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INTEGRATED STEM EDUCATION MODEL FOR FOSTERING TPACK OF IN-SERVICE SCIENCE TEACHER

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SUMMARY

Currently, STEM education is getting attention from various parts of the world. Along with the development of digital technology, a number of ideas have emerged to integrate STEM education to be synthesized with the TPACK framework for the purpose of teacher professional development. Unfortunately, however, the professional development of teachers for integrative STEM education for in-service science teachers is lacking. This study attempts to integrate the STEM and TPACK frameworks as a means to advance the situation. Specifically, this study aims to conduct a STEM-TPACK survey for Southeast Asian in-service science teachers and explore the STEM-TPACK profile of science teachers in the context of the mixed-method study. We collected quantitative data to provide a general picture about STEM-TPACK. Then qualitative data were collected from in-depth interviews. Moreover, these interviews also offered insights into the reasons why the strategies succeed or fail as well as influences on in-service science teachers' TPACK. Results show that science teaching efficacy and beliefs and STEM career awareness of science teachers are in the good category. These findings can generally reveal that science teacher efficacy is significantly influenced by the implementation of integrated STEM education in their learning, both exemplary lessons and their own custom lessons. Science teachers also have integrated technology not only in learning but also to facilitate their work in the world of education.

Keywords: STEM Education; TPACK

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I. INTRODUCTION

Technological advances have enabled many pedagogical changes that were previously envisioned by educators but were sometimes challenging to implement due to limited resources. This limitation is especially the case for constructivist-oriented learning cases where students are encouraged to engage in authentic problem solving using ICT as a cognitive exploration tool (Ashburn & Floden, 2006; George & Sanders, 2017; Huang & Chiu, 2015).

Currently, a number of technological devices and applications that have been used in education are very diverse and sophisticated, ranging from computers, laptops, handheld devices, liquid crystal display projectors, wireless technology, digital video, interactive whiteboards, cameras, and productivity software applications, such as designed for word processing, number processing, designing digital presentations, and graphic media (Delgado et al., 2015; Woods et al., 2008). One of the advances in information technology that has the potential to empower authentic constructivist-based learning is the invention of mobile computing devices such as smartphones (Hwang et al., 2008). Mobile devices such as smartphones enable learning anytime and anywhere. Therefore, the successful use of information technology, including smartphones, the key lies in the pedagogical design that appropriately utilizes learning strategies that are in accordance with the capabilities and sophistication of technology (Chu et al., 2010; Hwang et al., 2017).

Nonetheless, pedagogical design has been identified as a reasonably popular barrier to technology-assisted learning (Tsai & Chai, 2012). Thus there is a continuing need to improve teacher design capacity through early and ongoing teacher professional development (TPD) based on digital technology (Garzon Artacho et al., 2020; Knobel & Kalman, 2016). The current development on the trend of pedagogical design for technology-supported learning for the purposes of TPD most of the various emerging studies relate to the idea of technological pedagogical content knowledge (TPACK) (Chai, 2019; Koh & Chai, 2011). Along with that, integrative TPD development studies for Science, Technology, Engineering, and Mathematics (STEM) are also still lacking (Al Salami et al., 2017; Chai, 2019), despite the increasingly complex future challenges. STEM education will be a wise choice for the most potential solutions in the future (Abdurrahman et al., 2019; Enderson & Watson, 2019; Syukri et al., 2020). Therefore, this study explored several elements of technology-assisted learning in TPACK teachers and in-service science teachers for integrated STEM education.

