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Development of TPACK-Based Physics Magazine as Teaching Material for High Schools: A Study on Rotational Dynamics and Rigid Body Equilibrium

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ABSTRACT

This study aims to develop a physics teaching magazine based on Technological Pedagogical and Content Knowledge (TPACK) for senior high school students, focusing on rotational dynamics and equilibrium of rigid bodies. Employing a Research and Development (R&D) approach with the 4-D model, the process encompassed definition, design, and development stages. The magazine's content and media aspects were validated by experts, achieving feasibility scores of 94% and 87.9%, respectively. The magazine was evaluated by students of SMAN 1 Lembah Seulawah Aceh Besar, with results indicating strong acceptance and effectiveness as a learning medium. While the study confirms the potential of TPACK-based interactive learning materials in science education, its limited scope and sample size suggest caution in generalizing the findings. Future research should expand the scope, involve larger samples, and integrate diverse technological tools. This research contributes to the discourse on digital competencies in science education, emphasizing the need for innovative materials and continuous professional development.

INTISARI

Penelitian ini bertujuan untuk mengembangkan majalah pengajaran fisika berbasis Technological Pedagogical and Content Knowledge (TPACK) untuk siswa SMA, dengan fokus pada dinamika rotasi dan kesetimbangan benda tegar. Dengan menggunakan pendekatan Penelitian dan Pengembangan (R&D) dan model 4-D, proses tersebut mencakup tahap definisi, desain, dan pengembangan. Aspek konten dan media majalah divalidasi oleh para ahli, mencapai skor kelayakan 94% dan 87,9%. Majalah dievaluasi oleh siswa SMAN 1 Lembah Seulawah Aceh Besar, dengan hasil yang menunjukkan penerimaan dan efektivitas yang kuat sebagai media pembelajaran. Sementara penelitian ini mengonfirmasi potensi bahan ajar interaktif berbasis TPACK dalam pendidikan sains, ruang lingkup dan ukuran sampel yang terbatas menyarankan kehati-hatian dalam menggeneralisasi temuan. Penelitian mendatang harus memperluas cakupan, melibatkan sampel yang lebih besar, dan mengintegrasikan berbagai alat teknologi. Penelitian ini berkontribusi pada diskursus kompetensi digital dalam pendidikan sains, menekankan kebutuhan akan bahan ajar inovatif dan pengembangan profesional yang berkelanjutan.

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A. Introduction

The rapid advancement of technology in the current era of revolution, particularly its increasing integration in educational contexts, represents a significant shift in teaching and learning practices worldwide [1]. In the realm of physics education, this transition is pivotal, as the subject inherently involves both process and product, necessitating not only the understanding of theoretical concepts but also the mastery of practical applications [2]. The development of educational materials, therefore, becomes crucial in enhancing the quality of student learning experiences, requiring resources that are systematically designed, engaging, and aligned with instructional norms [3], [4]. This necessity underscores the importance of innovative and technology-integrated educational materials in the field of physics education, especially at the secondary school level.

Observations in educational settings, such as SMAN 1 Leumbah Seulawah in Aceh Besar, have revealed that students often find physics challenging and unengaging. This perception could be attributed to the use of unappealing teaching materials [5]. The role of educators in developing innovative teaching materials using available technologies becomes vital in addressing this issue [6], [7]. For instance, the integration of physics content into magazine formats has shown potential in making the subject more accessible and enjoyable for students [8], [9]. Such innovations not only provide visual and textual content but also include educational information that can broaden students' perspectives and enhance their understanding of physics concepts [10], [11].

The concept of Technological Pedagogical and Content Knowledge (TPACK) emerges as a critical framework for integrating technology, pedagogy, and content knowledge in educational practices [12], [13]. TPACK facilitates educators in effectively utilizing technology to support teaching and learning activities [14], [15]. Previous studies have emphasized the importance of TPACK in the development of instructional materials, highlighting its role in enhancing teacher effectiveness and student engagement in physics learning [16]–[18].

In the context of physics education, the application of TPACK through mediums like physics magazines presents a unique opportunity to revolutionize teaching methods. Ekawati and Prastyo [19] found that project-based learning in micro-teaching courses improved TPACK capabilities, indicating the potential of such innovative approaches in physics education. Additionally, studies by Puspitasari et al. [20] and Masrifah et al. [21] support the effectiveness of TPACK-based educational resources in enhancing both teacher literacy and student learning outcomes. These findings underscore the need for educators to adapt and innovate their teaching practices to align with the evolving educational landscape.

