

TEACHER READINESS IN STEM EDUCATION: VOICES OF INDONESIAN PHYSICS TEACHERS

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Abstract

STEM (science, technology, engineering, mathematics) education is widespread around the globe, with various theoretical frameworks and challenges from practical perspectives. In classroom practice, teacher readiness to conduct STEM learning is essential for its successful implementation. This study explores physics teachers' readiness for STEM education using the Alignment, Capabilities, Engagement, or ACE, framework. Data collection is based on 101 teachers' responses to six open-ended questions. Interestingly, all the teachers showed strong alignment with STEM education and how to implement it. Most of them have known STEM education as integrating technology, engineering, and mathematics to science (physics), but only about half of them have experience conducting STEM lessons. They have basic capabilities of identifying the possibilities of implementation in various physics curricula, such as motion, electricity, and fluids. However, in the online learning made necessary by the COVID-19 pandemic, the possibility of implementation is weakened. The teachers showed their engagement to explore more detail in designing and implementing STEM in their classrooms. Also reflected in the study was a significant challenge in terms of pedagogical and time management. Therefore, professional development in STEM education is essential to support teachers' alignment, capabilities, and engagement to develop their readiness. As specific examples, STEM learning materials in motion, electricity, and fluids could help teachers understand the design and implementation of STEM education.

Keywords – STEM education, In-service Physics teacher, Teacher readiness.

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1. Introduction

During the pandemic era, teachers face the significant challenge of shifting the traditional classroom to online learning. Physics teachers in particular must change their practice of traditional, in-person instruction and field-based experiences to one that fully uses the online platform (Campbell, Melville, Verma & Park, 2021). Simultaneously, the philosophical and sociological perspectives of science are expected to be the foundation for students' education (Reiss, 2020), especially scientific thinking with regard to the pandemic. However, the practical issues of how lessons should be conducted are a

constant challenge. From when the pandemic began in late 2019 to the writing of this document in early 2021, the role of technology in science education has been undeniable. The pandemic situation has also been a reminder that problem-based learning is a significant need in science classrooms, as stated in previous research (Miller & Krajcik, 2019; Valdez & Bungihan, 2019). The problem is complex, and science can no longer stand as a single subject. The integration of science with other relevant areas is necessary.

The terminology of science-technology-engineering-mathematics (STEM) education was first introduced in 2013 (Bybee, 2013); since then, STEM education has spread worldwide with various ways of explorations. Some studies have focused on educational policy perspectives (Allen, Chang, Gorrall, Waggenspack, Fukuda, Little et al., 2019; Chikahiko, Tadashi & Masataka, 2017) and students' perspectives (Dare & Roehrig, 2016; Dierking & Falk, 2016; Nimmesgern, 2016; Sulaeman, Putra, Mineta, Hakamada, Takahashi, Ide et al., 2020), while others focus on teachers' perspectives (Ring, Dare, Crotty & Roehrig, 2017). From the implementation perspective, the teachers play an essential role to bring the theories into practice. Teachers in different STEM disciplines have different perceptions about STEM integration, leading to different classroom practices (Wang, Moore, Roehrig & Park, 2011). Therefore, a deeper exploration of the practices of specific teachers within specific subjects is needed. In Asia, a fixed curriculum containing separate subjects with specific goals for each has become a significant challenge (Lee, Chai & Hong, 2019). To spread STEM education widely in Asian countries, understanding and addressing the context of each country is essential. Indonesia's science education is an exciting context to explore for national and international discussion (Wahyudi & Treagust, 2004) because it represents a country in Asia with a high population and high diversity. Indonesia is the fourth most populated country in the world (Ariteja, 2017) that a pluralistic society, social class, ethnicity, religion, race, and inter-group (Wasino, 2013). This geographical context in this study could be valuable insight for others country that in the early stage of infusing STEM education through their educational system especially from the teachers readiness aspects.

Research about STEM education in Indonesia focusing on teachers has been based on STEM conceptualization (Putra & Kumano, 2018), the suitability of STEM education within the Indonesian curriculum context (Rahmasuwarna & Kumano, 2019), developing STEM learning materials (Hartini, Mariani, Misbah & Sulaeman, 2020). As a new approach to learning, the implementation of STEM education urges teachers' readiness for it. While science teachers, in general, tend to have a strong understanding of STEM (Nugroho, Permanasari & Firman, 2019), and the terminology of STEM education is understandable (Permanasari, Rubini & Nugroho, 2021), the specifics of teachers' readiness to implement STEM have remained unclear. As professional occupation, the readiness to STEM education could be explore through a concept of Alignment, Capability, and Engagement (ACE) framework (Schiemann, 2012). The exploration using the ACE framework also outlines the process of achieving teacher readiness, which progresses from their alignment to their capability to their engagement with STEM education. Our findings yield insight for teacher professional development on STEM education. The professional development on STEM education should begin with teacher alignment, especially to 21st-century skills for their students. STEM learning materials on specific topics could be beneficial to increase their readiness for actual classroom activity. For physics teachers, lesson examples for motion, electricity, and fluids could help teachers understand the design and implementation of STEM learning.

