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When studying applied physics: what problems are there, and do pre-service physics teachers need?

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ABSTRACT

Applied physics courses are essential for pre-service physics teachers (PsPTs), but they often encounter challenges in pursuing this educational pathway. This study aims to identify the problems and learning elements that PsPTs need in applied physics learning using the McKillip discrepancy model. The data were collected using questionnaires and bibliometric techniques. A total of 23 PsPTs participated in the study. Additionally, 1,000 articles were consulted as a data source. The data analysis uses descriptive statistics and the VOSviewer software. The first finding is primary issues identified in applied physics learning e.g., the difficulty of locating suitable learning resources, the dearth of in-depth physics comprehension, the absence of visualization like augmented reality (AR), the failure to undertake empirical activities in the laboratory, and global warming and climate change topic were pertinent at the high school level, entailed intricate issues, and were abstract. The second finding is a learning module that is integrated with science, technology, engineering, and mathematics (STEM), and AR is needed by PsPTs. Finally, this need has been paramount over the past decade to meet PsPTs' needs. Thus, the needs analysis results serve as an initial reference point for decision-makers to identify elements and develop integrated STEM and AR applied physics learning modules.

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1. INTRODUCTION

The applied physics course enables pre-service physics teachers (PsPTs) to learn physics through technology [1], [2] in theory and practice to effectively build communication skills [3]. By studying applied physics, PsPTs can use creative ideas to solve physics problems, physics education, and interdisciplinary physics-related issues [4], [5]. Therefore, applied physics courses are essential for PsPTs because they can develop physics problem-solving skills and scientific creativity, use technology, and conduct interdisciplinary, integrated activities based on theory and practice in the laboratory/field.

Good mastery of applied physics is urgently needed for PsPTs to apply knowledge and skills in life. PsPTs will become physics teachers in schools where they will work in senior high schools and vocational schools that require theoretical [6] and practical and field experience [7]. However, a previous study indicates that PsPTs in Indonesia continue to encounter challenges in attaining proficiency in applying physics concepts in real-life contexts or their practical implementation. First, PsPTs tend to have low creative thinking skills [8]. Second, PsPTs have low physics problem-solving skills [9]. This tendency is because contextual problem-solving skills are not sufficiently trained in the ongoing learning process [9]. In addition, pre-service teachers have the perception that they have not yet mastered technology [10] because they assume that technology is limited only to hardware [11] in the form of internet search engines [12]. Therefore, previous studies have mostly discussed the difficulties of PsPTs in applying physics concepts to real life, but have not commented in depth on the problems they face in applied physics learning.

This study investigates the needs of applied physics learning for PsPTs. While previous studies have focused more on engineering students and have not systematically and explicitly described the needs and trends of the importance of applied physics learning. The previous study investigates applying physics learning models within the context of the display, inquiry, learning community, and authentic assessment model. The investigation uses video, the inquiry process, community learning, and authentic assessment to address issues [13], [14]. Furthermore, research exploring teamwork between applied physics and engineering students in challenge-based learning has focused on theory and practice but has not explicitly explored the interdisciplinary relationships between challenges that support utilizing learning resources [15]. Therefore, research is needed that specifically examines the learning needs of applied physics for PsPTs, considering that previous research has not described this systematically and clearly.

This study utilizes the McKillip discrepancy model as a novel solution to analyze these problems and needs comprehensively. The researcher selected the McKillip discrepancy model due to its numerous advantages, which have been extensively employed in education, including the need analysis of modules [16]–[20]. Furthermore, the discrepancy model is characterized by its clarity and structured approach [16]. An analysis of learning trends over the past decade was also conducted to underscore the significance of applied physics learning. A comprehensive needs analysis highlights the contribution of this research to the practical application of applied physics learning for PsPTs in bridging the understanding between theory and practice in applying physics in life. Therefore, this study aims to answer the following research questions.

i) What problems in applied physics learning do PsPTs face?
ii) What solutions do PsPTs need to overcome problems in applied physics learning?
iii) How can trends in physics learning support the importance of assessment of the need for applied physics learning?