II. LITERATURE REVIEW

Shulman (1987) originally proposed seven knowledge bases a teacher needs in order to create quality instruction: (i) CK, (ii) PCK, (iii) (general) pedagogical knowledge (PK), (iv) curriculum knowledge, (v) knowledge of learners and their characteristics, (vi) knowledge of educational context, and (vii) knowledge of educational ends, purposes, and values. The first three of these knowledge bases, CK, PCK, and PK, are presently widely considered to form the core of teachers' professional knowledge (van Driel et al., 2014). Among these knowledge bases, CK represents the knowledge of the subject matter; that is, knowledge about the academic content of the respective discipline, how this content is arranged into topics as well as how new knowledge within the discipline is constructed (Gess-Newsome et al., 2019; Shulman, 1986). In addition, (pre-service) teachers need to develop an overview across a broad range of topics in their discipline to follow the developments in the field throughout their teaching career (Grossman, Schoenfeld, & Lee, 2005). In addition to CK, PCK is proposed as a knowledge that represents the "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of understanding" (Shulman, 1987). PCK is the kind of knowledge that teachers draw on to make the content comprehensible for students (Shulman, 1986).

TPACK originated from an examination of Shulman's (1986) study on pedagogical content knowledge (PCK). According to Shulman (1987), PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). Teachers need to have a rich conceptual understanding of the material they teach. This rich conceptual understanding is combined with expertise in the development, use, and adaptation of teaching procedures, strategies, and approaches in particular classes. These skills are combined to form knowledge of content and pedagogy as defined by Shulman

(1987). PCK is developed over time and through experience; it is considered to be a cornerstone of the craft of teaching (Loughran et al., 2012). This new understanding of the interaction between content and pedagogy has prompted educators to define a new technology-based knowledge form that was initially constructed by Mishra & Koehler (2006), as seen in Table 1 showed the constructs and definitions of the TPACK. In parallel with TPACK literature, research on pre-service teachers' technology integration knowledge and abilities has been limited (Chai et al., 2010). In addition, a limited number of studies have examined the effects of technology intervention on pre-service and in-service PE teachers' technology integration and TPACK variables (Agyei & Voogt, 2012; Chai, 2019).

Table 2.1. Brief Teachers Knowledge Constructs and Definitions of the TPACK (Mishra & Koehler, 2006).

Construct	Definition
Pedagogical Knowledge (PK)	"…knowledge about the processes and practices or methods of teaching and learning and how it encompasses, among other things, overall educational purposes, values, and aims. This is a generic form of knowledge that is involved in all issues of student learning, classroom management, lesson plan development and implementation. It includes knowledge about techniques or methods to be used in the classroom; the nature of the target audience; and strategies for evaluating student understanding." (p. 1026–1027)
Content Knowledge (CK)	"…knowledge about the actual subject matter that is to be learned or taught, including knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organize and connect ideas; and knowledge of the rules of evidence and proof (Shulman, 1986)." (p. 1026

Technological Knowledge	"…knowledge of operating systems and computer hardware, and the ability to use standard sets of software tools such as word processors, spreadsheets, browsers, and email. TK includes knowledge of how to install and remove peripheral devices, install and remove software programs . . ." (p. 1027)
Pedagogical Content Knowledge (PCK)	"…exists at the intersection of content and pedagogy. Thus, it goes beyond a simple consideration of content and pedagogy in isolation from one another. PCK represents the blending of content and pedagogy into an understanding of how particular aspects of subject matter are organized, adapted, and represented for instruction." (p. 1021)
Technological Pedagogical Knowledge (TPK)	"…knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies." (p. 1028)
Technological Content Knowledge (TCK)	"…knowledge about the manner in which technology and content are reciprocally related. Although technology constrains the kinds of representation possible, newer technologies often afford newer and more varied representation and greater flexibility in navigating across these representations." (p. 1028)
Technological Pedagogical and Content Knowledge (TPACK)	"…is the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to

	learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge…" (p. 1029)