To guide this research, the following research questions were asked:

1. To what extent are physics teachers' goals in alignment with STEM education?
2. To what extent do physics teachers' capabilities and resources enable STEM education? Has there been any change during the pandemic era?
3. To what extent are physics teachers engaged with STEM education?

2. Literature Review

2.1. STEM Integration

STEM integration has been defined as integrating science, technology, engineering, and mathematics to solve real-world problems based on the students' experience to improve 21st-century skills (Guzey, Moore & Harwell, 2016; Moore, Stohlmann, Wang, Tank, Glancy & Roehrig, 2014a). The former idea of integration curricula could be traced in the 1990s (Fogarty, 1991; Schumacher, 1995) and involved the development of curricula from a single separate discipline toward increasingly integrated subjects. Recent research described integrated subjects variously as multidisciplinary, interdisciplinary, and transdisciplinary (Roehrig, Dare, Ring-Whalen & Wiesemann, 2021). A multidisciplinary subject indicates that each subject is identified in the topic of the curriculum (Lederman & Niess, 1997). Interdisciplinary subjects are interconnected to the point where it could be challenging to distinguish them (Moore, Tank, Glancy, Siverling & Mathis, 2014b). Transdisciplinary STEM subjects are connected with social, economic, political, or environmental topics (Roehrig et al., 2021).

Although the need of integration is urge, the perspective of STEM from teacher is fluid. According to Bybee (2013), teachers include nine possible approaches for instruction, ranging from STEM as a separate science to STEM as a trans-discipline of the program. In the application of STEM approaches, Ring et al. (2017) found the STEM continuum model to be preferable. This model is based on the results of their implementation of STEM instructional design in the classroom and offers possibilities for integrating and implementing STEM in the classroom: integrated discipline, science as context, engineering design process as context, science, and engineering design process as context, real-world problem solving as context, STEM as separate disciplines. All the conceptualizing of the model emphasized the interconnecting between the STEM field and the real-world problem for presentation in the classroom.

2.2. Defining Teacher Readiness in STEM Education

As the spread of STEM education, teacher aspect become one of vital component especially related to how to train the teachers (Margot & Kettler, 2019) and build their readiness in STEM education (El-Deghaidy, Mansour, Alzaghibi & Alhammad, 2017). Teacher readiness has a solid correlation to student improvement (Lynch, Smith, Provost, Yeigh & Turner, 2017) because it can mediate students' learning process (Baharuldin, Jamaluddin, Shahril, Shaharom, Mohammed & Zaid, 2019). Therefore, the readiness of teachers in STEM education is a crucial issue to explore. The definition of readiness can be traced in studies in the management field. Readiness is defined as the state in which the organizational conditions are such that teachers are prepared to engage with an improvement process (Lynch & Smith, 2016) that was developed based on work in resources management (Schiemann, 2012). Specifically, in teacher readiness, the definition is related to the ability to begin teaching activities (Sulaiman, Hamzah & Abdul-Rahim, 2017). Other researchers argue that readiness refers to the extent to which teachers demonstrate willingness and confidence in taking charge of their teaching (Hung, 2016).

From the literature, teacher readiness on STEM education is the extent of the ability that teachers have to take charge of STEM education. Exploration of teacher readiness in specific STEM professional development programs concluded that collaboration among teachers is essential (Rukayah, Widodo & Rochintaniawati, 2020). On the other hand, identification of teacher readiness based on their understanding of each component of STEM with difficulties in engineering component was also found (Asiroglu & Akran, 2018). Science teachers tend to feel confident with their ability in teaching the science subject, therefore we argue that their readiness depends on each specific subject that they taught and exploration of teacher readiness in a specific science subject such as physics is needed. The process toward readiness in STEM education defined as multifaceted transformation (Weinberg, Balgopal & McMeeking, 2021). Therefore, to clarify their readiness need deeper exploration. Understanding of teacher readiness on a new approach such as STEM education could be discussed from a perspective that

teacher is a professional occupation that many times in their job they need to deal with changes. Teacher readiness has three significant elements: Alignment, Capabilities, and Engagement (ACE) (Doe, Willis, Peddell, Lynch & Yeigh, 2020; Schiemann, 2012, 2014). While the original framework used the word ‘talent’ in reference to the person, we have adapted the context for physics teachers. In our research, these elements can be understood as (1) Alignment—the synchrony of the teacher with STEM education; (2) Capabilities—the knowledge, skills, information, and resources that initially exist and consequently can be enhanced; and (3) Engagement—the satisfaction, commitment, and willingness of the teacher to act for improvement. The three components are essential to explore the readiness and useful for mapping the area of improvement that needed for implementing STEM education.

