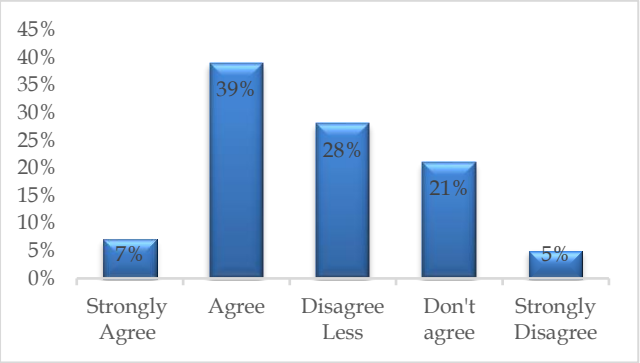

Figure 7. Average percentage of technical barriers and student readiness aspects

The benefits and effectiveness of media are also considered in the learning process. The results of the analysis of these aspects are presented in Table 8.

Table 8. Analysis of the questionnaire responses to benefits and effectiveness

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Benefits and Effectiveness						
1	Digital media helps me in developing more interesting and interactive learning	44	52	4	0	0
2	The use of digital media can improve students' critical thinking skills	40	36	24	0	0
3	The use of digital media accelerates the process of student evaluation and assessment.	36	56	8	0	0
Amount		**120**	**144**	**36**	**0**	**0**
Average Percentage		**40**	**48**	**12**	**0**	**0**

Based on the analysis of benefits and effectiveness, the majority of respondents responded positively to the use of digital media in physics learning. Digital media is considered capable of helping teachers create more engaging and interactive learning, while also supporting the development of students' critical thinking skills. Furthermore, the use of digital media is also perceived to simplify and accelerate the evaluation and assessment processes of learning. These findings indicate that digital media not only serves as a means of delivering material but also contributes to improving the quality and effectiveness of the overall physics learning process.

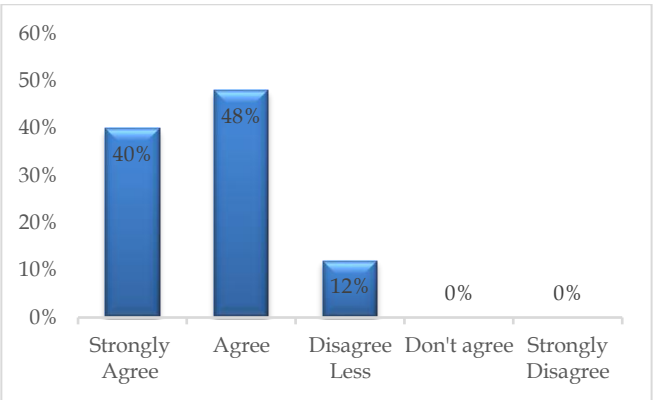

Figure 8. Average percentage of technical barriers and student readiness aspects

The final aspect to be considered is the need for professional development. Teachers also require professional development to develop their own competencies and professionalism. The results of the analysis of the responses to professional development needs are presented in Table 9.

Table 9. Analysis of the professional development needs response questionnaire

No	Aspects of Response	Response Results (%) 5	4	3	2	1
Professional Development Needs						
1	I need further workshops/training regarding the use of digital media for physics	48	28	24	0	0
2	I feel the need for a practical guide to using digital media that is in accordance with the Independent Curriculum	40	48	12	0	0
3	I want to collaborate with other teachers to develop digital physics media	44	40	16	0	0
4	I feel burdened by the demands of using digital media without optimal support from the school	4	8	40	32	16
Amount		**136**	**124**	**92**	**32**	**16**
Average Percentage		34	**31**	**23**	**8**	**4**

Based on the analysis of professional development needs, the majority of teachers indicated a high need for further training related to the use of digital media in physics learning.

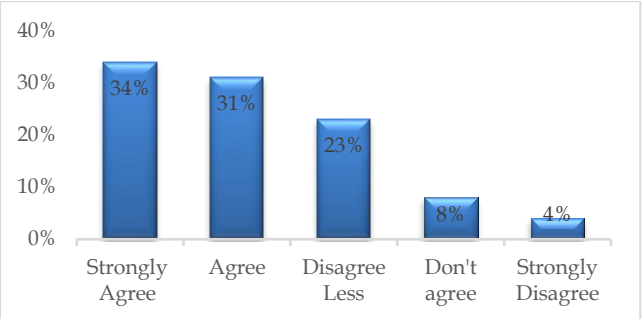

Figure 9. Average percentage of aspects of professional development needs

Furthermore, teachers felt the need for practical guidance aligned with the implementation of the Independent Curriculum to ensure more effective digital media use. A strong desire to collaborate with other teachers in developing digital media was also evident, indicating a culture of sharing and collective professional development. However, some respondents still felt burdened by the demands of digital media use, which were not fully supported by school facilities and policies. These findings indicate that teacher competency development needs to be balanced with adequate institutional support for optimal digital learning implementation.