2. RESEARCH METHOD

2.1. Research design

This study uses the McKillip discrepancy model as a standard model for analyzing the needs of learning module development. The discrepancy model is one of three needs analysis models proposed by McKillip. As shown in Figure 1, the model includes five steps for the needs analysis process.

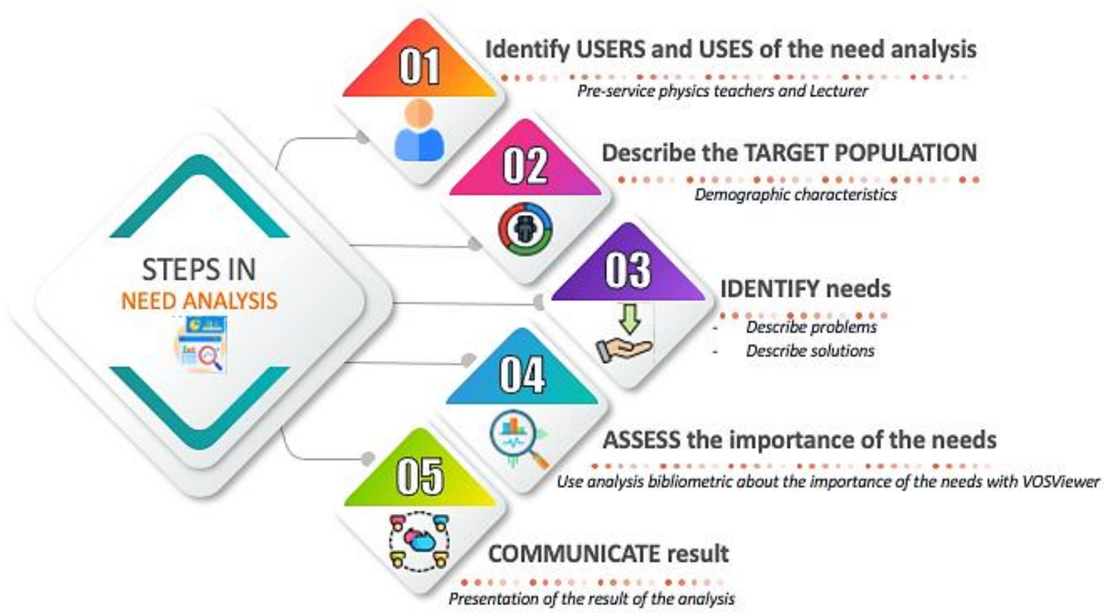


Figure 1. Step in need analysis [16]

Figure 1 shows the five stages of needs analysis as follows. The first step is to identify who the users are and how they will use the results of the needs analysis. Second, the target group is described in terms of demographic characteristics such as gender, age, and initial ability of the target group. Thirdly, the needs for module development (problems the target group faces when learning and solutions) should be identified. The problems are related to implementing applied physics learning, augmented reality (AR) technology, and applied physics topics. The solutions offered are those needed by PsPTs, and they are evaluated in terms of cost, impact, and feasibility. Fourthly, the importance of the needs is assessed by comparing the results of the needs identification with the trend of research urgency in physics education over a decade. Finally, the needs analysis results are communicated to users and decision-makers through graphs, tables, and diagrams.

2.2. Participants

The respondents in this study were 23 PsPTs who had taken applied physics courses at a university in Indonesia. This participant met the requirements because all samples measured each unit of the population (PsPTs who took applied physics were aged 19-22) [21]. In addition, descriptive and exploratory studies with a sample size of 10-30 people meet the requirements to be research participants [22]. The sampling technique uses purposive sampling with typical case sampling. Typical case sampling is used to represent situations that match the essential characteristics of the research population [23]. Thus, the respondents in the study have met the requirements as research respondents.

