Professional Development Program for Secondary School Teachers to Improve Knowledge and Self-Efficacy in Energy Science

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Abstract

Teaching STEM is essential for nurturing future generations of leaders as well as increasing awareness of career opportunities that are available in the energy fields. Despite an increased number of informal professional development programs for STEM teachers in the past few years, few efforts have been made on testing the effectiveness of professional teacher development programs in energy science. This study utilized a quantitative and qualitative approach to investigate the effectiveness of teacher professional development programs to improve their knowledge and self-efficacy in teaching energy science. More than 100 secondary teachers from various science education backgrounds participated in a one-week intensive learning experience on energy science concepts and applications in the form of lectures, group discussions, field trips, hands-on activities, collaborative project designs with students, and lesson plan development.

Results indicated an increase in teacher knowledge and self-efficacy in teaching energy science after program completion. Knowledge gained was also found to be a significant positive predictor of teacher self-efficacy. This study also generated several themes related to knowledge gained, use of knowledge gained, and barriers to energy science teaching implementation. These findings highlighted the importance of mastery experiences in energy science learning as a foundation for the development of teacher confidence in the delivery of STEM pedagogy. Implications for theory and practice of STEM pedagogy are discussed.

1. Introduction

Teaching is an important foundational building block for science, technology, engineering and mathematics (STEM) programs and teachers require energy instruction resources beyond their college education. A literature review of more than 160 articles related to STEM in international journals suggested that teacher professional development activities should involve a focus on career awareness, inquiry-based and problem-based learning, multidisciplinary approaches, workshops, and site visits [1]. Research studies have been conducted on STEM teacher professional development programs in marine and environmental science [2], astronomy [3], geology and biological sciences [4], mathematic and general science [5], but less attention has been devoted to the topic of interdisciplinary energy sciences.

One particular study on energy sciences to measure the effectiveness of a hybrid (face-to-face and online) program using teaching science as inquiry framework to increase student teaching ability through inquiry [6]. Implementation of teaching strategy was found to be improved, but teacher confidence in teaching energy science was low compared to other subjects. This study highlights the need for teacher development programs in energy science that focus on improving knowledge and teaching confidence.

Teaching energy science in the classroom requires more than content knowledge and effective pedagogical approaches but also self-efficacy, which has been associated with positive functioning in teacher professional roles. A review of teacher self-efficacy studies suggested that teachers with high self-efficacy tend to explore alternative methods of instruction, respond effectively to stressful situations, perform better in training, exhibit a higher level of professional commitment, and produce better student outcomes [7]. Improving teacher self-efficacy will increase student performance and empower teachers to be social change agents that benefit the society around them by addressing grand global challenges.

Self-efficacy is defined by Bandura as an individual's belief in his or her own ability to succeed in specific situations [8]. Self-efficacy helps individuals to accomplish goals and overcome challenges in many aspects of life. Bandura further suggested four sources of self-efficacy beliefs: (a) mastery experiences, (b) vicarious experiences, (c) verbal persuasion, and (d) emotional and physiological states. Mastery experiences, which specifically entail a variety of direct experiences of accumulating success in learning specific subject matters, is the most influential source of self-efficacy. Mastery experiences provide authentic and concrete proof of successful attempts that serve as a reminder for an individual to believe in his or her capabilities to perform tasks.

Mastery experiences will differ from one professional role to another. In the teaching domain, mastery experiences reflect what Shulman called three categories of content knowledge as their central requirement for teaching: subject matter content knowledge, pedagogical content knowledge, and curricular content knowledge [9]. Subject content knowledge acquisition has been found to be positively correlated with teacher self-efficacy in elementary school reading teachers [10], high school food science teachers [11], and preservice reading literacy teachers [12]. These studies suggested that increased subject matter knowledge resulting from involvement in a professional development program was also related to increases in their self-efficacy.

Summary of the literature highlighted various professional development programs that address the importance of knowledge mastery to improve teacher self-efficacy because teacher self-efficacy was found to be positively related to teacher's positive professional attitudes and improved student outcomes. Nevertheless, there is a lack of professional development programs that address the contribution of knowledge gained to teacher self-efficacy in interdisciplinary energy science. The Duke Energy Academy at Purdue (DEAP) is designed to incorporate interdisciplinary energy science learning experience to empower teachers in their professional roles.