3. Method

3.1. Context of Curriculum (A glance at Indonesian Physics Curriculum in Junior and Senior High School)

The curriculum used in Indonesia is known as Curriculum 2013 (Amendments to the Regulation of the Minister of Education and Culture Number 58 in 2014 Concerning the 2013 Curriculum for Junior High Schools, 2018; Amendments to the Regulation of the Minister of Education and Culture Number 59 in 2014 Concerning the 2013 Curriculum for Senior High Schools, 2018). Its purpose is to prepare Indonesians to live as individuals and citizens who are productive, creative, innovative, effective, and able to contribute to the life of their society, nation, state, and civilization. The 2013 curriculum was developed by improving the mindset, including patterns of strengthening learning centered on students, interactive learning, network learning, active-seeking learning, individual and group learning patterns, multidisciplinary learning patterns, and strengthening critical learning patterns. Therefore, the intended to strengthen multidisciplinary learning such as STEM education could be traced in the curriculum (Rahmasuwarna & Kumano, 2019). Even though, the STEM subject cannot find in the junior or senior high school, general intended of integrated subject is clearly stated.

At the junior high school level, the one-week learning load for Grades VII, VIII, and XI is a minimum of 38 lesson hours. Junior high school subjects are grouped into general subjects Group A, Group B, and Group C. General subjects Group A is a curricular program that aims to develop students' competency attitudes, knowledge competencies, and competency skills to strengthen social, national, and state life abilities. General subjects Group B are curricular programs that aim to develop attitudinal competencies, knowledge competencies, and environmental skills competencies in social, cultural, and artistic fields.

Physics subjects in senior high school are included in the academic specialization Group C. The scope of physics subjects comprises the knowledge, skills, attitudes, and values formulated in the essential competencies of physics that students must possess. Physics subjects at the junior high school level are integrated into science subjects. Science is taught as a general science subject consisting mainly of biology and physics, with relatively few chemistry concepts. In practice, biology and physics are taught separately with equal time allocations of three classroom periods per week (Wahyudi & Treagust, 2004). Physics competence in senior high school is a continuation of science competence in junior high school. Also, physics in senior high school is a prerequisite for further study of physics in higher education and is helpful in solving everyday life problems. Physics subjects are designed so that students can 1) form spiritual attitudes and scientific attitudes; 2) develop experiences in applying scientific methods; 3) develop reasoning skills using concepts and principles of physics; 4) have the skills to build knowledge and; 5) develop self-confidence as a provision to continue education at a higher level and develop technological knowledge (Suharto, 2015). The topics for science in junior high school and physics in senior high school are shown in Figures 1 and 2.

