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ARTICLE

The Grand Challenge: Helping Teachers Learn/Teach Cutting-Edge Science via a PBL Approach

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A mixed-methods research study was designed to examine teachers' knowledge and confidence for implementing a STEM-based problem-based learning (PBL) unit in their 6–12 grade science and math classrooms. Twenty-one teachers (7 in-service and 13 pre-service) participated in an intensive two-week summer workshop during which they engaged in, and then created, an immersive PBL unit related to sustainable energy. Data were collected through a pre-post content knowledge test and two pre-post surveys—one measuring knowledge and confidence for implementing PBL and one measuring science teaching efficacy. Daily reflections and focus group interviews provided additional data regarding teachers' changing knowledge and confidence related to both content and PBL methods. Results revealed significant gains in content knowledge related to concepts in energy, confidence for implementing PBL, and science teaching efficacy. Implications for the professional development of rural STEM teachers and the importance of engaging teachers in a professional development experience that integrates STEM content and PBL methods also are discussed.

Keywords: STEM PBL, in-service teachers, pre-service teachers

Recent data from national and international reports (National Center for Educational Statistics, 2008; National Science Board, 2008) suggest that U.S. high school students continue to perform poorly in science subjects and to hold low aspirations for becoming science majors or entering science careers. Given this, numerous programs have been initiated across the country to enhance K–12 science learning and increase students' interest, motivation, and aspirations for careers in STEM (science, technology, engineering, and mathematics) fields (National Academies, 2007; National Research Council, 2012). However, despite this national push to increase STEM learning in K–12 schools, rural students still appear to be "underserved and underrepresented in the teaching of STEM" (Avery & Kassam, 2011, p. 2). Due to a number of factors (such as reduced state funding, outdated infrastructure, and high teacher turnover), rural students often lack access to effective STEM education (Barley, 2009; Mollekopf, 2009).

Engaging Rural Students in STEM content: The Potential of PBL

According to Avery and Kassam (2011), rural students are likely to embrace STEM subjects, majors, and careers if STEM instruction is made relevant to their daily lives as well as the economic viability of their communities. Because many of the grand challenges facing the world today (such as climate change or energy supply) have direct implications for rural life in terms of both job growth and career opportunities, it is important to engage students in efforts to address these challenges. For example, many of the rural communities in Indiana are involved in providing resources for sustainable energy through crop production and wind farm development. By examining specific sustainable energy concepts, students and teachers in these historically isolated districts can begin to understand how they can play an important role in the future economy of the state, as well as the nation as a whole. Connecting the cutting-edge research in bioscience to the core curricula for high school students can motivate student learning by demonstrating both the urgency and the significance of the needed solutions.

The challenge for STEM educators, however, is to connect these grand societal challenges to STEM content in ways that are relevant to students' current lives as well as effective in motivating and preparing them to tackle future challenges in STEM fields. One curricular model that holds strong potential is technology-enhanced problem-based learning (PBL), which promotes students' active construction of knowledge

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through engagement in meaningful problem solving (Hmelo-Silver, 2000). A PBL curriculum is organized around a series of ill-structured, authentic problems that encompass discipline-based content (Ertmer & Simons, 2006). Students learn to analyze these problems, using authentic tools of the discipline (primary source documents, graphing calculators, scientific probes, etc.), in order to identify what information they need, how to integrate facts and concepts from different disciplines and sources, and how to evaluate the strength of their proposed solutions. In addition, the curriculum is structured to foster group work, self-directed learning, critical thinking, and self-reflection (Hmelo-Silver & Barrows, 2006).

Technology plays a key role during the PBL process, serving as an important tool for both teachers and students (Park & Ertmer, 2007). For teachers, technology supports both the planning and implementation processes. Not only can teachers use technology to access specific background information about the issue/problem to be addressed, but they also can use it as an authentic means to introduce and engage students in the problem (Kim et al., 2011; Liu, 2002). For students, technology can increase their engagement in the problem (Liu, Horton, Olmanson, & Toprac, 2011; Zumbach, Kumpf, & Koch, 2004), as well as scaffold their efforts during the problem-solving process (for example, through use of thinking aids such as calculators, concept-mapping tools, or computer-based scaffolds; Kim & Hannafin, 2011). In addition, technology can support students' organization and collaborative efforts, allowing them to interact with both local and distant peers and experts and providing the means to track their progress over time.