2.3. Study instrument and data analysis technique

Data relating to the respondent's description of the target population and identifying needs (problems and solutions) were collected using a questionnaire and document analysis. The scale of agreement in the questionnaire used a 4-point Likert scale, where 1=strongly disagree, 2=disagree, 3=agree, and 4=strongly agree. There are also additional open-ended questions in the comments section. The questionnaire used is valid and reliable. In this study, the questionnaire content was validated by seven experts in the fields of physics education, physics, and educational technology. The results of the content validation show that the content validity index (CVI) has a value of 1.00 for items (I-CVI) and scales (S-CVI). The acceptable CVI index value for three to five experts is 1; for six to eight experts, the acceptable CVI is at least 0.83; and for at least nine experts, the acceptable CVI is 0.78 [24]. All items are considered valid if the S-CVI is >0.80 [16]. After refining the instrument according to the expert's advice, the instrument was administered to 23 PsPTs who had taken applied physics courses but were not part of this study's actual population or respondents to prove the instrument's internal consistency. The instrument's reliability can be established on at least 20 respondents other than the research sample [25]. The reliability analysis results of the questionnaire showed that the Cronbach's alpha value was 0.889. The obtained Cronbach's alpha value was more than 0.60, and the alpha value of 0.80-1.00 was very reliable. Thus, the questionnaire used was found to be valid and reliable.

Bibliometric techniques are used to investigate learning trends in physics education. This technique involves collecting 1,000 articles using the keywords "Applied physics", AR, and science, technology, engineering, and mathematics (STEM) based on information available in the title and abstract of the article. Article data is collected using the Publish or Perish application. The information obtained from these keywords is filtered based on the search results in the title and abstract of the article. In this way, bibliometric analysis can provide information on the urgency of the need for applied physics learning.

The data collected from the questionnaire concerning the description of the target population and the identification of needs in terms of problems and solutions were analyzed using descriptive data analysis techniques. This analysis technique presents data in tables, graphs, percentages, means, and standard deviations. In addition, supporting data from articles to assess the importance of needs were analyzed using VOSviewer. In this way, information about urgency and research trends in physics education can be effectively presented.

3. RESULTS AND DISCUSSION

The target users in the context of this study are PsPTs involved in applied physics learning. The results of the user identification and the usefulness of the analysis provide information about the competencies and learning experiences needed by PsPTs in applied physics learning. In addition, these results also help lecturers to prepare learning according to user needs. The demographic characteristics of the target population consisted of 21 females and two males with different age variations, namely, five people (20 years old), 12 people (21 years old), five people (22 years old), and one person more than 22 years old. In addition, the entry physics competencies of the target population can be seen in Table 1.

Table 1. Entry physics competency of the target population

Item	Category	Number (people)/competency level		
		Low	Moderate	High
Entry physics competencies (theory)	Basic physics 1	0	5	18
	Basic physics 2	0	8	15
	Mechanics	0	14	9
	Thermodynamics	0	1	22
	Electricity and magnetism	0	8	15
	Waves and optics	0	7	16
	Mean	0	7	16
Entry physics competencies (practice)	Basic physics experiment 1	0	1	22
	Basic physics experiment 2	0	3	20
	Classical physics experiment	0	2	21
	Mean	0	2	21

Table 1 shows the entry physics competencies of PsPTs that support applied physics learning from several theory and practice courses. Several indicators of physics learning need to be applied, with PsPTs' entry competencies (theory and practice) being at least in the moderate category. This competence is an essential basis for mastering applied physics skills. Most PsPTs have a high level of initial competence in theory. In addition, almost all PsPTs have high entry levels of practical competence. Thus, PsPTs in the target population have sufficient entry competencies to participate in applied physics learning.

3.1. What problems in applied physics learning do PsPTs face?

3.1.1. Description of applied physics learning problems

The needs analysis results show that PsPTs face several problems during applied physics learning. Identifying problems in the implementation of applied physics learning helps to evaluate the solutions needed by PsPTs. Table 2 presents the problems that pose challenges for PsPTs when engaging in applied physics learning.

