Energy Learning Progression and STEM Conceptualization Among Pre-service Science Teachers in Japan and Indonesia

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Abstract

We explored energy learning progression and STEM conceptualization among pre-service science teachers (PSTs) in Japan and Indonesia. This study used a survey design to collect data using questionnaires on energy content knowledge (energy forms, transformation, dissipation, and conservation) and STEM conceptualization (definition, connectedness, and visualization). Results indicated that the Japanese PSTs have greater energy content knowledge than the Indonesian PSTs. Furthermore, content knowledge has a significant correlation with STEM conceptualization.

Keywords: *energy learning progression, STEM conceptualization, Pre-service science teachers*

Introduction

Energy efficiency is a topic that poses significant challenges to developing science, technology, engineering, and mathematics (STEM) materials for schools (Bybee, 2013). Energy is important to life throughout the world. Explaining energy can be covered in biology, physics, chemistry, or earth sciences. Energy is a fundamental concept when explaining other scientific concepts. For example, the biologist will use energy to explain the relationship between organisms and the ecosystem, a chemist will interpret chemical reaction by tracking energy change,

a physicist will use energy to clarify the movement of a particle, and a geologist will use energy to explain the shapes and structures of the earth's surface (Fortus, Adams, Krajcik, & Reiser, 2015; Nordine, Krajcik, & Fortus, 2011). The Next Generation of Science Standards (NGSS) provides a framework for interdisciplinary concepts covering core ideas, practices, and crosscutting concepts. The framework also presents energy and systems. Within this framework, the concept of energy is explained via life science, earth and space sciences, physical science, and engineering design. All energy concepts in this framework are linked between grades from elementary through high school (Krajcik, 2014). When teachers introduce the concept of energy, it becomes the foundation of students' knowledge, allowing for easier understanding in higher grades. In this way, students see the possible applications of energy in the real world, and STEM becomes a bridge that makes problem solving easier.

The integration of energy concepts in STEM classes has been extensively researched at Shizuoka University, Japan (Kumano, 2018). During this research, materials were developed in relation to energy in Japan, such as nuclear power plants, steam power plants, and the country's energy requirements. The goal of this pilot project was to increase students' awareness of effective energy use and alternative energy sources. The use of the STEM structure was adjusted to Japan educational conditions, with engineering still looking for the best form.

Indonesia is an energy exporter in international trading. This resource-rich archipelagic nation is the world's fourth-largest producer of coal. Indonesia is also Southeast Asia's biggest gas supplier, with exports accounting for roughly 45% of its production (International Energy Agency, 2014). This creates an education policy that views energy as an important topic in the curricula. An approach is needed that can organize energy concepts and bring them into the classroom effectively. Students need to understand Indonesia's energy supply to fulfil the country's potential in the future. A draft of the Indonesian science curriculum mentions a STEM approach to organizing Indonesia's educational future.

The presented research aims to compare the energy content knowledge of pre-service science teachers (PSTs) in Japan and Indonesia using the STEM approach in classrooms, based on a 2015 Trends in International Mathematics and Science Study (TIMSS), which showed that Japanese students have higher grades in science than Indonesian students (TIMSS Overview, 2015). Notably, in Indonesia the science curriculum includes STEM, yet its integration has not been made a formal part of educational policy. We also hypothesize that the PSTs' STEM conceptualization will be linear regarding content knowledge (Stohlmann et al., 2012). The research questions that guided this study are as follows:

1. What is the level of energy content knowledge of Japanese PSTs and Indonesian PSTs?
2. What is the relationship between energy content knowledge and STEM conceptualization?

Research Methodology

This research was a cross-sectional survey design, with the researcher collecting data at a single point in time (Creswell, 2017). The research described PSTs' current attitudes to energy content knowledge and STEM conceptualization. Two questionnaires were modified based on the original (Radloff & Guzey, 2016a; Ring, Dare, Crotty, & Roehrig, 2017), researching STEM conceptualization. To develop and use these instruments, the author contacted and received permission for this research. Questionnaires were adjusted to the sample conditions, in that STEM is not deeply entrenched in the education systems.

The first questionnaire tested teachers' knowledge of energy concepts in physics, chemistry, and biology. The questions followed a sequence of energy concepts, as explained by Driver, Asoko, Leach, Scott, & Mortimer (1994), and are ordered from simple to complex:

1. The forms of the energy, such as electricity, heat, wind, nuclear, etc.
2. The transformation of one form of energy into another, such as wind into electricity, by a generator.
3. The dissipation of energy, such as internal heat energy being transferred from a warmer body to a cooler body.
4. The conservation of energy, and that mechanical energy consists of potential and kinetic energy.

A total of six questions were included, which aimed to ascertain PSTs' concept of energy and more specifically, how the PSTs were grading according to real-world contexts.

The second questionnaire tested the PSTs' knowledge of STEM concepts, including its definition, connectedness, and visualization. The STEM definition includes three questions that explain STEM from different contexts, not only the four subject areas, and the PSTs' perspective on STEM integration with language and art. STEM connectedness is the proportion of each subject practiced by the students.