DEAP is a one-week summer intensive education and learning informal setting program that aims to inspire teachers to communicate the importance of STEM and energy scholarship in their classrooms and also to provide them with resources and incentives. The DEAP program also intends to inspire students to enter the STEM disciplines and to consider energy-related fields in their educational and professional career goals. A hallmark of the DEAP program is an emphasis on teacher mastery experiences relative to content knowledge and pedagogical knowledge in energy science.

Teachers and students alike are involved as co-learners in discussion and lectures on energy concepts from top management professionals who work in the energy field to a number of different technical experts who spend most of their time in the field maintaining energy infrastructure. Teacher and student participants are exposed to cutting edge research and technologies, machineries, and energy-generating mechanisms through hands-on activities, researching in labs, and touring power-generating facilities. DEAP utilizes senior teachers as mentors to incoming teachers, and the new teachers also serve as mentors to the students to facilitate the learning process. Teachers work together with the students on specific energy concepts group projects and learn to develop lesson plans from resources provided during the program. DEAP emphasizes an experiential learning process for teachers to develop their professional competency through subject knowledge acquisition and hands-on experiences to increase success in delivering energy concepts to their students.

Our aim in the current study was to test the effectiveness of the DEAP program in improving teacher's knowledge acquisition and self-efficacy in energy sciences using Bandura's theory as a theoretical framework. This study utilizes a mixed methodology of quantitative and qualitative inquiry. Hypotheses for the quantitative analysis are

1. Knowledge will exhibit significant growth from pretest (T1) to posttest (T2)
2. Teacher self-efficacy will exhibit significant growth from T1 to T2
3. Knowledge acquisition at posttest (T2) will be a positive predictor of teacher self-efficacy at T2

Qualitative analysis will explore teacher participant responses to the following questions:

1. What was the most important lessons you gained or learned from your participation in the program? (knowledge gained)
2. How do you plan to use the knowledge gained from the Energy Academy? (use of knowledge gained)
3. What are the potential challenges and obstacles for integrating energy concepts and energy investigations into the course you teach? (barriers to implementation)

2. Method

This study reported data that were collected from 2012 to 2018. Participants consisted of 110 secondary science teachers and more than 80% originate from the state of Indiana. Sixty-three participants identified as female and 47 identified as male. Most participants were White (92), followed by Asian/Asian American (6), Latino (5), and Pacific Islander (1). Six participants identified as some other race/ethnicity. Teachers were carefully selected based on several criteria such as the quality of their motivation essays, previous number of subjects taught, number and quality of project proposals, and previous teaching experiences.

To assess teachers' knowledge of and self-efficacy for teaching energy concepts, we developed 24 items that reflect concepts such as sources of energy, energy economics and policy, energy transmission, distribution, and energy utilization. Participants were asked to rate the items on a Likert scale ranging from 1 (no knowledge/not at all confident) to 5 (very knowledgeable/very confident). We computed Cronbach's alpha coefficients to assess the reliability of the measures. At T1, alpha coefficients of .97 for knowledge and .97 for self-efficacy were obtained. At T2, alpha coefficients were .97 for knowledge and .89 for self-efficacy.

Participants were administered the T1 measures on the first day of the program immediately after check-in. The T2 measures were administered after participants completed the last activity of the program, which involved presenting the results of the participants' group research projects and lesson development plans. At the end of the program, an open-ended survey was also distributed to participants to explore participants's responses and feedback on the program. Analysis of the open-ended portion was done by thematic coding using Nvivo software. The themes that emerged after the coding were then summarized.

3. Results

A. Quantitative Analysis

We performed repeated measures analyses of variance (ANOVA) to test the hypotheses that science knowledge and teacher self-efficacy would evidence significant growth from pretest to posttest. Both hypotheses were supported. As Table 1 indicates, the mean score for energy knowledge increased from 77.08 at T1 to 98.59 at T2 while the mean score for teacher self-efficacy increased from 75.68 at T1 to 100.44 at T2. Table 1 indicates that the significant differences found in energy knowledge and self-efficacy between pre/post program is at 99% confidence interval (p <.01). T1 self-efficacy ($\beta = .25$, $p = .01$) and T2 energy knowledge ($\beta = .76$, $p < .001$) were significant positive predictors of T2 teaching self-efficacy.