Table 2. Problems faced by PsPTs in applied physics learning

Problems	Frequency	Percentage (%)
Difficulty in finding learning resources/references appropriate to applied physics problems	10	43.48
Difficulty in understanding physics concepts in depth about the application of physics in life	4	17.39
Lack of direct visualization of applied physics tools/products	4	17.39
The absence of empirical laboratory activities, such as practical and making of simple experimental tools	3	13.04
Lack of in-depth understanding of projects among PsPTs because of the variety of projects created	1	4.35
Lack of variety in media for learning	1	4.35
Total	23	100

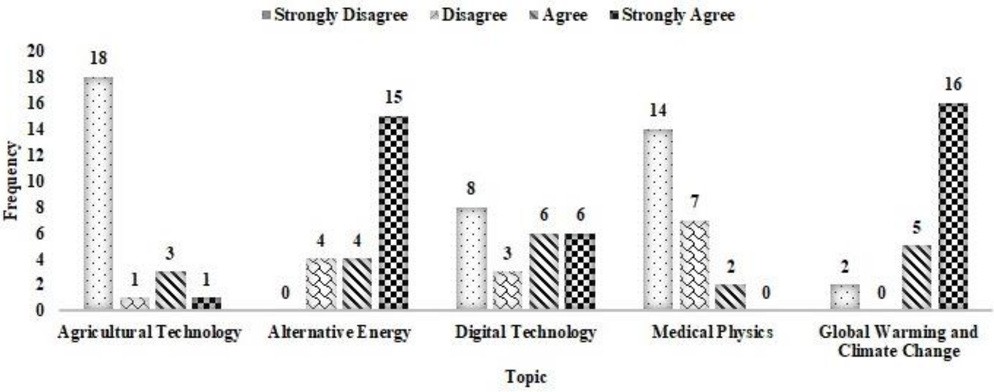
This study found that the main problem in applied physics learning is the difficulty in finding sources suitable for applied physics problems. This problem causes the learning of applied physics to be unfocused. One of the learning sources often used in universities is learning modules, although many of the modules in Indonesia do not match the characteristics of learning materials [26]. Another problem is the lack of in-depth understanding of physics among PsPTs, which affects their problem-solving skills, which have not yet developed. A deep understanding of concepts helps PsPTs develop problem-solving skills and engage in meaningful scientific investigations [27]. The lack of visualization concerning applied physics products is also a problem that needs to be addressed. Visualization is an important part of learning deep conceptual understanding and is helpful as a first step in solving real-world problems [28]. In addition, the lack of implementation of empirical activities in the laboratory, such as hands-on work and making simple tools, may lead to a lack of development of scientific creativity in PsPTs [29]. Therefore, the main problems PsPTs face need to be addressed by addressing the needs and requirements of the course's learning outcomes.

3.1.2. Using augmented reality technology in applied physics learning

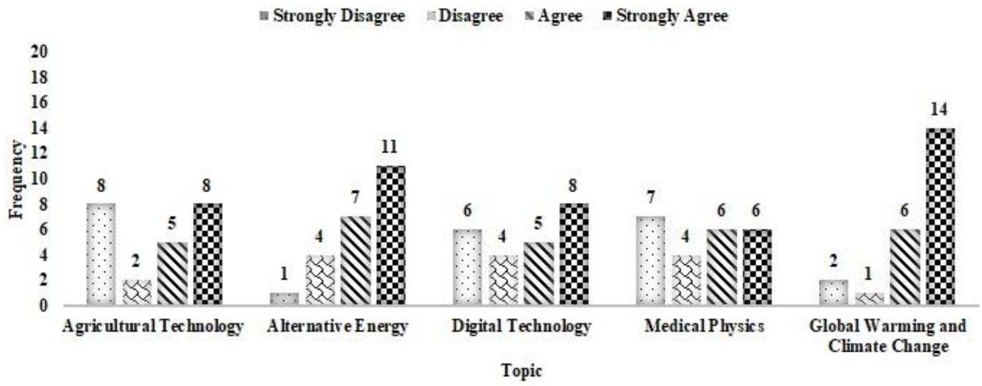
The questionnaire in this section was used to collect data related to the use of AR technology in applied physics learning. AR technology is one of the immersive technologies that are widely used in various fields, including education. This study found that AR technology has never been used in applied physics learning. The never-used AR technology has resulted in the unfulfilled requirements for learning outcomes in applied physics courses that require solving physics problems interdisciplinary manner using technology. The lack of technology that allows for the visualization of real-world problems in applied physics learning affects the failure to meet the learning outcomes of this technology-oriented course. Learning to use AR for PsPTs will be more effective as a supplement in a laboratory environment where PsPTs are taught how to apply physics to real-life situations [30]. In addition, using AR in laboratory activities can reduce the cognitive load of PsPTs compared to traditional teaching [31]. Therefore, AR plays a vital role in applied physics learning because it can help visualize real-world problems that can be used to initiate empirical activities in the laboratory.