Science, Technology, Engineering and Mathematics (STEM) are key subject matter knowledge that are interrelated. Among these subjects, engineering is in fact the cross disciplinary subject which integrates science and mathematics through design thinking to generate tools, products and processes to solve real-world problem (Chai et al., 2020). The outcome of the design processes can be broadly classified as technologies (Brophy et al., 2008; Chai, 2019). As mentioned above, one example of such technology is the mobile computing devices. The devices encapsulate myriad science and mathematical knowledge and they afford anywhere and anytime access to information, computation and communication. Technologies subsequently form the facilitating means for the advancement of scientific research, mathematical modelling and collective problem solving, which in turn drive new design through engineering efforts. The interrelated and reciprocal relationships between the STEM subjects imply that it is at least pedagogically sensible to consider the teaching of these subjects in an interrelated manner (Chai et al., 2020). In addition, the power to create advancement in technologies is vital for a society to stay economically competitive in the 21st century (Hoeg et al., 2017). Thus, education authorities are advocating 21st century STEM curriculum. An immediate and obvious pedagogical implication of 21st century STEM curriculum is the need to develop teachers who can foster deep understanding of STEM knowledge through engineering-oriented design knowing (English, 2017). There is therefore a clear need for teacher educators to articulate some form of theoretical frameworks to ground research in TPD for STEM education (Chai et al., 2020; Lee et al., 2014; Parker et al., 2015).

III. RESEARCH METHODOLOGY

A complementarity mixed-method study was adopted in this study, which consisted of collecting, analyzing, and integrating quantitative and qualitative data during the research process (Creswell, 1999; Teddlie & Tashakkori, 2009). In such a complementarity mixed-method design, both qualitative and quantitative methods are used to measure overlapping but also different facets of a phenomenon, yielding an enriched, elaborated understanding (Cresswell & Clark, 2011). The quantitative data were first collected from in-service science teachers to provide a general picture about STEM-TPACK. The qualitative data were collected from in-depth interviews. Moreover, these interviews also offered insights into the reasons why the strategies succeed or fail as well as influences on in-service science teachers' TPACK.

By doing so, this two-step complementarity mixed-method study seeks elaboration, enhancement, illustration, and clarification of the results from one method with the results from the other method (Greene et al., 1989). Quantitative study sample a survey had been conducted in 199 in-service science teachers from Southeast Asian Countries. Based on the variance-covariance matrix, the measurement model containing the representations of constructs as latent variables by manifest variables and the structural model containing the relations between latent variables are specified, and the corresponding model parameters are estimated. To evaluate the extent to which a structural equation model represents the data, the model's goodness-of-fit was evaluated (Marsh et al., 2005). For an acceptable (reasonable) model fit, the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI) should have values larger than or equal to .95 (.90), the Root Mean Square Error of Approximation (RMSEA) should be smaller than or equal to .05 (.08), and the Standardized Root Mean Square Residual (SRMR) should be smaller than or equal to .08 (.10).

Furthermore, qualitative investigation is adopted as a mode of inquiry for this study, since it is most suitable for conducting in-depth interviews for exploring the acquisition and implementation of teachers STEM-TPACK. Although in a qualitative research the number of participants is small (John W Cresswell, 1994), in-depth interviews are helpful in exploring those phenomena which are otherwise not possible using a quantitative research design.

OUTPUTS

There are two targeted outputs, namely mandatory and additional outputs. The mandatory output address to execute the implementation of research collaboration projected road map. Meanwhile, the additional outputs are international publishing in the international journal which SCOPUS or Web of Science indexed.

IV. RESULT AND DISCUSSION

Our research has involved 199 in-service science teachers from Indonesia and outside Indonesia. The distribution of data related to the respondents involved from can be seen in Table 4.1. Table 4.1 describes the percentage of respondents in terms of gender, teaching experience, educational background, and belonging of a professional certificate.

Table 4.1 Data of Respondents

No	Component	Percentage
1	**Gender**	
	Male	28,14%
	Female	71,86%
2	**Teaching Experience**	
	Less than 5 years	14,07%
	5 – 10 years	13,07%
	More than 10 years	72,86%
3	**Undergraduate Educational Background**	
	Physics	33,67%
	Chemistry	8,04%
	Biology	12,56%
	Mathematics	8,04%
	Others (Social Sciences, Physical Science, ICT, Technical Information)	37,69%
4	**Educator certificates**	
	Yes	75,63%
	No	24,37%

Data on the number of teachers from several countries outside Indonesia involved in this study can be seen in Table 4.1. Based on Table 4.1, it can be identified that most of the science teachers involved in this study are senior teachers who have been active in education for more than 10 years. This means that they have had a lot of teaching experience for a long time and have implemented several learning designs. In addition, many of them also have professional certificates as teachers, which means that their professionalism in teaching has been recognized.