Table 1. Means, standard deviations, and F statistics for repeated measures ANOVAs

	Time 1		Time 2			
Variable	*M*	*SD*	*M*	*SD*	*F* (1, 78)	*p*
Energy Knowledge	77.08	17.51	98.59	14.06	170.19	< .001
Teacher Self-Efficacy	75.68	18.36	100.44	18.05	144.60	< .001

Next, we performed a hierarchical regression analysis with gender, race/ethnicity, and number of STEM courses previously taught entered as statistical control variables. T1 teaching self-efficacy and energy knowledge at T1 and T2 were entered into the regression equation on step 2. Results

Table 2. Results of hierarchical regression analysis predicting T2 teaching self-efficacy

Predictor	*B*	*SE*	β	*p*
Step 1				
Gender	-5.82	4.09	-.16	.16
Race/ethnicity	2.63	2.06	.14	.21
Number of STEM subjects taught	2.98	1.94	.17	.13
Step 2				
Gender	1.34	2.43	.04	.58
Race/ethnicity	2.12	1.22	.12	.09
Number of STEM subjects taught	.73	1.14	.04	.52
Energy knowledge T1	-.10	.11	-.10	.33
Teaching self-efficacy T1	.24	.09	.25	.01
Energy knowledge T2	.97	.11	.76	<.001

Note. T = time.

are presented in Table 2. The step 1 model was not significant, F (3, 76) = 1.75, p = .16, as the predictors only explained 6.5% of the variance in T2 teaching self-efficacy. However, the step 2 model was significant, F (6, 73) = 28.64, p < .001, with the predictors explaining an additional 63.7% of the variance in T2 teaching self-efficacy.

B. Qualitative Analysis

This section reports the results of a qualitative analysis of teacher learning outcomes from the STEM energy topics related intensive program. Each question revealed a number of themes that represented several categories extracted from participants' comments or answers to the survey questions. The first question revealed four themes: (a) general knowledge, (b) networking, (c) classroom application, and (d) career knowledge (See Figure 1)