3.1.3. Applied physics learning topics

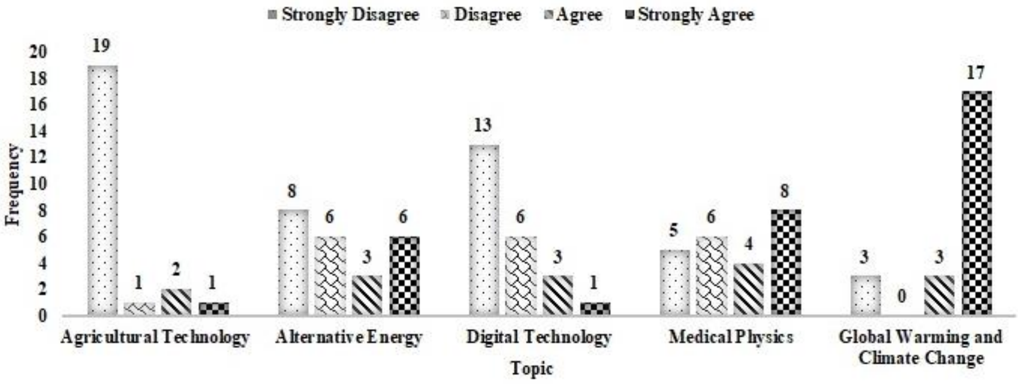
Applied physics learning is related to five learning topics: agricultural technology, alternative energy, digital technology, medical physics, global warming, and climate change. Figure 2 shows the applied physics learning topics. Figure 2(a) shows the topics that are considered most relevant for physics learning in senior high school, Figure 2(b) shows the topics that involve complex real-life problems, and Figure 2(c) shows the topics that involve visualization of objects that are difficult to observe directly (abstract).



(a)



(b)



(c)

Figure 2. Applied physics learning topics are (a) relevant to physics learning in senior high school, (b) contain complex problems in real life, and (c) contain visualizations of objects that are abstract

Figure 2 shows that most PsPTs perceive the topic of global warming and climate change. Global warming and climate change are one of the most challenging topics in applied physics because the physics problem objects in this topic are abstract. Interdisciplinary solutions are needed to successfully address the world's significant challenges, such as climate change, which require using new and transformative technological applications [32]. Global warming impacts various sectors of life, so studies from different scientific perspectives will provide good insights for PsPTs [33]. The topics of global warming and climate change are also in line with the sustainable development goals (SDGs), and some of them are included in the scope of the Indonesian curriculum implemented in senior high schools today. Therefore, global warming and climate change are applied physics topics that must be developed using strategies and media that align with the solutions that PsPTs need in applied physics learning.

3.2. What solutions do PsPTs need to overcome problems in applied physics learning?

In this section, the researcher identifies the elements PsPTs need to solve their problems in applied physics learning. These elements are taken from four national higher education standards: graduate competency standards, learning content standards, learning process, and assessment standards, the Indonesian curriculum, and the applied physics learning syllabus. Table 3 provides an overview of the elements PsPTs need when applying physics learning.