The percentage of the number of science teachers involved by country of origin can be seen in Figure 4.1. If seen in Figure 4.1, it can be seen that the research participants who came from outside Indonesia were still very few. This is due to time constraints in recruiting respondents from outside Indonesia. However, based on our data, the science teachers involved are science teachers who are already professionals and have a long teaching experience, which is more than 10 years and already have a professional certificate.

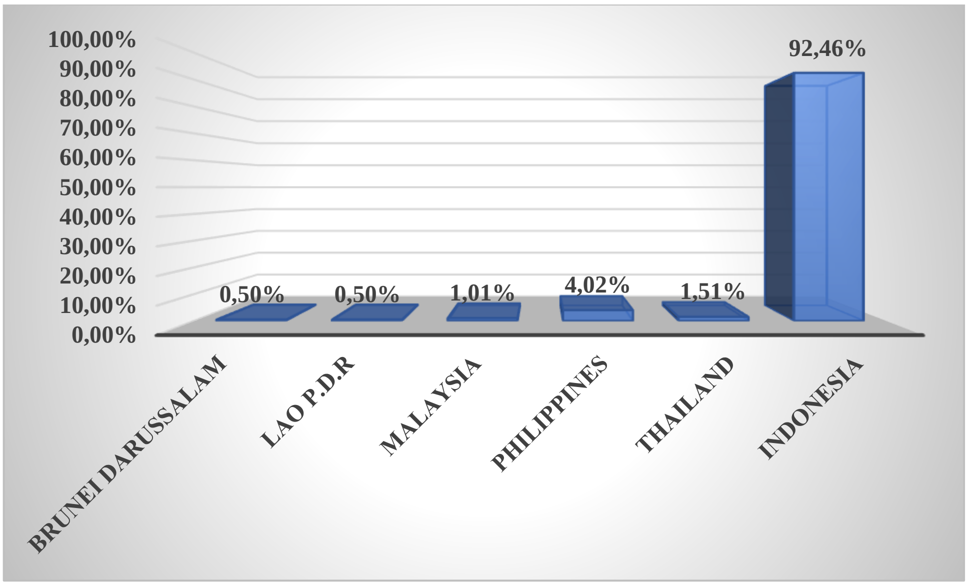

Figure 4.1 Distribution of Respondents by Region

We collected quantitative data to provide a general picture about STEM-TPACK. Then qualitative data were collected from in-depth interviews. Moreover, these interviews also offered insights into the reasons why the strategies succeed or fail as well as influences on in-service science teachers' TPACK.

We conducted a web survey on two variables, they are science teaching efficacy and beliefs and STEM career awareness. The responses given by participants from within Indonesia are shown in Table 4.2 and Table 4.3.

Table 4.2 Science Teaching Efficacy and Beliefs Based on Indonesian Teachers' Perspective

No	Item	SA	A	NAOD	D	SD
1	I am continually improving my science teaching practice.	25%	65%	8%	2%	1%
2	I know the steps necessary to teach science effectively.	15%	61%	23%	1%	0%
3	I am confident that I can explain to students why science experiments work.	17%	65%	17%	2%	0%
4	I wonder if I have the necessary skills to teach science.	7%	50%	21%	18%	5%
5	I understand science concepts well enough to be effective in teaching science.	14%	60%	22%	4%	1%
6	Given a choice, I would invite a colleague to evaluate my science teaching.	26%	59%	14%	1%	1%
7	I am confident that I can answer students' 8science questions.	15%	68%	14%	2%	1%
8	When a student has difficulty understanding a science concept, I am confident that I know how to help the student understand it better.	16%	66%	16%	0%	2%
9	When teaching science, I am confident enough to welcome student questions.	22%	65%	11%	1%	2%
10	I know what to do to increase student interest in science.	19%	64%	16%	1%	1%