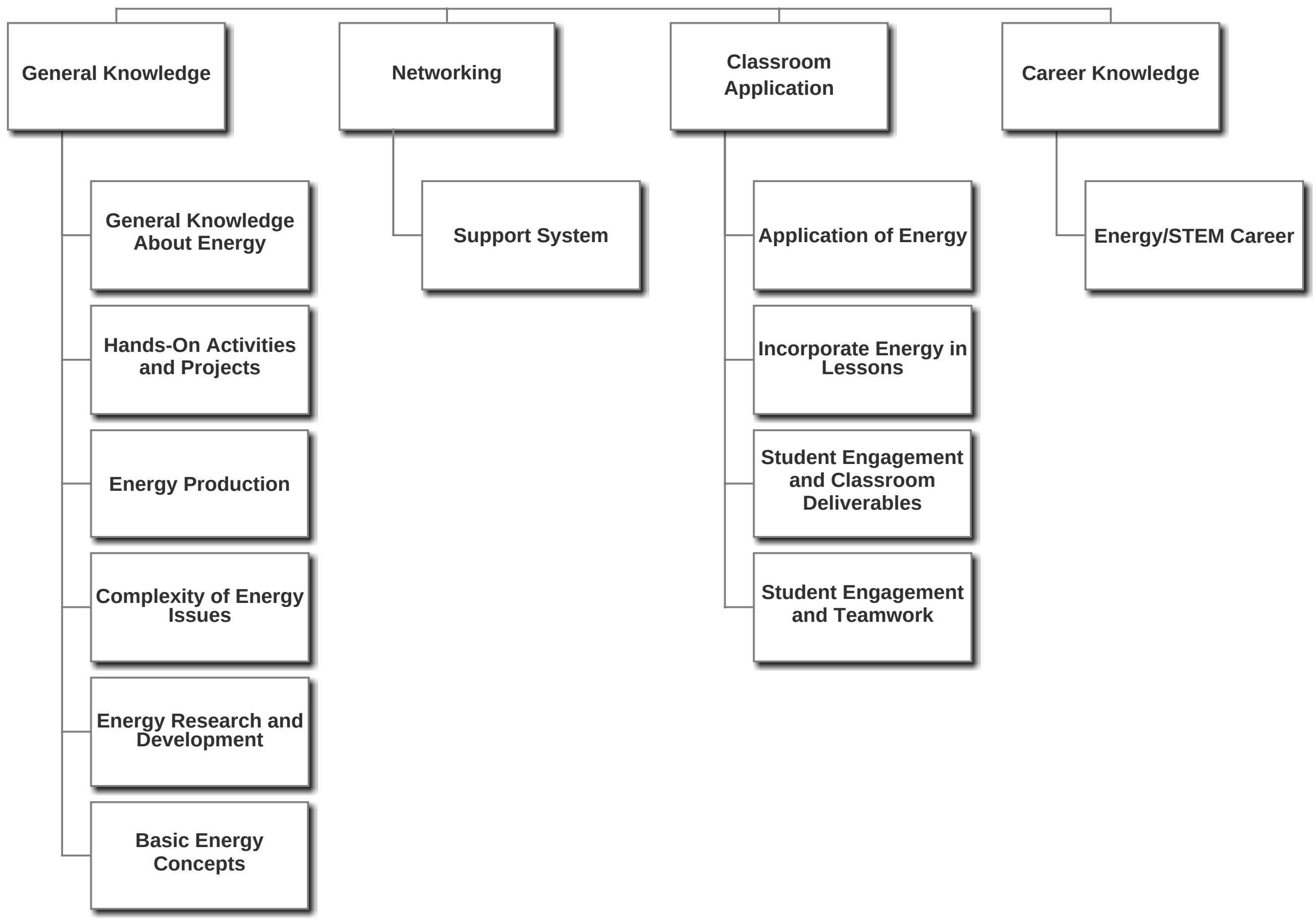

Figure 1. Primary and secondary themes for knowledge gained

Networking yielded support system as the secondary theme, whereas secondary themes that emerged for general knowledge reflected increased awareness of how energy is produced, complex issues such as how to manage supply and demand for energy, energy efficiency of buildings, and more specific knowledge about how to carry out the various hands-on activities and projects that were covered in the program. One teacher provided the following comment regarding classroom application (student engagement and classroom deliverables):

"I now understand that our students can do so much more than we expect. We have very intelligent students in our classes and really need to let them work through some of these issues without holding them back."

The second question presented two themes: (a) professional competency and (b) social responsibility (see Figure 2). Secondary themes that emerged reflected an increased understanding of how to improve one's lesson plan and implement these concepts in the classroom, as well as how to communicate with people outside the classroom regarding the importance of being aware of energy issues (e.g., developing renewable forms of energy). Regarding professional competency (implement concepts in the classroom) one teacher stated:

"In Integrated Curriculum Planning (ICP) and Environmental science, I teach - or will be teaching - about the different types of energy. I feel I have several ideas I can implement into my classes and have resources with the information from others on the website."

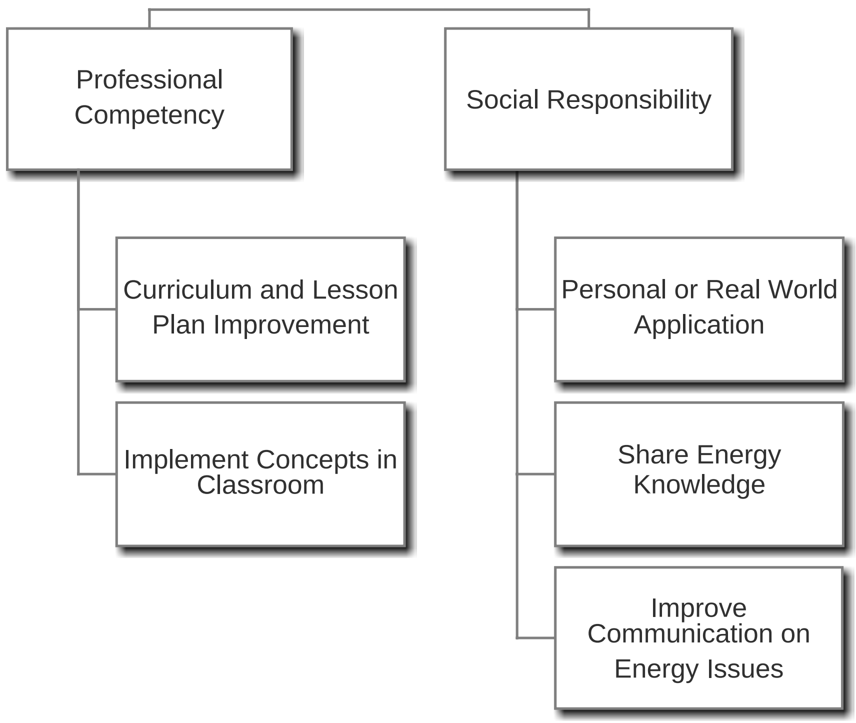

Figure 2. Primary and secondary themes for use of knowledge gained

The last question in the interview revealed three thematic areas: (a) educational support system, (b) teacher professional development and (c) student engagement (see Figure 3). Secondary themes that are related to inadequacies in teachers' support systems reflected issues such as lack of time and instructional resources, and a perceived mismatch between energy-based lesson plans and Indiana state curricular standards. Regarding the latter, one teacher stated:

"Fitting into a curriculum with Indiana Department of Education (IDOE) standard where energy is not addressed (is a problem). Much of what I teach is online curriculum that does not concentrate on energy."

4. Discussion

The purpose of this study was to test the effectiveness of DEAP programs to increase teacher's knowledge and self-efficacy in energy science. The result of this study showed that teacher's knowledge of energy science before (T1) and after completing the DEAP program (T2) increased significantly, therefore hypothesis 1 was supported. This finding is consistent with previous studies that demonstrate the effectiveness of intensive informal programs for STEM teacher professional development across different program designs [4], [10], [11], [12].

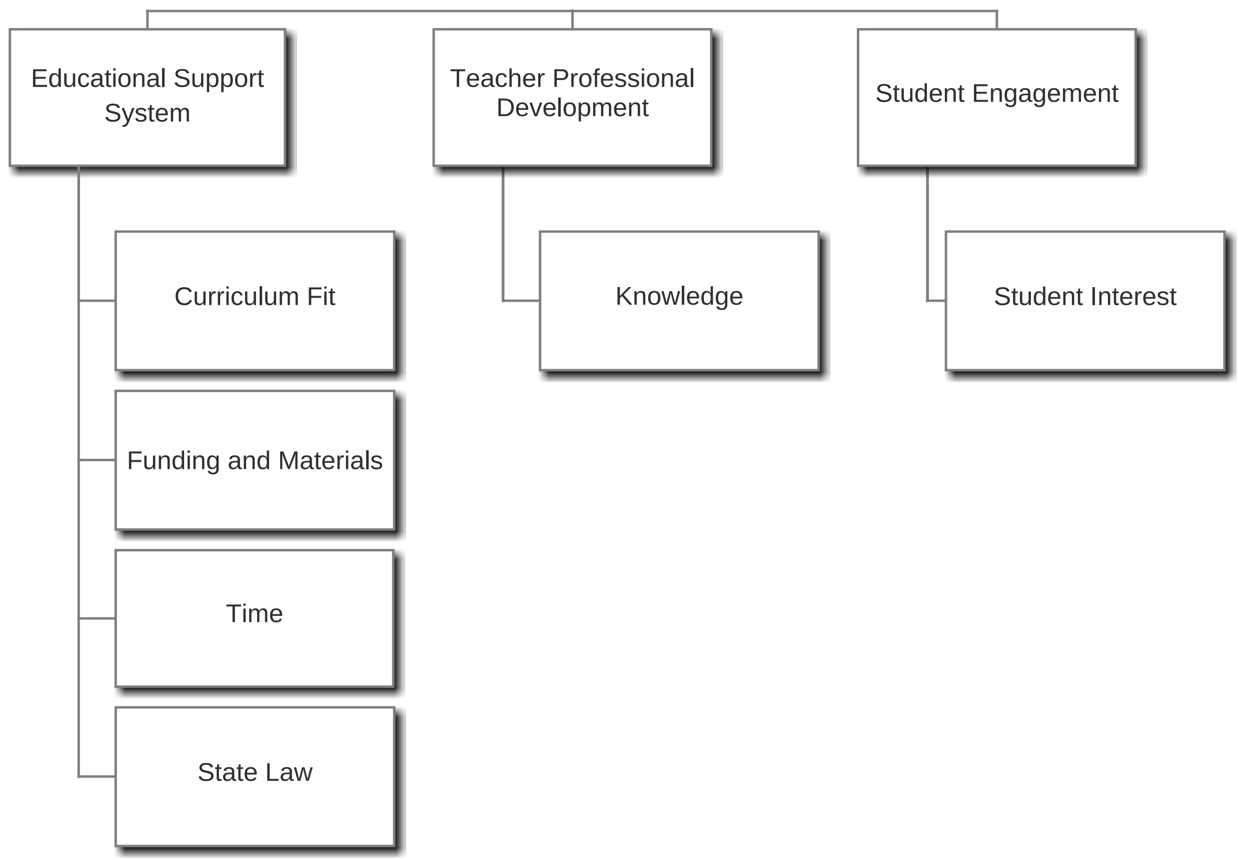

Figure 3. Primary and secondary themes for barriers to implementation

Qualitative analysis from this study elaborated further on general knowledge about energy themes gained by the teacher participants throughout DEAP program activities. Teachers reported learning ways of making energy more accessible and operationalization of energy industries on production, transmission, and distribution. Teachers also learned various energy sources (e.g., fossil, solar, wind) and developed a new awareness of energy impact on the real world and how to harness alternative sources of energy. Teacher began to reevaluate current energy production methods that are insufficient to maintain sustainability of energy resources in the future under the environmental constraint (e.g. climate change).

The current results also supported hypothesis 2, namely, that teacher self-efficacy would show significant growth throughout the program. The average score of teacher self-efficacy from repeated measures of ANOVA analysis showed a significant difference from the beginning (T1) to the end (T2) of the program. Improvement in teacher self-efficacy as a result of the professional development program is also found in previous studies that implement teacher professional development programs for various STEM subjects such as environmental science [2], food science [11], and reading literacy [10], [12]. Analysis of participants' responses to the post-program survey suggested that teachers intend to use their gained knowledge to improve their professional competency by strengthening their overall teaching by connecting concepts and strategies through all topics, finding creative ways to expose their student to energy fields, improving their student understanding of energy issues. Teachers hoped to implement several new ideas in the classroom with additional resources from the websites, and to apply their developed STEM lesson plan during the program by reworking their energy unit in Integrated Curriculum Planning (ICP). Further analysis on the qualitative data acquired from the survey questionnaires also suggested several important themes in terms of knowledge gained, use of knowledge gained and barriers to implementation that warranted further discussion. These themes are described below:

A. Networking