Discussion

Based on the analysis of research data, it was found that physics teachers implementing the Independent Curriculum generally have a positive perception of the use of digital technology-based learning media. This finding is evident in the high level of teacher confidence in using digital media, the availability of supporting school facilities, and the belief that technology can improve the quality of physics learning. However, this study found that the main challenge no longer lies in basic technology use skills, but rather in the ability to integrate technology pedagogically and conceptually into physics learning. This finding provides a different nuance than several studies that tend to focus on obstacles such as low teacher digital literacy or limited access to technology. Anggraini (2025), which states that teacher training is not yet evenly distributed and sustainable, limited supporting facilities (devices and internet access), high administrative burdens, making it difficult for teachers to innovate, and there is a lack of technological culture in schools, especially in remote areas. Wijayanti & Tirtoni (2023), stated that training and development of competencies of educators and education staff, increasing support from parents and the community, improving facilities and infrastructure, increasing supervision and monitoring, developing cooperation between education stakeholders, and encouraging participation in the driving educator program can be efforts made to overcome existing obstacles. Viola et al., (2024) provide recommendations for educational policies and training programs that can support teachers in optimizing the use of learning media so that the objectives of the Independent Curriculum can be achieved more effectively.

In the context of this research, most teachers are actually able to use digital devices and applications, but still experience difficulties in optimizing digital media to suit the characteristics of physics as an abstract, mathematical, and experimental science. This shows that the problem of technology integration in physics learning is not sufficiently understood as a purely technical issue, but is related to the complexity of the relationship between technology, pedagogy, and physics content as explained in the TPACK framework. From a TPACK perspective, the findings of this study indicate that teachers' Technological Knowledge (TK) competencies have been relatively developed, as seen from teachers' basic abilities in using digital media and learning applications. However, mastery of this technology has not been fully followed by Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK) abilities.

Teachers still struggle to determine appropriate pedagogical strategies when using digital media to explain abstract physics concepts, such as motion, waves, or microscopic phenomena. This situation demonstrates that the use of technology in physics learning is not simply about transferring material to a digital platform, but requires the ability to select media that can represent physics phenomena conceptually and experientially. Previous research has shown that technology integration tends to be successful in educational environments with mature digital infrastructure and an established technology culture. Costa, et.al, 2021, a successful digital transformation requires that schools increase their digital capacity levels, establishing the necessary "*culture, policies, infrastructure as well as digital competence of students and staff to support the effective integration of technology in teaching and learning practices* (Timotheou et al., 2022). However, based on the researchers' analysis in this study, teachers face a pedagogical dilemma between the use of digital simulations and the importance of maintaining real-world experimental experiences in physics learning. While digital simulations aid in the visualization of abstract concepts, teachers believe these media cannot fully replace direct observation, instrument manipulation, and students' empirical experiences in physics laboratory activities.

Furthermore, the research findings also show that school facilities and institutional policies do not automatically guarantee optimal digital learning implementation. Although most schools have adequate ICT facilities and positive principal support, technical barriers such as internet and power outages remain a major obstacle. These findings offer a different perspective, which generally places infrastructure as the primary factor in successful technology integration (Mahardika et al., 2023). In the context of this research, even adequate infrastructure is not fully capable of addressing implementation issues, as the biggest challenge lies in integrating digital pedagogy into physics learning. In other words, the success of digital learning is determined not only by the availability of devices but also by the teacher's ability to connect technology with learning strategies that are appropriate to the characteristics of the physics material and the students' learning needs.

Regarding teacher attitudes and perceptions, this study shows that teachers have a positive view of the use of digital media because they believe it can improve students' conceptual understanding and critical thinking skills. This finding reinforces the view that digital media has great potential in helping visualize physics concepts that are difficult to observe directly. However, some teachers also believe that the use of digital media can take up learning time and increase the burden of teaching preparation. These findings demonstrate a tension between the demands of digital learning innovation and the reality of teachers' workload in implementing the Independent Curriculum. Within the TPACK framework, this situation demonstrates that developing teacher competencies is not enough to simply improve technological skills but also needs to help teachers build a balanced integration between pedagogy, technology, and practical learning management.