SA : Strongly Agree
A : Agree
NAOD : Neither Agree or Disagree
D : Disagree
SD : Strongly Disagree

Based on Table 4.2, it can be indicated that of the ten favorite items, the percentage who respond strongly agree and agree is always more than 70%, this illustrates that the self-efficacy of science teachers is good. The question may arise why we use the self-efficacy variable as a basic indicator to develop several elements of technology-assisted learning in TPACK teachers and in-service science teachers for integrated STEM education. Several studies have shown that teacher self-efficacy has been found to be a factor in influencing students' persistence and retention in STEM subjects (Kelley et al., 2020; Painter, 2012). Therefore, teacher self-efficacy is an important variable to be identified as the impact point of a STEM integrated learning model implementation.

Table 4.2 STEM Career Awareness Based on Indonesian Teachers' Perspective

No	Item	SA	A	NAOD	D	SD
	I know ….					
1	About careers in the current STEM field	13%	55%	28%	4%	0%
2	A place to learn more about careers in STEM	15%	55%	26%	3%	1%
3	A place to find resources for teaching STEM careers to students	12%	60%	24%	3%	1%
4	A place to guide students or parents to find information about careers in the STEM field	14%	59%	24%	3%	0%

In addition, the research findings for science teachers' self-efficacy are significant in showing positive effects of professional development, which may improve student learning of STEM content and career interest (Kelley et al., 2020). These results match our findings, that of the four favorite items, some teachers gave positive responses (Table 4.2). The four items identify the teacher's knowledge related to STEM career and abilities in encouraging student careers in the STEM field.

Meanwhile, the responses from participants from outside Indonesia are shown in Table 4.4 and Table 4.5.

Table 4.4 Science Teaching Efficacy and Beliefs Based on Outside Indonesian Teachers' Perspective

No	Item	SA	A	NAOD	D	SD
1	I am continually improving my science teaching practice.	73%	20%	0%	0%	7%
2	I know the steps necessary to teach science effectively.	13%	60%	13%	13%	0%
3	I am confident that I can explain to students why science experiments work.	33%	40%	13%	7%	7%
4	I wonder if I have the necessary skills to teach science.	13%	40%	33%	13%	0%
5	I understand science concepts well enough to be effective in teaching science.	20%	47%	20%	7%	7%
6	Given a choice, I would invite a colleague to evaluate my science teaching.	40%	40%	7%	7%	7%
7	I am confident that I can answer students' 8science questions.	27%	47%	20%	0%	7%
8	When a student has difficulty understanding a science concept, I am confident that I know how to	20%	53%	20%	0%	7%

No	Item	SA	A	NAOD	D	SD
	help the student understand it better.					
9	When teaching science, I am confident enough to welcome student questions.	47%	33%	13%	0%	7%
10	I know what to do to increase student interest in science.	20%	60%	13%	0%	7%

Table 4.5 STEM Career Awareness Based on Outside Indonesian Teachers' Perspective

No	Item	SA	A	NAOD	D	SD
	I know ….					
1	About careers in the current STEM field	40%	40%	13%	0%	7%
2	A place to learn more about careers in STEM	20%	47%	27%	0%	7%
3	A place to find resources for teaching STEM careers to students	27%	40%	27%	7%	0%
4	A place to guide students or parents to find information about careers in the STEM field	20%	47%	27%	7%	0%

Data obtained from filling out questionnaires by science teachers from outside Indonesia also showed the same results and trends (can be seen in Tables 4.4 and 4.5). The science teaching efficacy of these teachers showed a large percentage of positive responses. Based on the results of filling out questionnaires by respondents, both from within and outside Indonesia, it can be seen that the science teaching efficacy and beliefs of science teachers are in the good category. These findings can generally reveal that science teacher efficacy is significantly influenced by the implementation of integrated STEM education in their learning, both exemplary lessons and their own custom lessons. These results indicate that science teachers strengthen their self-efficacy through the process of implementing integrated STEM lessons. These findings reinforce Bandura's theory (Bandura, 1994) about increasing self-efficacy through continuous feedback between the stages of learning new skills, practicing those skills, and receiving feedback on successes and failures.