Despite the promising aspects of TPACK-based educational materials, challenges and gaps still need to be addressed in their widespread implementation and

effectiveness. Akuma and Callaghan [22] identified gaps in teacher competencies in implementing inquiry-based practical work, highlighting the need for further development in this area. Similarly, Wahyuni et al. [23] and Syukri et al. [13] found that while physics teachers are capable of designing STEM-based lessons, certain aspects of TPACK abilities still pose challenges. These insights point to the need for ongoing research and development in the field of TPACK-based physics education.

The present study aims to address these gaps by developing a physics magazine-based teaching material grounded in the TPACK framework. This initiative seeks to bridge the identified limitations in current teaching practices and materials, particularly in enhancing the appeal and effectiveness of physics education for high school students. The focus is on creating a resource that is not only pedagogically sound and content-rich but also technologically integrated, catering to the diverse needs of today's learners. By doing so, this study endeavors to contribute to the growing body of knowledge in the field of physics education and technology-enhanced learning, offering a novel approach to teaching complex scientific concepts in an engaging and accessible manner.

The objective of this research is twofold: firstly, to develop a physics teaching material in the form of a magazine based on the Technological Pedagogical and Content Knowledge (TPACK) framework, and secondly, to assess the feasibility of this product through expert evaluation and to ascertain student responses to the TPACK-based physics magazine. This study aims to not only contribute to the field of educational technology and physics education but also to provide a practical and innovative resource for enhancing the teaching and learning of physics in high school settings. The anticipated outcome is a more engaging and practical approach to physics education, aligning with the needs and interests of contemporary students and the evolving landscape of educational technology.

B. Method

The method used in this research is the research and development method, abbreviated as R & D, with a 4-D model (four D model) which consists of 4 stages, namely stage Define, Design, Development and Dissemination in order to produce a product and test the effectiveness of the resulting product [24]. In general, this research was carried out in three stages, namely the definition stage, design stage, and development stage. At the definition stage, researchers are expected to obtain complete information related to students and material so that it can become a basic idea and the product can be designed well and attractively. The design stage aims to create the arrangement of learning tools, namely teaching materials in the form of magazines, according to the required materials and images. The development stage seeks to produce a product that has been revised based on expert input [25]. There are three activities carried out in this development stage, namely validation testing,

product revision, and trial stages. Meanwhile, the deployment stage was not carried out because it required a lot of time and significant funds.

The data collection instruments used in this research were validation sheets and student response questionnaires. The data collection techniques used in this research were expert validation sheets and student response questionnaires. Validation of teaching materials was carried out by two validators, namely three media experts and three physics experts. The validation sheet observed in the research was a validation sheet for physics teaching materials in the form of a magazine. The validator's assessment of physics teaching materials in the form of magazines consists of 5 categories, namely very suitable (1), right (2), quite right (3), not applicable (4), and very unsuitable (5). This questionnaire was given to 6 students after completing the activity or teaching and learning process and then filled in by the students to answer the questions. This questionnaire was used as an instrument to collect data in this research trial.

Data collection is analyzed using a predetermined formula:

$$\overline{X} = \frac{\Sigma X}{N} \quad (1)$$

With:

$\overline{X}$ = Average score of assessments by experts

ΣX= total score obtained by the expert

N = number of questions.

To change the average score of expert assessments in order to determine the feasibility/validity of the magazine. The results of the development of physics teaching materials in the form of magazines, which initially had value in the form of scores, were converted into qualitative data using the percentage formula:

$$\text{Eligibility percentage} = \frac{\text{Average of all aspects}}{\text{aspect of the highest score assessment}} = x100\ \% \quad (2)$$

Meanwhile, to determine the suitability of physics teaching materials in the form of magazines, researchers used percentage analysis based on categories as a reference for assessing data produced by expert experts. The percentage assessment scale can be seen in Table 1

Table 1. Expert Validation Sheet Criteria

Value Percentage (%)	Criteria	Number
81-100	Very worthy	5
61-80	Worthy	4
41-60	Not worth it	3
21-40	Not feasible	2
<21	Not really worth it	1

To calculate the average score of student responses, the following formula is also used:

$$\overline{X} = \frac{\Sigma X}{N} \quad (3)$$

With:

$\overline{X}$ = Average score of assessments by students

ΣX = total score obtained by students

N = number of questions.