Table 3. Learning elements needed by PsPTs in applied physics learning

Items	Scale/frequency				Mean	Standard deviation
	1	2	3	4		
Learning outcomes of applied physics						
PsPTs need to be equipped with STEM knowledge	0	2	7	14	3.52	0.67
PsPTs need to be trained in STEM skills	0	2	4	17	3.65	0.65
PsPTs need to solve interdisciplinary applied physics (STEM) problems using communicative language	0	4	6	13	3.39	0.78
PsPTs need to solve interdisciplinary applied physics (STEM) problems in groups	0	2	9	12	3.43	0.66
PsPTs need to solve interdisciplinary applied physics (STEM) problems by producing creative ideas/processes/behaviors/ responses/products that are appropriate to the physics context	0	4	6	13	3.39	0.78
Learning content of applied physics						
Applied physics learning needs to address real-world problems	0	0	6	17	3.74	0.45
According to PsPTs, applied physics courses need to be integrated with other disciplines, such as mathematics, technology, and engineering	0	2	7	14	3.52	0.67
Learning implementation of applied physics						
Applied physics learning should be carried out with a learning strategy based on the engineering design process	1	4	13	5	2.96	0.77
According to PsPTs, AR is suitable for applied physics courses	3	2	9	9	3.04	1.02
According to PsPTs, AR can help to recall initial knowledge related to the applied physics topics to be studied	3	2	12	6	2.91	0.95
PsPTs need a STEM approach and AR to learn applied physics	1	5	11	6	2.96	0.82
Learning evaluation of applied physics						
PsPTs need an initial test before applied physics learning	3	4	9	7	2.87	1.01
PsPTs need initial tasks (homework) to recall initial knowledge related to applied physics topics that will be studied in Applied physics learning	2	2	13	6	3.00	0.85
PsPTs need a series of tasks in the form of complex problem-solving activities by producing creative ideas/processes/behaviors/responses/products appropriate to the physics context in applied physics learning	2	0	13	8	3.17	0.83
PsPTs need a test to check whether the knowledge they have is in line with the expected learning objectives in applied physics learning	2	0	11	10	3.26	0.86
Cognitive reflection is needed in applied physics learning	2	0	16	5	3.04	0.77
Applied physics learning needs affective reflection	2	1	15	5	3.00	0.80
Applied physics learning must include follow-up	2	1	6	14	3.39	0.94

Table 3 shows that PsPTs need learning elements related to the STEM approach and AR in applied physics learning to solve problems in applied physics learning. The applied physics learning outcomes aspect has a high mean (3.39-3.65) and a low standard deviation (0.65-0.78). The element of applied physics learning content requires real-life problems and is integrated with STEM content, with the highest mean and the lowest standard deviation. Implementing applied physics learning has a mean close to 3.00 with a standard deviation of less than 1.03. In the assessment of applied physics learning, PsPTs need authentic assessments as they disagree that the initial test is an element of the module. Therefore, all items from each aspect of learning related to the STEM and AR approach have been approved by PsPTs to be used as solutions to solve applied physics problems.

PsPTs need the use of STEM approach and AR technology in applied physics learning, both in learning outcomes, learning content, learning processes, and learning assessments. PsPTs need to see science, mathematics, and STEM integrated into fieldwork practice and to see rigorous, practical, and thoughtful science and STEM experiences as essential to the learning of PsPTs [34], [35]. The engineering design process often integrates science and mathematics through brainstorming, writing, and laboratory activities [36]. It is related to interdisciplinary knowledge [37]. Engineering design plays a role in integrating STEM content [38]–[40]. PsPTs who use AR in STEM have better outcomes [41], and this is generally done in schools with marker-based applications [42]. Higher education institutions should use authentic assessments to solve realistic and contextualized problems [43]. Therefore, the previously identified learning elements need to be presented explicitly, in detail, and a targeted manner throughout the learning module.