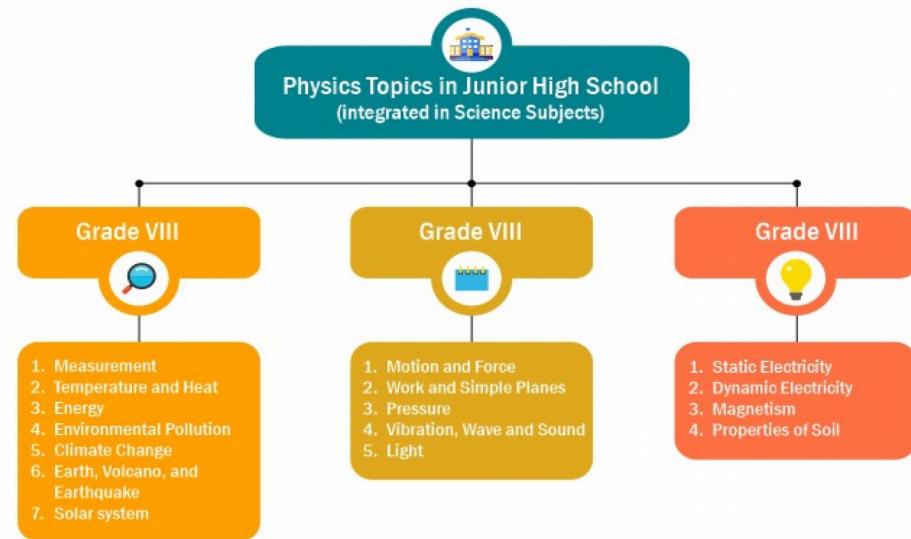


Figure 1. Physics topics in junior high school

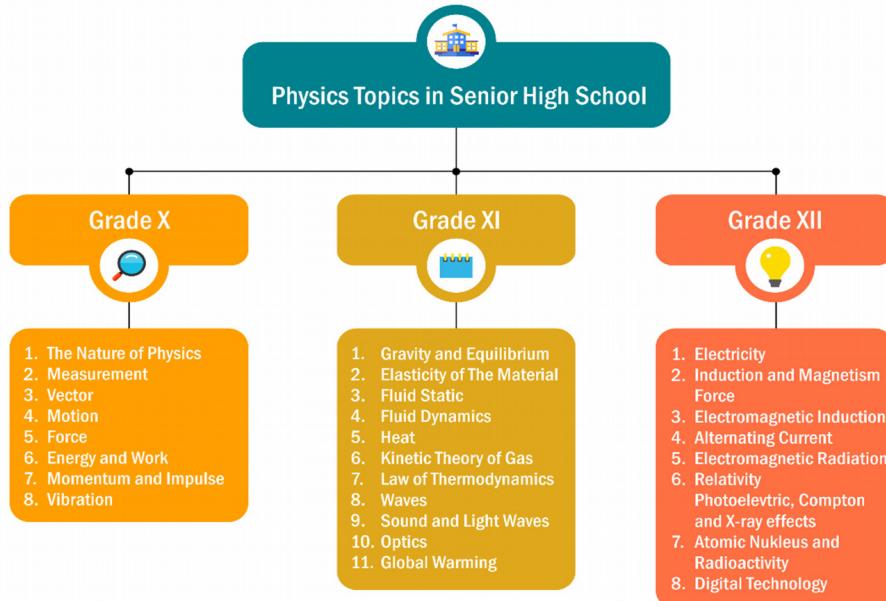


Figure 2. Physics topics in senior high school

3.2. Data and Participants

In this study, the data were collected mainly from a questionnaire containing open-ended questions. The framework of the questionnaire was based on the definitions taken from the literature review. The questionnaire was developed through focus group discussion (FGD) to ensure its validity. Experts involved in the process are researchers in STEM education (2 experts) that published their research related to STEM education and university professors in the physics education program (2 experts) that have experience in STEM education professional development for teachers. The FGD was held two times, each time around two hours. The first meeting discussed the experiences of experts related to teacher readiness in STEM education and the introduction of teacher readiness with ACE concepts. During the second discussion, researchers lead the discussion and summarized possible questions to explore teacher readiness in STEM education from the experts. From the discussions, most experts agreed that the teacher readiness with ACE aspects through the six questions. The questions are not distributed equally for each aspect with considering that the capability aspect needs more questions to clarify teachers' capabilities. The capabilities aspect is also recognized as the core of teachers' readiness, therefore more questions are needed. Six questions were developed, as can be seen in Table 1.

To address the research questions, the questionnaire was speeded through physics teachers' association in Indonesia for inviting in-service physics teachers to participate. Although we shared the questionnaire to all main island in Indonesia, due to the pandemic of COVID-19, all of the coordination was fully dependent on online. Although we shared the questionnaire to all main island in Indonesia, only 101 teachers from 4 major islands were willing to participate and respond to our questions completely and qualified for further analysis.

The number of participants from each island is not equally distributed because of the limitation of the teachers that actively involved in teacher association activities. The questionnaire was given to the participants through Googleform. The information regarding participants' gender and the duration of their STEM knowledge is displayed in Table 2. Each participating teacher spent around 30 minutes completing research consent and answering the questions in Table 1. Participants were also asked their demographic characteristics such as gender, education level, and teaching experiences.

Readiness aspects	No.	Question
Alignment	1	As a teacher, what do you know about STEM (science, technology, engineering, and mathematics) learning?
Capabilities	2	If you want to try STEM-based learning, at what level and grade will you implement it?
	3	If you want to try STEM-based learning, on what topic will you implement it?
	4	Have you ever implemented STEM-based physics learning in teaching?
	5	Do you think that STEM-based learning is possible for distance learning? Explain why?
Engagement	6	Regarding STEM learning, what do you want to know more about?