Meanwhile, to change the average score of student responses into a criterion value, the following percentage formula is used:

$$\text{Eligibility percentage} = \frac{\text{Average of all aspects}}{\text{aspect of the highest score assessment}} = x100\ \% \quad (4)$$

For more clarity, see Table 2 regarding the criteria for evaluating teaching materials.

Table 2. Educator Response Percentage Criteria

Value Percentage (%)	Criteria	Number
81-100	Very interesting	5
61-80	Interesting	4
41-60	Not enough interesting	3
21-40	No interesting	2
<21	Very not interesting	1

C. Result and Discussion

The research used is using research and development to produce specific products and test the effectiveness of a product in the form of teaching materials in the form of magazines based on technological pedagogical and content knowledge (TPACK) in SMA/MA. This research uses a 4D model, which consists of several stages.

In the first stage, namely the definition stage, the research aims to obtain information from students regarding characteristics, problems of students during learning, learning methods used by teachers, other supporting media used during learning, and reviewing the curriculum used. At this stage, there are several steps, namely initial analysis; the researcher first determines the research subjects, namely class XI students at SMAN 1 Lembah Seulawah. Then, researchers carried out an analysis process of the curriculum and materials. The curriculum used by SMAN 1 Lembah Seulawah is the 2013 curriculum. The material that will be presented in the magazine is about rotational dynamics and equilibrium of rigid bodies.

After carrying out the analysis process, the researcher began the magazine design process by using the Canva application. First, the researcher collected reference material on rotational dynamics and equilibrium of rigid bodies from various reading sources in the form of books and learning websites. Second, researchers also collected images used in magazines, especially images related to that material. This image was obtained from the researcher's shots during observation and was taken from several sources on the internet. Below, Figure 1 is presented, which is a graphic design application that provides various and exciting features in it. The appearance of the Canva application can be seen in Figure 1.

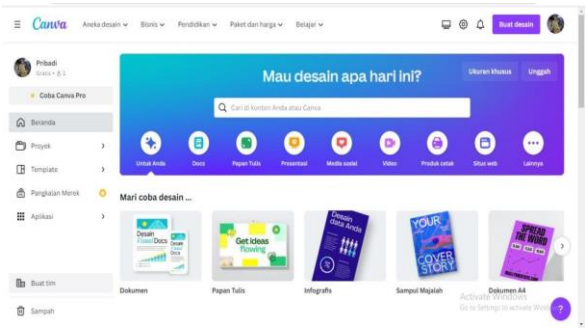

Figure 1. Canva application display

After carrying out the design process, the researcher carried out the development stage of the resulting TPACK-based magazine by asking for suggestions and comments from the supervisor. This stage is carried out as an improvement to the magazine made at the planning stage. Then, the revised magazine product entered the validity testing stage with 3 material experts and 3 media experts.

Table 3. Material Expert's Comments and Suggestion

No	Material Validator	Comments and Suggestions
1	V1	Cover improvements (illustrations, supervisor's name), writing typos, italics, paying attention to font size, image layout, inserting references with numbering [1], [2], adjusting to the bibliography, using equation editor formulas, using human icons which are Islamic.
2	V2	Please pay attention to each writing so that it is more organized
3	V3	Check again for typos, etc. (EYD), image layout, and enter reference formulas according to the rules.

Table 4. Media Expert's Comments and Suggestion

No	Media Validator	Comments and Suggestions
1	V1	They were developed in software form so that animations and videos can be clicked directly.
2	V2	The use of font type and size should be consistent; don't have too many font types, recheck the performance of the barcode, and make sure all barcodes can be accessed.
3	V3	This magazine is suitable as a teaching module. Scientific magazines have a particular format.