All questions were closed-ended using the Likert Scale from one (strongly degree) to six (strongly degree). Questions were developed as both negative and

positive to ensure participants read the questions fully before answering. The questions were presented using an online Google form. The authors co-operated with a lecturer who had a science education class of PSTs complete the questionnaire in 20 minutes.

The study included 100 science education undergraduate students from Japan and 150 science education undergraduate students from Indonesia as participants. These countries were selected because they have both undergone STEM, with a focus on energy systems (Kumano, 2016). This research was based on an assumption that students from these universities would be of similar quality. The participants selected were second- or third-year students who had already learned science concepts and physiological education. The number of participants in Indonesia was larger than that in Japan because the population ratio between the two countries is 1:3 for Japan and Indonesia.

After the data was collected, the first step was to ignore any data that showed similar tendencies on the scale (e.g., answering all the questions with 1 or 6). Furthermore, only the participants who had completed the entire form were analyzed to avoid data bias. The second step was to transform the data collected from ordinal to interval data. Afterward, the data was entered into an SPSS (IBM 25) program to assess the differentiation of energy content knowledge and STEM conceptualization between the PSTs in Indonesia and Japan with an ANOVA test.

Research Results

Table 1 shows the result of the PSTs' energy content knowledge and STEM conceptualization in Japan and Indonesia. Of the 100 Japanese PSTs participants, there were only 66 selected for analysis. Of the Indonesian PSTs, only 115 participants were selected for analysis in the ANOVA test.

Table 1. Results of PSTs in Japan and Indonesia

		N	Mean	SD	Minimum	Maximum
Energy Content Knowledge	Japan	66	4.4400	0.76832	2.20	6.00
	Indonesia	115	3.8424	0.62611	2.00	5.20
STEM Conceptualization	Japan	66	3.7848	0.41003	2.33	4.67
	Indonesia	115	3.5177	0.38551	2.58	4.83

Table 2 shows a significant difference in content knowledge and STEM conceptualization between the PSTs in Japan and Indonesia.

Table 2. ANOVA analysis

		SS	df	MS	F	Sig.
Content Knowledge	Between Groups	14.974	1	14.974	28.891	0.000
	Within Groups	92.777	179	0.518		
STEM Conceptualization	Between Groups	2.992	1	2.992	18.578	0.000
	Within Groups	28.826	179	0.161		

Although the mean in the two samples differed by only a decimal, the result is still significant [$F(1,179) = 28.891, p = 0.000$]. The Japanese PSTs' energy content knowledge ($M = 4.44, SD = 0.76$) was higher than that of the Indonesian PSTs ($M = 3.84, SD = 0.62$) (Table 2). STEM conceptualization differed between the two samples [$F(1,179) = 18.578, p = 0.000$]; it was higher in Japan ($M = 3.78, SD = 0.41$) than in Indonesia ($M = 3.51, SD = 0.38$).

To further the investigation, a learning progression graph (Figure 1) was created to analyze the PSTs' ability to complete the energy content knowledge items on the test. The x axis is the indicator of energy learning progression, which was arranged from simple to complex concepts, and the y axis is the Likert scale from a minimum of 0 to a maximum of 6. The graphs indicate the average score in each energy concept indicator. The four concepts (as mentioned in Methodology) demonstrate a sequence of understanding in the Japanese PSTs' learning progression. Interestingly, the Indonesia PSTs had the lowest score in the dissipation of energy concept.

Figure 1. Energy learning progression between PSTs in Indonesia and Japan

The relationship of content knowledge and STEM conceptualization as demonstrated in Table 3.

Table 3. Correlation analysis

		Energy Content Knowledge	STEM Conceptualization
Energy Content knowledge	Pearson Correlation	1	.319**
	Sig. (2-tailed)		0.000
STEM conceptualization	Pearson Correlation	.319**	1
	Sig. (2-tailed)	0.000	
** correlation is significant at the 0.01 level (2-tailed)			

The results of the Pearson correlation (Table 3) indicated that there was a significant positive association between energy content knowledge and STEM conceptualization, ($r(117) = 0.319$, $p = 0.000$). These results prove that the PSTs who had high scores in energy content knowledge did well in STEM conceptualization. This result suggests that if the PSTs apply the STEM approach in the classroom, they must have a good grasp of the content knowledge. Table 4 presents the results of the PSTs' STEM conceptualization.

Table 4. Percentages of participants' STEM conceptualization

Indicator	Strongly disagree				Strongly agree	
	1	2	3	4	5	6
1. STEM as integration between S-T-E-M subjects	0%	2.92%	5.26%	30.99%	48.53%	12.28%
2. STEM disciplines are dependent on each other	2.33%	14.03%	23.39%	27.48%	28.07%	4.67%
3. STEM is overlapping material and can be taught in sequence	2.39%	14.03%	23.39%	27.48%	28.07%	4.67%

Indicator number 1 was the definition of STEM, number 2 was STEM connectedness, and number 3 was STEM visualization. Almost all the respondents agreed that STEM is an integrated approach.

Discussion

One of the purposes of this research was to compare the energy content knowledge of PSTs in Japan and Indonesia. The overall directions of the results were significant and supported our hypothesis. In this section we will discuss the extent to which the findings support the hypothesis.