Table 1. Exploration questions

Location	Number of Participants (Duration of teaching experience)				Total
	> 5 Year	5 – 10 year	>10 -15 year	> 15 year	
Java	18	23	15	5	61
Kalimantan	9	16	7	–	32
Sumatra	7	–	–	–	7
Sulawesi	-	1	–	–	1
Total	34	40	22	5	101

Table 2. The participants

4. Result and Discussion

In this section, teachers' perspective of their readiness in implementing STEM in Indonesia is presented. The results are clustered according to the readiness theory: Alignment, Capabilities, and Engagement. To understand teacher readiness, the general question about teachers' readiness in STEM was explored. This was followed by a detailed exploration of the suitability of STEM in the curriculum.

4.1. Alignment to STEM Education

To understand teacher alignment to STEM, exploring the conceptualization of STEM from their perspective is essential. The conceptualizations of STEM of the 101 teachers involved in the study are summarized through the co-occurrence network analysis result in Figure 3. The common conceptualization is the integration of four disciplines in STEM. An example of a simple response like this could be observed from that of Teacher 98. Another conceptualization is more sophisticated, relating STEM to developing essential 21st-century skills such as problem-solving and critical thinking, as in the response from Teacher 11.

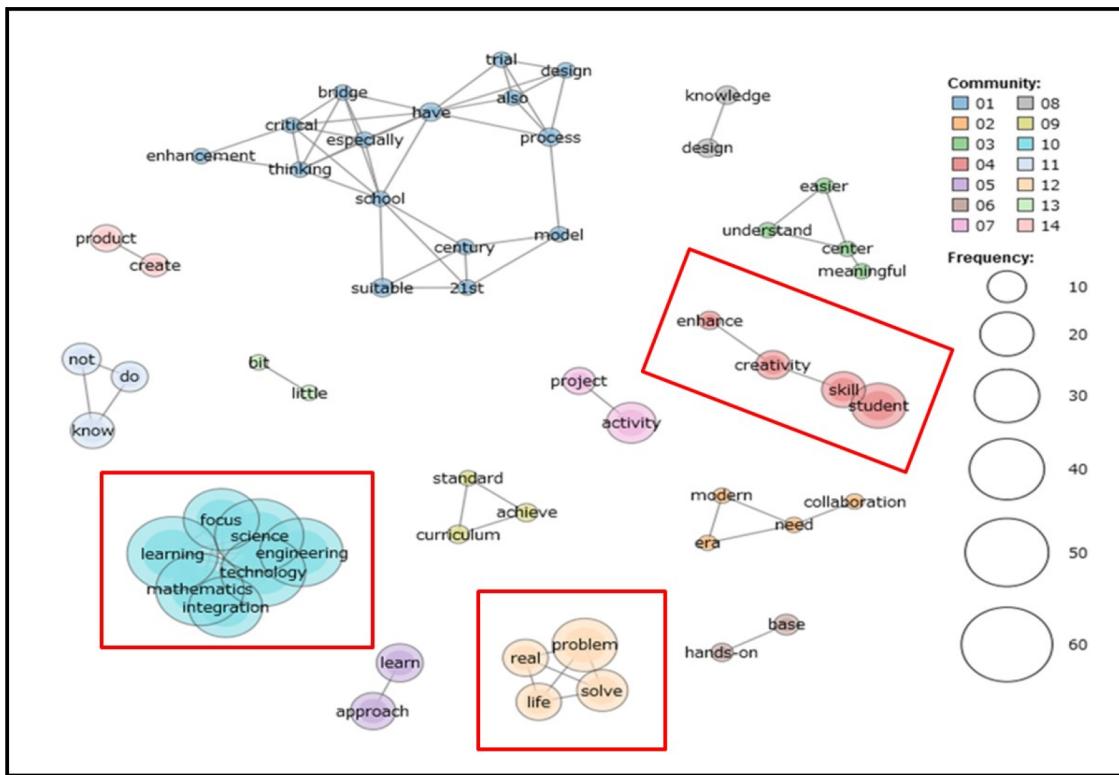


Figure 3. STEM conceptualization

T 98: a learning that focuses on the integration of science, technology, engineering, and mathematics.

T 11: a learning that integrates science, technology, engineering, and mathematics through design and creates products that allow students to have learning experiences that are beneficial for their future. Students also have opportunities to learn science literacy and to design, explore the trial-and-error process, analyze probability, create products, conduct trial processes for their products and share their products.