The findings of quantitative data are supported by the findings of qualitative data from interviews. Se interviewed teachers on three important components, the first was about their perpective on integrated STEM education, the second was about how they practically implemented TPACK in learning, in another way is how they implemented STEM-TPACK in learning. The teachers we interviewed have explained how they apply integrated STEM education in the learning they do with their students. They also explain how TPACK practices in their STEM learning.

First discussion: Regarding to teachers' perspective related to STEM education how this perspective affects STEM career awarenes, we summarize the results in Figure 4.2. We focus our questions on the key principles of how teachers implement the STEM approach in their integrated learning content. We refer to Struyf et al. (2019) that the first key principle is the integration of STEM content, which entails purposefully integrating content from various STEM disciplines. Secondly, problem-centred learning indicates the use of authentic real-world problems to increase the relevance of the learning content. Third, inquiry-based learning, in this context, refers to engaging students in questioning, experiential learning and hands-on activities that allow them to discover new concepts and develop new understandings. The fourth key principle, design-based learning, refers to learning environments that engage students in technological or engineering design. The final principle, cooperative learning, relates to the promotion of teamwork and collaboration with others through the use of, for example, small learning groups.

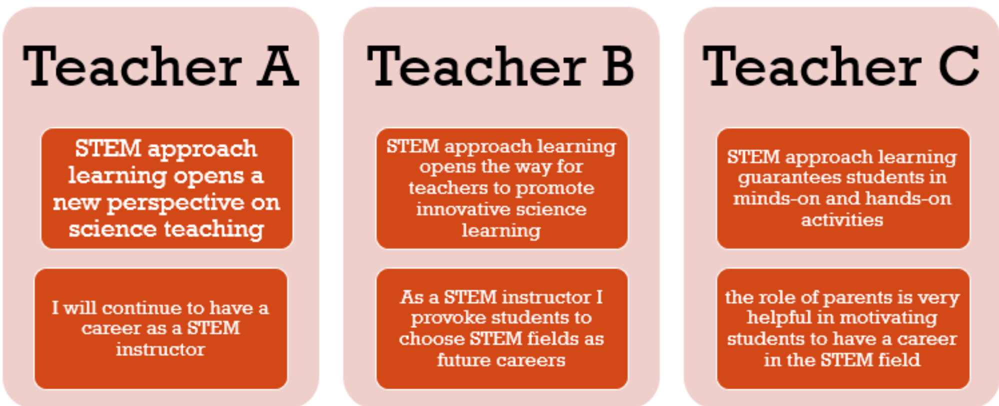

Figure 4.2 In Depth Interview Result

Based on Figure 4.2, it can be seen that the point of view of science teachers regarding the implementation of STEM education is indirectly in line with their intention to encourage their students to have a career in the STEM field. According to them, STEM education has traditionally been about teaching subjects separately, e.g. Science class only, or Mathematics. There has also been less focus on Engineering and Technology within the curriculum. In this study, integrated STEM learning means combining the subject matter of two or more STEM subjects into a joint learning experience. For example, teaching Science using an Engineering process (design-based learning). This approach recognises that each STEM subject has overlapping, shared skills to offer. For example, each STEM subject supports systematic problem-solving and critical analysis skills.