One of the core purposes of this STEM program was to introduce teachers to a number of energy experts including business professionals, university professors, graduate students, technical experts in the field, and senior teachers who completed the program in the past and returned to serve as mentor teachers for the incoming teacher participants. Participant interaction with experts in energy topics during lectures, hands on activities, tour into facilities and companies increased their awareness on the many unexpected important pieces of information they can get from energy experts. Establishment of contacts in energy industries led to further involvement of the energy experts as guest speakers in the classroom session and student collaborators in the future. Early career teachers also voice their appreciation of gaining a lot of teaching guidelines practice, classroom procedures problem-solving, and lesson improvement from interacting with mentor teachers who had experienced similar programs in prior years. Another teacher was also able to receive a grant through information shared by fellow teachers during the DEAP program.

B. Classroom Application

Teacher participants in this STEM program were engaged in co-learning mode with high school student participants throughout most of the program activities from lectures and discussion, to field trips and working in a hands-on energy related project. Through their information from lectures, tours, new exposures to lab activities, energy-generating sources and mechanical tools the teachers were inspired to develop new ideas of incorporating energy related topics and closing the gaps between theoretical and real-life application of energy source in their classroom. At the same time, they also learned practical application and innovation that can be included in their own subject teaching curriculum. Teacher involvement in hands-on activities with the students allow an access into the student's true cognitive abilities, which expands the teacher's flexibility and options to create new labs for designing energy sources with their students. Teachers also improve design classroom experiences with less structure that allows for independent and creative learning as well as project-based learning that involves teacher-student collaboration.

C. Career Knowledge

The STEM program exposed teacher participants to different types of energy topic related professional careers that spread across work settings, job structures and technical expertise or skills requirements. These types of careers include academic positions such as graduate students and university professors or lecturers, technicians and supervisors in the field, and business professionals who manage and lead well known energy industries and power plants. Teachers learned that energy sectors are looking for workers who have a sufficient education. Careers in energy science have changed gradually over the years due to the changing nature of energy infrastructure where engineering and information technology skills are intertwined on the operational level. While early generations who have struggled to keep up with the new and sophisticated technology begin to decrease in numbers, future generations who grow up surrounded by advanced information technology will swiftly adapt to the changing nature of work in this energy science field.