From the ways of integrating STEM education (Ring et al., 2017) as context and real-life problem as context are those most used by the teachers studied. The teachers' perspectives of STEM education related to their implementation of scientific learning in their science classrooms. Recent research showed that most science teachers in Indonesia could plan and implement scientific learning in their activities (Qadar & Haryanto, 2019). This perception also builds from the Ministry of Education and Culture (Faisal & Martin, 2019). The experience in teaching with scientific learning and policies delivered by the government builds their initial perception of STEM.

The fundamental perspective mainly sees STEM education as the integration of four components, as stated by Teacher 98. Other teachers show that their primary perspective of STEM education is the opportunities for students to learn essential skills such as design that are beneficial for their future, as stated by Teacher 11. The awareness of essential 21st-century skills is central in this perspective. These perceptions are also found in secondary school teachers in Vietnam (Nguyen, Nguyen & Tran, 2020), the United States (Guzey et al., 2016) and globally (Penprase, 2020). Among STEM education challenges in instructional design, the broader goal of students' skills for their future was identified by teachers as being essential (Moore et al., 2014b). These goals provided the motivation for teachers to improve their alignment with STEM education.

4.2. Capabilities Toward STEM Education

4.2.1. STEM in the Curriculum

From the responses, physics teachers' perspectives on the possibility of STEM education in middle grades curriculum is summarized in Figure 4. Overall, STEM could be implemented in all grades in junior and

senior high school. The highest percentage of implementation is at the senior high school level with 61.6 percent. The curriculum in the second grade of senior high school is considered the most suitable for STEM. In line with the suitability in senior high school, the second grade of junior high school was also considered the most suitable. Our participants showed a tendency that STEM education is too sophisticated to be conducted at the elementary school level. For junior high school level, grade 8 is the most suitable due to the topics of science on that grade and the readiness of the students. Moreover, for senior high school, grades 10 and 11 are suitable for integrated STEM. Both in junior and senior high school, the last grade of each level is not appropriate for new approaches or projects like in STEM lessons. Grades 9 and 12 are considered as the time for the conventional learning process for preparing their students for the national exam.

To clarify the suitability of topics, the teachers stated the possible topics in the physics curriculum. The results are presented in Figure 5.