They also explained about the benefits of integrated STEM learning they experienced. According to them, besides being able to improve their knowledge and skills in developing STEM-related ideas and processes, the bigger thing is that students can recognize how the STEM skills they acquire can be applied in the real world outside of school. This can indirectly guide students to have the intention to have a career in the STEM field. One of them said: *"….For a long time we should have thought about what kind of learning model can ensure our students will get better and decent jobs in the future. We are now trapped in efforts to prepare students for professions or jobs that may even later be no longer exists, considering that in this disruptive era there have been so many professions and jobs that have been reduced, even almost extinct. The STEM field is one of the promising career fields, but unfortunately students' interest in a career in that direction is still not high. Therefore, we as teachers should be able to open their horizons and explore their interests for a career in the STEM field………."*

Then we inquire further about how teachers can do that. They stated that the first thing they did was they tried to implement integrated STEM education by collaborating with other STEM teachers to integrate the materials and learning strategies that would be used. Then, they try to always invite students to always carry out real-world work practices on the theory being studied. In addition, they revealed that the most important thing that should not be ignored is never stop to continue to innovate in learning as they do, be it in terms of innovation in learning strategies, activities, projects, or others.

Second discussion: The contemporary education presents many challenges to improve teaching quality, including instructional practices knowledge, of teachers in science, technology, engineering, and mathematics (STEM) disciplines. To promote higher teaching competency for STEM teachers, the technological pedagogical content knowledge (TPACK) framework is recognisably and essentially adopted. We also conducted interviews with several teachers regarding the implementation of TPACK. They revealed that they practically describe the implementation of TPACK in their STEM teaching and learning in the following eight components.:

1. They use ICT to assess students. For example, they use Microsoft Excel to process grades, use online quizzes to assess student participation, use group chats to understand how to communicate through social media and so on.
2. They use ICT to understand the learning material. For example, packaging abstract material into video animation, simulating the working principle of a machine using animation, providing reference links for further learning and so on.
3. The integrate ICT to understand students. For example, asking students to visualize their ideas using WhatsApp or email to accommodate student complaints, providing online consultation forums and so on.
4. They integrate ICT in curriculum design including policies. For example, involving teachers in the development of digital learning resources, regular discussions on digital content development, including ICT literacy improvement programs for teachers and so on.
5. They integrate ICT to present data. For example, using ICT to present academic data, student master data, student mutation data, create graphs and so on.

6. They integrate ICT in learning strategies. For example, developing web-based learning, managing online discussion forums, conducting teleconferences, using learning videos to motivate students and so on.
7. They apply ICT for learning management. For example, using ICT for online attendance, entering and processing student values, using academic information systems and so on.
8. They integrate ICT in the context of teaching. For example providing online-based learning options, creating a learning environment

From the interviews, it can be seen that science teachers have integrated technology not only in learning but also to facilitate their work in the world of education. However, we have not seen directly how it is practiced in the classroom. that is the weakness in this study apart from the proportion of respondents. We only explored directly based on the teacher's confession and experience. TPACK is considered as a new model of teacher expertise to be applied in learning in the 21st century (Mishra and Koehler 2006). Meanwhile, STEM education requires teachers to integrate technology, pedagogy, and content knowledge through actualized learning designs. Therefore, the role of technology in STEM education is very important. Almost all contemporary STEM professionals need to master some form of profession-specific technology. For example, biologists need to master bioinformatics and engineers need to be trained in computer-aided design (Chai, 2019). An integral part of TPACK and STEM education is technology. It is now generally accepted that teachers need to develop TPACKs to integrate technology and it appears that STEM education will require teachers to enable and extend their TPACKs for STEM lesson design.

V. CONCLUSION AND SUGGESTION

Based on the findings presented here, we would like to make the following conclusion:

1. Science teacher teaching efficacy and belief is in a good level.
2. Science teacher STEM career awareness also in a good level. They have a good intention to guide students to choose their career in the STEM field.
3. Science teachers have a good perspective regarding the implementation of integrated STEM education based on their experiences after they applied it in the classroom.
4. Science teachers have also integrated technology in learning and in their daily work as teachers. They package technology in STEM learning, which means they have practically implemented STEM-TPACK.

Based on the discussion revealed, we would like to make the following suggestion:

1. STEM teachers still need to increased their self-efficacy after successfully implementing integrated STEM lessons in their classrooms.
2. Future research is expected to reveal how statistically the application of the integrated STEM Education model in learning can directly affect teacher TPACK.
3. Further research can also be directed at the application of the integrated STEM Education model to pre-service teachers which is the starting point for future educational development.

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