This study also found that digital media is considered relevant to the implementation of the Independent Curriculum, particularly in supporting differentiated learning and more

flexible learning activities. Good learning media must be appropriate to students' cognitive developmental stages (Sartika et al., 2024). However, some teachers still experience difficulties in integrating digital media into project-based learning. According to Azizi et al., (2024) The importance of systemic support from educational institutions and the government to improve teacher adaptation, recommendations include improving structured training programs and developing policies that support technology integration in the curriculum. These findings indicate that the challenge of implementing technology in the Independent Curriculum lies in the ability to design learning activities that are not only interactive, but also authentic and collaborative. From a TPACK perspective, this condition is related to the low integration between Pedagogical Knowledge (PK) and Technological Knowledge (TK) in the context of project-based learning. Teachers have not been fully able to utilize technology as a means of building scientific investigations and in-depth exploration of physics concepts. This is an important contribution of the research because it shows that the obstacles to the use of digital media in physics learning lie not only in the technical aspects of application use, but also in transforming learning designs in accordance with the Independent curriculum paradigm.

A supportive school environment and a collaborative culture among teachers are important factors in increasing teacher readiness to utilize digital media. Discussion forums, learning communities, and peer support help teachers build confidence in using learning technology. These findings demonstrate that teacher TPACK development does not occur individually, but is influenced by the professional community and school culture. However, this study also found that student readiness for digital learning remains a challenge, particularly in independently understanding physics material through digital media. Although most students have adequate learning tools, their ability to understand representations of physics concepts through digital media is not yet fully optimal. This finding contrasts with research that tends to assume that the digital generation is ready to use technology in learning (Chambia & Haryanto, 2025). Sartika et al., (2024), states that digital learning media is needed by students, especially to make it easier for them to learn science material, make learning more fun, and increase motivation and science learning outcomes. Thus, the media needs to be implemented at the education level. In the context of physics learning, student readiness is not only determined by device access, but also by cognitive abilities in interpreting visualizations, simulations, and mathematical representations found in digital media.

These differences in findings are likely influenced by the context of the implementation of the Independent Curriculum in Indonesia, which still faces limited laboratory facilities and diverse teachers' digital competencies. In countries with more mature technological infrastructure, digital media tends to be positioned as a reinforcement for experimental learning, whereas in the context of this study, digital media is often used as a substitute for physical laboratories. This situation creates a pedagogical dilemma for physics teachers, between the need for technology-based visualization and the importance of maintaining the nature of physics as an experimental science. These findings indicate that technology integration in physics learning cannot be viewed solely as a matter of adopting digital tools, but also involves transforming the physics experimentation pedagogy itself.

Overall, this study shows that the implementation of digital technology-based learning media in physics learning within the Independent Curriculum is a complex and multidimensional issue. The obstacles experienced by teachers cannot be reduced solely to low digital literacy or limited facilities, but are closely related to the ability to meaningfully integrate technology into physics pedagogy and content. Therefore, the professional development of physics teachers needs to be directed at strengthening TPACK competencies as a whole, particularly the ability to develop digital learning that maintains the essence of physics as an experimental science. Thus, this study provides a new contribution that the main challenge in digital physics learning lies not in the use of technology itself, but in how technology can support students' conceptual and empirical

experiences in a balanced manner in the implementation of the Independent Curriculum.

CONCLUSION

Physics teachers generally have a positive perception of the use of digital technology-based learning media in the implementation of the Independent Curriculum. Digital media is considered capable of facilitating the visualization of physics concepts, increasing the interactivity of learning, and supporting student learning. Supportive school facilities and a collaborative work environment are also supporting factors in the use of digital media in schools. However, this study shows that the main obstacles faced by physics teachers are not only related to technical skills in using technology, but also to the ability to effectively integrate technology with physics pedagogy and content.

Teachers' Technological Knowledge (TK) competencies are relatively well developed, but the integration between Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK) still requires strengthening. Therefore, physics teacher professional development needs to be directed not only at training in technology use but also at strengthening digital pedagogical competencies relevant to the characteristics of physics learning and the implementation of the Independent Curriculum. Thus, the use of digital media in physics learning is expected to not only serve as a means of delivering material but also to support students' conceptual and experimental learning experiences in a more meaningful and balanced manner.

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