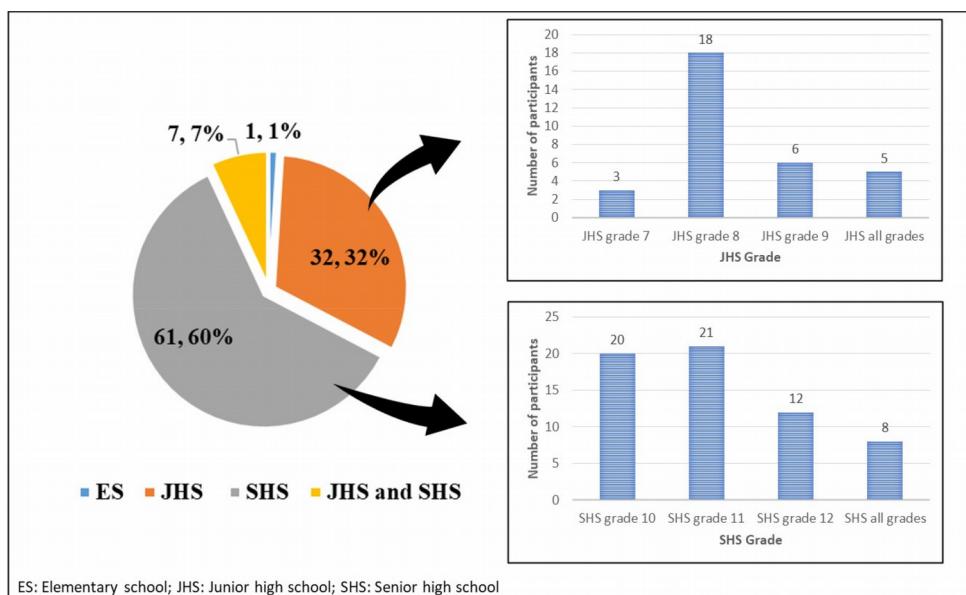


Figure 4. Suitability to the grades

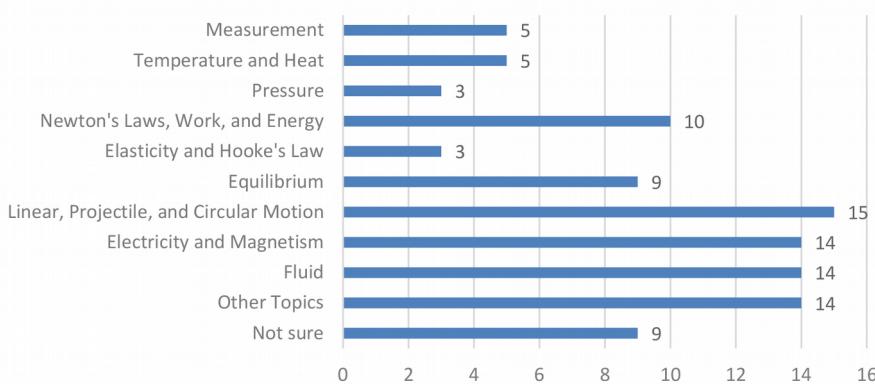


Figure 5. Suitability of STEM to the topics in the curriculum

Based on Figure 5, the topics related to kinematics, such as linear motion, projectile motion, and circular motion are the preferred choice by the teachers. However, some respondents (9 respondents) stated that they are unsure which topics would be suitable for STEM integration. Confirmation of these teachers' responses through the following questions in our instruments showed that they are "not sure" because they had been heard about STEM education, but they never have opportunities to visualize the concept

into the classroom experience. This finding indicates that the provisional development in STEM education for Indonesian teachers needs to be more practical and the example of lesson plans require to be developed especially in junior high school grade 8 and senior high school grade 11 and 12.

4.2.2. Possibility and Experiences of STEM Education Implemented in Physics Classrooms in General and During the Pandemic

Figure 6 shows the teachers' experiences in implementing STEM education in their science classrooms. More than half of the respondents stated that they never try STEM education, while others have implementation experience.

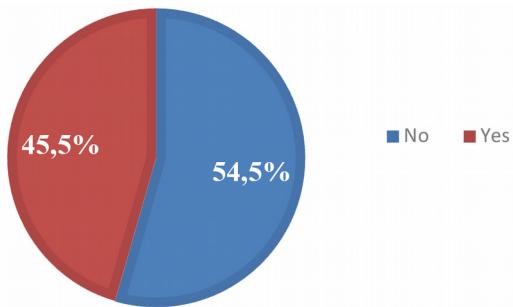


Figure 6. Experiences in implementing STEM in the physics classroom

The pandemic has forced teachers to make significant changes to their classrooms to utilize online platforms (Mansor, Zabarani., Jamaludin, Nor, Alias & Mansor, 2021). Even though it is an online classroom, teachers still believe that STEM education can be conducted if it is supported (Figure 7). However, during the pandemic, almost all schools in Indonesia switch to the online system. Thus, the influence of teacher digital literacy (Efwinda & Mannan, 2021) and school facilities increases significantly. An example response from T2 showed that STEM lessons could not be conducted in the pandemic situation at his school. This response highlights that teacher readiness is also related to school readiness and that there is an interplay between them, especially in educational integration (Petko, Prasse & Cantieni, 2018). The issues of facilities are most difficult for schools in rural areas to conduct online learning in Indonesia (Aditya, 2015).

T2: STEM education strongly addresses problem-based learning through hands-on activity, therefore during the pandemic, it is difficult to make the STEM lesson. My school is in a rural area that struggles with the difficult connection of the internet and most of the students do not come from good social-economic status.

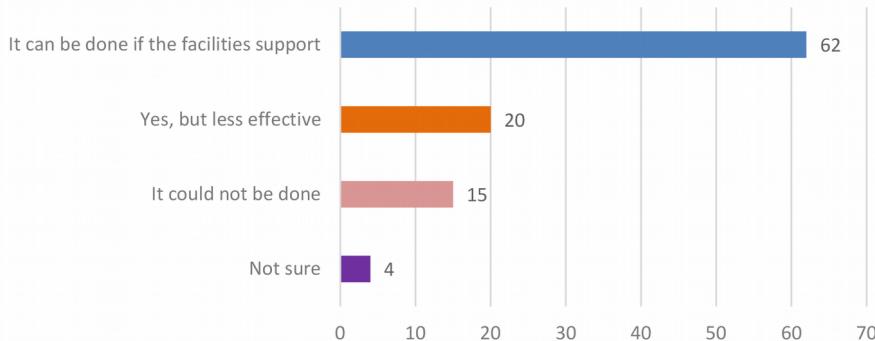


Figure 7. Possibility of implementation of STEM during COVID-19 pandemic

4.3. Engagement in STEM Education

The last element of readiness is engagement, which refers to teachers' demand to learn more about STEM education. The summary of the teachers' responses is shown in Figure 8. Interestingly, most teachers

show an interest in improving the design and implementation of STEM education. The response from Teacher 78 is an example of the demand to learn in more detail about the implementation of STEM education.