D. Social Responsibility

The STEM intensive program increased teacher participants' understanding on the development of energy resources, consumption, and application for daily life activities. Teachers' improved knowledge leads to the development of positive attitudes and actions toward energy fields. Some teachers tend to discuss energy education that is beyond teaching the students in the classroom but also to their school administrators and colleagues. The teachers believe that their new knowledge had improved their articulation as discussion leaders. Other teachers were acting toward promoting this STEM program to their colleagues so that they can learn and experience first-hand in order to enrich their lesson plans. Several teachers decided to apply this energy knowledge to their personal life and the real world such as auditing energy and making changes in local districts as well as spending more time on alternative energy than before. Other teachers who participated in the past have also successfully written research grant proposals and eventually received a grant to build a solar panel in coordination with the high school arts students and solar wind turbine for their energy house.

E. Educational Support System

Beyond their knowledge gained and intention to use the knowledge in the STEM intensive program, teacher participants were also able to consistently identify the barriers that are part of an educational support system such as curriculum fit, funding and materials, time availability, and state laws. Teachers described that incorporating energy-related topics as they learned during the program will be a challenge not only because current standardized and established curriculum in various different subjects are intensive in their own content, but there is a difficulty in integrating and differentiating instruction on energy problems within these subject's curriculum. Furthermore, the Indiana Standard on ICP no longer includes clean energy or sustainability that have presented issues for administrators. Despite their belief in the importance of energy education to their students, many teacher's efforts to implement energy topics have been limited by time constraints. Some energy topics require investigative activities that take more time. The established curriculum also covers a large quantity of materials; therefore, a time slot for introducing or expanding topics on energy may not be available. Even if the time is available, teachers may have to choose between depth and breadth issues. Another identified barrier is funding, resource, and materials being used in the knowledge implementation process. Limited resources, supplies, and funding have been hindering teachers' aim to incorporate hands-on activities, technologies, and lab kits in their classroom design, especially in a school system where the majority of students come from disadvantaged socioeconomic backgrounds.

F. Teacher Professional Development and Student Engagement

Teachers' roles as professionals who want to deliver classsroom materials to the students effectively requires basic and expanding knowledge in regard to the subjects they teach to the students. Despite the teachers' successful completion of the STEM intensive program, the teachers understand that their lack of awareness, knowledge, and resources about the subject will be the biggest obstacles in delivering energy learning to students. While the school may provide some resources for teachers, they also need to take initiative to gain knowledge of their teaching subjects. Delivering learning materials to students in the classroom does not solely depend on the teacher and content of the subject curriculum but also involves student interest, which may be affected by other factors. Teacher participants' challenge is to create engaging hands-on activities that integrate energy concepts

5. Conclusion

The results of DEAP seven-year study from 2012 to 2018 suggested that teachers' self-efficacy prior to the program and teacher knowledge acquisition after the program were both positive predictors of teacher self-efficacy following the program. This result implies that teachers need to acquire both content and pedagogical knowledge that are specific to energy science to increase their confidence in teaching energy science regardless of their previous backgrounds and knowledge. On the practical level, the DEAP program also successfully expands teacher knowledge beyond learning energy science as a classroom material. Increased awareness of energy acquisition, maintenance, and infrastructure development enhance the teacher's initiative to have social responsibility as the social agent to promote energy awareness and natural resources conservation to the general public, colleagues and future generations of students. The teacher also gained professional resourcefulness through networking with professional colleagues and influential top management positions in the energy industries who will serve as their support in their future professional careers. Despite the educational system barrier and limited resources that appear to be continually present as challenges to implement energy science materials in classroom settings, teachers had acquired learning experiences to improve their lessons plans and deliver them in creative and innovative ways.

The results suggested that gaining specific knowledge in energy science is a very important piece to be added to teacher's confidence and positive attitude toward general science teaching. The DEAP program expands teacher knowledge of content and pedagogical knowledge in energy science and increase teachers' confidence in teaching energy science-related concepts in their classrooms. This particular study also confirmed the predictive value of knowledge gained as a significant contributing factor to teacher self-efficacy whereas previous studies have focused on measuring the association between these variables without further investigating causal connections between knowledge and self-efficacy. This study did not measure content knowledge and pedagogical knowledge separately to understand how each knowledge type contributes to self-efficacy. Knowing what proportion of each type of knowledge contributes to teaching self-efficacy would allow greater flexibility in designing future programs depending on which knowledge type is emphasized. Longitudinal studies on measuring teacher self-efficacy following the DEAP program would also enhance our understanding of the extent to which the mastery experiences acquired in DEAP have an enduring impact on teacher self-efficacy.

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