19 out of 23 (83%) PsPTs need an integrated learning module with a STEM approach and AR in applied physics learning because they need more focused learning as a solution to problems in applied physics learning. After using the learning module, PsPTs can apply what they have learned [44]. Learning modules engage PsPTs in actively and independently exploring concepts [45]. Learning modules can facilitate relevant skills [46] if the module elements meet the user's needs [47]. Using modules in learning can accommodate all the components that PsPTs need in applied physics learning. This study used three criteria to evaluate the solutions needed by PsPTs related to the development of applied physics learning modules integrated with the STEM approach and AR. While other studies did not use the criteria [19], [20]. Cost, impact, and feasibility are the criteria for evaluating the solutions that are needed in learning [16]. Therefore, PsPTs need an integrated learning module with a STEM and AR approach in learning as a solution to the problem, and evaluate it using three criteria.

In cost criteria, the applied physics learning module, which integrates the STEM approach and AR, is designed to be affordable. The learning module is already presented in a complete learning unit equipped with different media [48], so there's no extra cost. Using environmentally friendly materials in a STEM approach [49] in applied physics learning will reduce the cost of manufacturing products. Furthermore, since 2017, AR technology has been used on devices at more affordable costs [50]. As a result, the cost of production and use of the integrated STEM and AR applied physics learning module was low.

In the impact criteria, the applied physics learning module can be used independently. It can potentially train the skills of PsPTs in a targeted way if integrated with the STEM approach and AR. Provide materials, activities, and resources that can contribute to developing relevant skills, e.g., for pre-service teachers [51] in a learning module format. The STEM approach can break down the traditional barriers that separate STEM and integrate them into real-world, relevant learning experiences [52]. An integrated STEM approach provides opportunities to develop problem-solving and inquiry-based teaching skills and disciplinary content knowledge [53]. An integrated STEM approach should start by providing PsPTs with problem-solving tasks [40], [54]. The STEM approach provides valuable hands-on learning experiences, enabling PsPTs to apply their knowledge to solving real-world problems [55], [56]. STEM in learning can also develop scientific creativity [57]. PsPTs are also trained in using the latest technology using the STEM approach with the help of AR technology [58]. Thus, integrating the STEM approach and AR into applied physics learning modules can potentially improve physics problem-solving skills and scientific creativity.

In feasibility criteria, the applied physics learning module that integrates the STEM approach and AR is feasible and needs to be developed. This evaluation is because of several factors. First, although the implementation of STEM in Indonesia will increase significantly from 2015 to 2019, it will decrease in 2020 [59]. Second, STEM implementation in Indonesian higher education is relatively low [59], [60] compared to the implementation of STEM in Indonesian primary schools and senior high schools [59]. The Republic of Indonesia issued several policy efforts since 2020, namely the education roadmap 2020 to 2024 based on technology, the development of science, technology, engineering, arts, and mathematics (STEAM) learning in higher education on roadmap 2025 to 2045, the STEM program for primary and middle school students, and the implementation of the Indonesian Curriculum in higher education. Thus, developing an integrated applied physics learning module of STEM and AR technology becomes feasible to help PsPTs have sufficient STEM knowledge and experience.

3.3. How can trends in physics learning support the importance of assessment of the need for applied physics learning?

Studying learning trends in physics education, mainly applied physics, can support the importance assessment of the need for applied physics learning. A bibliometric analysis was carried out to obtain up-to-date information on the form of implementation aligned with learning over the last decade. The articles' results were analyzed using VOSviewer to see the distribution of learning trends in physics education. The results of the relationship between the need for applied physics learning and learning in the field of physics education are presented in Figure 3.