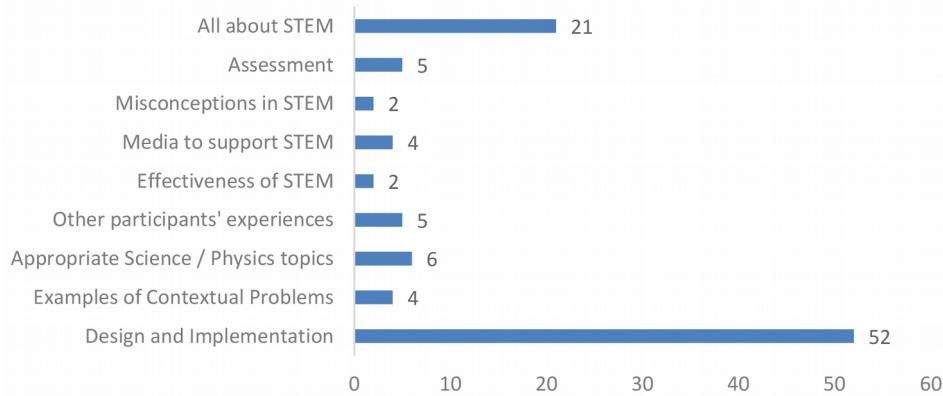


Figure 8. Further needs for STEM professional development

T 78: I want to know more about the implementation of STEM in the learning activity, the syntax, how the conclusion of the lesson could be drawn. If we can learn from a full classroom video, it would be a great help to our school and help us design lessons for the other topics.

Challenges to integrating STEM education with the fixed curriculum and workload were also identified. This is also found in teachers' perceptions in Korea (Park, Byun, Sim, Han & Baek, 2016), Thailand (Srikoom & Faikhamta, 2018), and more broadly within the Asian context (Lee et al., 2019). The issues of learning environment and circumstances in implementing STEM education show up in some of our study's teachers' responses, for example, in Teacher 34 below. Moreover, concern about the possibility of STEM implementation in rural areas is revealed. The challenge for rural area schools is also highlighted in another research (Lomarak, Nuansai, Promden & Sangsila, 2019). Supporting teachers in rural areas is essential because many talented students are not located in cities, and local knowledge is also helpful for exploring as context in STEM activities (Morris, Slater, Fitzgerald, Lummis & van Etten, 2019). In the case of Indonesia being an archipelago country, rural areas are abundant. The dissemination of STEM education both in cities and rural areas needs to be considered.

T34: I am eager to explore how we could implement STEM education with limited time in the curriculum and minimum access to science material in the rural schools.

From the results, physics teachers in Indonesia have basic knowledge and familiarity with STEM education. Their interest in STEM education shows their eagerness to learn and improve their teaching skills to integrate STEM education, especially in designing and implementing issues. This interest was also found in former research that concluded that teachers need comprehensive training in STEM education (Asiroglu & Akran, 2018; Osadchy, Valko & Kushnir, 2019). This notion is also related to the essence of teachers' role as a central factor in nurturing students' talent development and holding views and experiences that will influence their STEM instruction. The dynamic relation between teachers and students also influences teachers' interest in deepening their skills in STEM integration. Teachers consider STEM important for both themselves and their students.

5. Conclusion

The readiness of Indonesian physics teachers to apply STEM learning in their classrooms and online can be observed from their Alignment, Capabilities, and Engagement. The teachers showed strong alignment with STEM education and how to implement it. Most of them have known STEM education terminology but have not had many experiences conducting STEM lessons. They can identify the possibilities of implementation in various physics curricula in Indonesia, such as motion, electricity, and fluids. However, in the online learning made necessary by the COVID-19 pandemic, the possibility of implementation is weakened. Teachers show their engagement to explore in more detail the design and implementation of STEM in their classrooms.

Our conclusion imply that teacher readiness is essential for the implementation of STEM education. As one of starting point to infusing STEM education to science lesson, teacher professional development needs more attention. Teacher readiness in STEM education is multifaceted transformation that could be seen from their alignment, capabilities, and engagement. Professional development in STEM education need to consider how to build teachers' alignment, capabilities and engagement toward STEM education.

6. Further Research

Professional development in STEM education is needed for both in-service and pre-service teachers to develop their readiness, which is an initial step toward the implementation of STEM education in the classroom. Our research is limited to exploring the readiness of physics teachers; exploration in different subjects is also needed to identify the possible integration of those topics. In addition, the challenge of the pandemic needs to be explored further as the adaptation of teachers to conduct STEM activities is highly valuable. Finally, further research in teacher implementation is essential for the successful implementation of STEM education.

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