Overall, the experts stated that the TPACK-based magazine developed was valid and suitable for use by considering several improvements according to the suggestions and comments received. The feasibility of physics teaching materials in the form of a magazine based on TPACK on rotational dynamics and equilibrium of rigid bodies by two validation experts consisting of media experts and material experts can be seen in Table 5

Table 5. Validator Percentage Data

No	Validator	Percentage	Criteria
1	Media expert	87, 9 %	Very worthy
2	Material expert	94 %	Very Worth It
Total average score		90.95 %	Very Worth It

Furthermore, this assessment was assessed by 6 students at SMAN 1 Lembah Seulawah according to the student response sheet grid. In developing this magazine, 11 questions had to be answered by students. The following is data on the results of assessing students' responses to physics teaching materials in the form of TPACK-based magazines in SMA/MA.

Table 6. Student Response

Assessment Aspect	Criteria Evaluation	Validator						Score	∑ Each Indicator	Average	Percentage	Criteria
		1	2	3	4	5	6					
Question	1	4	5	5	5	5	5	29	316	4.78	95%	Very interesting
	2	5	5	5	5	5	5	30				
	3	5	4	5	5	5	5	29				
	4	5	5	5	5	5	5	30				
	5	4	5	5	5	4	5	28				
	6	5	5	4	4	4	4	26				
	7	5	5	4	5	5	4	28				
	8	5	5	5	5	5	5	30				
	9	5	5	5	5	5	5	30				
	10	5	4	5	5	5	5	29				
	11	5	4	5	4	5	4	27				

The development of TPACK-based Physics Magazine as teaching materials in high school education reflects a significant advancement in educational technology and pedagogical methods. This discussion section integrates findings from the current research with insights from previous studies.

This research aligns with the growing emphasis on integrating technology into education, as exemplified by studies like those of Maryati et al. [26] and Baihaqi [27], who demonstrated the effectiveness of TPACK-based educational tools in physics. The necessity for such innovative teaching approaches is further underscored by Walan [6] and Syukri et al. [7], who highlighted the role of digital technology in enhancing student motivation and facilitating teacher assessments. Moreover, the findings of Susila et al. [14] and Ilmi and Sunarno [15] emphasize the potential of digital platforms to foster higher-order thinking skills and scientific attitudes among students.

The developed TPACK-based magazine received high validation scores and positive student responses, indicating its effectiveness in physics education. These outcomes resonate with the findings of Popilaya [28] and Susanti and Mukminin [16], who also reported the successful integration of TPACK in teaching materials. Additionally, this research extends the work of Wijaya [29] and Silva et al. [30], who emphasized the importance of teacher preparation in implementing TPACK in educational settings.

The results align with the findings of Rosenblatt and Zich [17] and Schubatzky et al. [18], who stressed the importance of initial solid knowledge of pedagogy and content for the effective use of digital media in teaching. The study also addresses the

gaps identified by Ekawati and Prastyo [19] and Puspitasari et al. [20] in assessing TPACK capabilities in educational settings. The high approval ratings and student engagement suggest that the TPACK-based materials effectively conveyed complex physics concepts. This finding is in line with the research of Masrifah et al. [21], who found that multimodal TPACK-based materials enhanced teacher ICT literacy. However, as noted by Akuma and Callaghan [22], the implementation of such innovative teaching approaches can be challenging, particularly in resource-limited settings.

The positive reception of the TPACK-based magazine indicates readiness among students and educators for interactive learning materials. This finding is supported by the work of Wahyuni et al. [23] and Syukri et al. [31], who developed validated TPACK measurement tools for educators. Further, the study contributes to the ongoing discourse on digital competencies in science education, as explored by Thoms et al. [32] and Bakri and Sunardi [33]. The need for continuous professional development in utilizing such materials, as suggested by Efwinda and Mannan [34] and Septiandari [35], is also highlighted.

D. Conclusion

The study successfully developed a TPACK-based physics teaching magazine for rotational dynamics and equilibrium of rigid bodies, primarily aimed at SMAN 1 Lembah Seulawah Aceh Besar students, using a Research and Development approach with the 4-D model. The magazine, validated by material and media experts, demonstrated high feasibility (94% and 87.9%, respectively) and was well-received by students, indicating its effectiveness as a learning medium. This underscores the growing readiness for interactive, technology-integrated learning in science education, aligning with the ongoing discourse on digital competencies. The study's limitations include its limited scope and small sample size, potentially impacting the generalizability of findings. Future research should expand the scope, have larger sample sizes, and explore the integration of various technological tools to enhance interactive learning. This study contributes to the field by highlighting the importance of innovative materials and continuous professional development in science education.

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