Research question 1: What is the level of energy content knowledge of Japanese PSTs and Indonesian PSTs?

As shown in Table 1 and Table 2, our data supported the hypothesis that Japanese PSTs have a greater understanding of energy concepts than Indonesian PSTs. Many energy programs in Japan use informal and formal education to encourage positive behaviors and attitudes toward energy consumption (Akitsu, Ishihara, Okumura, & Yamasue, 2017). Kumano, et al (2018) developed learning materials that can be used to understand the development and demand for energy in Japan. Through this material, students can access information on the variety of energy sources in Japan. On the other hand in Indonesia, although the handedness of energy is more than Japan but the accessibility in education is still (Yusup, Setiawan, Rustaman, & Kaniawati, 2017). This accessibility of energy will give students an understanding of how to apply energy in daily life.

How to present energy content is important when teachers are developing instructional material for students. Neumann, Viering, Boone, & Fischer (2013) conducted an empirical study and stated that content knowledge was central to the understanding of core science concepts and supported successful teaching. Ideally, the content knowledge of PSTs will guide students' understanding of core science concepts. The PSTs' results are in line with the TIMSS results, in that Japanese students have higher science scores than Indonesian students. As well, the PSTs have a greater level of understanding of core concepts in energy education. Keller, Neumann, and Fischer (2017) argued that teachers' pedagogical content knowledge is a major predictor of student achievement. Additionally, their research showed that teachers' content knowledge was able to direct student interest toward a subject.

A deeper comparison of energy concept knowledge is explained using learning progression in Figure 1. We predicted that the Indonesian PSTs would have more formal energy knowledge due to the support of the energy sector in their country. However, the Indonesian PSTs had a biased understanding of the chemical energy statement on the questionnaire, "nuclear reaction". The Indonesian PSTs were

unfamiliar with nuclear reaction as a potential source of energy. This is a basic level energy concept, and observable examples were needed to explain it. In Japan, nuclear energy is used in some regions, which is an easy way to educate society about nuclear energy sources (Akitsu et al., 2017).

The comparison graphics show that the Indonesians had inconsistent grades, e.g., the lowest score in the dissipation of energy concept. This is an advanced energy concept, as it requires an integrated idea of forms, transfer, and dissipation (Herrmann-Abell & DeBoer, 2018). This concept should be difficult for all PSTs. The dissipation of energy is explained in the law of thermodynamics, i.e., that there is equilibrium between a system and its surroundings. The Japanese PSTs had more consistent grades between the four concepts. This indicated that the learning progression in the Japanese education curriculum is particularly sequential. The PSTs understand the basic concepts, progress to the intermediate, and finally the advanced ones.

This research only tested PSTs in two countries, in which one country is an energy provider with many energy resources, and the other an energy consumer with an industrial and technological base. These contribute to the experiences of the teacher and will impact students' achievement, although this research did not test students' achievement directly. However, the data from the TIMSS supported this research. We believe that longitudinal research on PSTs' experiences and students' achievement will support our hypothesis and demonstrate the importance of PSTs' readiness to teach.

Research question 2: What is the relationship between energy content knowledge and STEM conceptualization?

Content knowledge is essential for developing STEM material. Table 3 shows the relationship between content knowledge and STEM conceptualization. The STEM approach to teaching concepts between two or more S-T-E-M domains is bound by practices with an authentic context (Kelley & Knowles, 2016). STEM conceptualization plays a role in the PSTs' understanding of STEM and their ability to practice it in the classroom. Radloff & Guzey (2016b) suggested that to effectively teach STEM, PSTs need STEM conceptualization. STEM conceptualization requires basic content knowledge and pedagogical knowledge. Content knowledge utilizes that pedagogical knowledge to ensure concepts are delivered.

The STEM conceptualization in this study included the STEM definition, STEM connectedness, and STEM visualization. Our participants agreed that STEM is an integrated approach to teaching science, which is more than knowledge focused

on certain subjects, but emphasizes the application of concepts in the real world. When practicing STEM in the classroom, the selection of real world problems demonstrates the teacher's connection to the content knowledge. Teachers who are weak in content knowledge will give confusing examples to students (Jiménez-Aleixandre & Crujeiras, 2017; Kelly & Licona, 2018).

The point of this research is to emphasize that when practicing the STEM approach, teachers need to improve their content knowledge about the topics taught. One limitation of our study was the sample size. Clearly, one university in each country is not enough to generalize. However, the analysis using the online form and keeping the sample with the valid answer supported our hypothesis. Furthermore, students, in-service, and pre-service teachers should be involved to ensure teachers' content knowledge positively influences students' achievement.

Conclusions

This paper has shown the energy learning progression among PSTs in Japan and Indonesia. The Japanese PSTs are better prepared to teach energy topics to students than the Indonesian PSTs because they have advanced knowledge to better understand energy concepts. Content knowledge is basic to applying the STEM approach in the classroom. There was a positive correlation between content knowledge and STEM conceptualization. It suggests that content knowledge should be a part of professional development in STEM education.

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