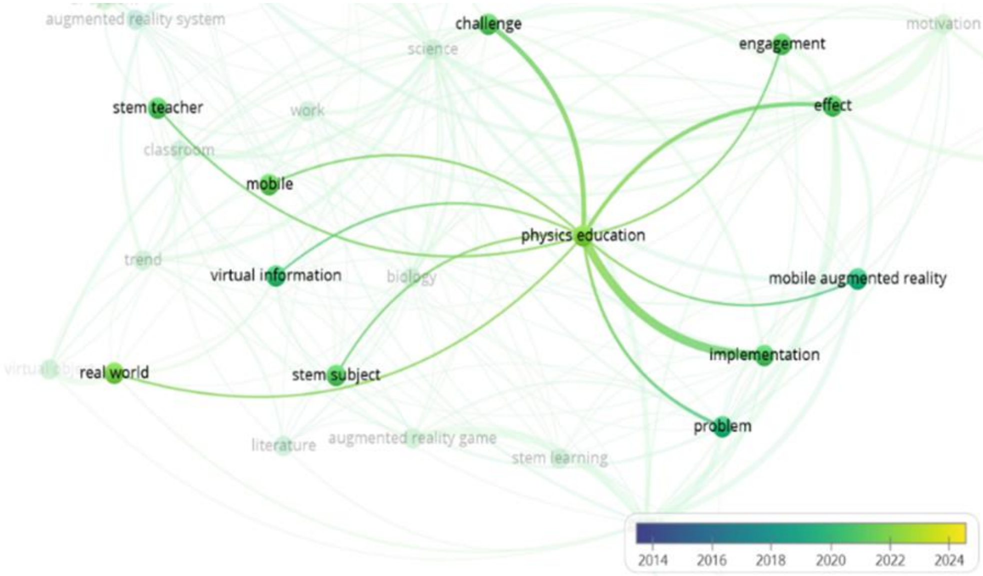


Figure 3. Learning trends in physics education

Figure 3 shows the results of mapping the form of learning implications in physics education from 2014 to 2024. The figure's yellow and light green colors indicate the most recent research supporting novelty as an innovative solution in physics learning. Physics learning is a research trend between 2022 and 2024, focusing on physics in learning with STEM, real-world problems, mobile AR, impact, engagement, and implementation in physics education. These findings provide information on learning trends in physics education related to real-world problems and STEM. STEM is one of the highlighted topics in the last two decades [61] and has been a top research topic in science education, including teaching physics, for the past 40 years [62]. In addition, mobile AR is a popular form of technology in physics education. STEM teachers are also popular in physics education. AR and STEM present learning with a realistic display and a contextual approach to solving problems as a whole. AR as an immersive technology is highly recommended for STEM education [58]. Therefore, applied physics learning using STEM and AR must be implemented as an innovative solution to train PsPTs to become STEM teachers.

4. CONCLUSION

The needs analysis results conclude that PsPTs still face various obstacles in applied physics learning, such as limited appropriate learning resources, low understanding of physics concepts related to applications in life, a lack of visualization, and minimal empirical practice in the laboratory. To overcome this, innovative solutions are needed through the application of AR and a STEM approach. The need to develop learning modules that integrate AR and STEM approach is a strategic step that is not only relevant to PsPTs' needs but also in line with current physics learning trends. This study is more resilient in presenting a clear and systematic analysis of learning module needs than previous studies. Future research can investigate the fundamental elements and practical methods for assessing each element of the learning module according to the results of this needs analysis. This study investigates the comprehensive needs of applied physics learning for PsPTs using the McKillip discrepancy model and bibliometric analysis through the VOSviewer. However, additional and in-depth research may be required to identify fundamental elements to design an applied physics learning module integrated with the STEM approach and AR technology through expert consensus. This identification is very important to design fundamental elements that will be the basis for designing learning modules that are appropriate and relevant to the needs of PsPTs.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

INFORMED CONSENT

Informed consent was obtained from all research participants.

ETHICAL APPROVAL

The research involving human participants in this study has complied with all relevant regulations and policies in accordance with the principles of the Declaration of Helsinki and has been approved by the Research Ethics Committee of Sultan Idris Education University.

DATA AVAILABILITY

Data not shared.

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