Evidence has shown that PBL is effective in helping students learn both discipline-based content and higher-order thinking skills including problem solving, critical thinking, and decision making (Glazewski & Ertmer, 2010; Mergendoller, Maxwell, & Bellisimo, 2006; Murray & Savin-Baden, 2000). Furthermore, there is evidence to suggest that PBL can help both pre-service (Park & Ertmer, 2007) and in-service teachers (Derry, Siegel, Stampen, & the STEP research group, 2002) change their ideas about how to structure instruction in their current and future classrooms. The emphasis in PBL on student-centered learning requires teachers to explicitly confront the traditional paradigm typically used in classrooms today (Barrett, 2005; Park & Ertmer, 2007).

In addition to helping teachers confront their pedagogical beliefs (Ertmer, 2005), PBL offers an assortment of strategies and techniques that can be applied within a variety of teaching approaches. Facilitation strategies, including questioning, are examples of key components of PBL that also have value in other instructional settings (Bhattacharyya & Bhattacharya, 2009; Savery, 2006; Zhang, Lundeberg, McConnell, Koehler, & Edberhardt, 2010). Other examples include classroom management (Bhattacharyya & Bhattacharya, 2009; Thomas, 2000), collaboration (Hmelo-Silver, 2004), assessment (Macdonald, 2005; Thomas, 2000), integration of interdisciplinary material (Hmelo-Silver, 2004), scaffolding and building on students' prior knowledge (Simons & Ertmer, 2005; Thomas, 2000), and the integration of technology (Bhattacharyya & Bhattacharya, 2009; Thomas, 2000). Additionally, PBL offers ideas for fostering student reflection and metacognition (Hmelo-Silver, 2004), as well as helping students take responsibility for their own learning (Yadav, 2011). Thus, courses such as the one described in this study offer in-service and pre-service teachers a vehicle for engaging their students with content and pedagogy in a collaborative, technology-enhanced environment designed to foster student learning (Bhattacharyya & Bhattacharya, 2009).

However, teachers' ability to implement PBL effectively is dependent on a number of factors. Chief among these are teachers' confidence for, and abilities to 1) assume a facilitative role (Ertmer & Simons, 2006; Hmelo-Silver & Barrows, 2006), 2) transition students into more active, accountable roles (Glazewski & Ertmer, 2010; Grant & Hill, 2006), and 3) design and implement alternative assessment measures that adequately capture growth in both student knowledge and problem-solving skills (Grant, 2011). In addition, teachers must be confident of their own STEM knowledge (Kolodner et al., 2003) and be willing to engage students in topics with which they, themselves, may have had little experience (Organization for Economic Cooperation and Development [OECD], 2009). According to Brush and Saye (2000), "successfully implementing student-centered learning requires skills and resources that are very different from those required by more traditional, teacher-centered classroom activities" (p. 80).

Research Purpose and Questions

This research was motivated by the need to improve rural STEM teachers' abilities to engage their students in global issues such as climate change and renewable energy. Although PBL methods offer a viable approach for introducing these issues in the context of meaningful problems that encompass students' subject area courses (e.g., biology, physics, chemistry, math, technology), learning outcomes ultimately are dependent on teachers' confidence and ability to implement PBL effectively, as well as their understandings of the specific content being targeted by the PBL unit. As part of a two-week summer course that simultaneously addressed the content area of sustainable energy and a PBL approach to teaching, we examined changes in teachers' confidence for using PBL methods to teach this content in their future 6–12 grade science and math classes. Specific research questions included:

1. What is the impact of a two-week summer course on pre- and in-service teachers' knowledge and confidence for teaching specific STEM content?
2. What is the impact of a two-week summer course on teachers' confidence for using technology-enhanced PBL methods in their middle and high school classrooms?
   a. With which aspects do they feel most comfortable?
   b. With which aspects are they most concerned?
3. What is the relationship between teachers' STEM knowledge and confidence and their PBL knowledge and confidence?

Methods

We used a mixed methods research design to examine teachers' knowledge and confidence for implementing a STEM-based PBL unit in their high school or middle school classrooms following an integrated summer workshop focused on teaching STEM content through a PBL approach. Data collection focused on the pre-service and in-service teachers who participated in the workshop. For consistency, the terms participants or teachers are used to refer to this group. The term student is used to refer to the 6–12 grade students who will eventually participate in these PBL activities. The term instructors refers to both the content and PBL faculty who led the workshop. Table 1 summarizes the data sources used to examine teachers' knowledge, perceptions, and confidence related to both sustainable energy content and PBL methods.

Context: Conceptual Framework

This research is part of a larger NSF I-3 project, *Research Goes to School*, designed to provide cutting-edge science content to rural middle and high school STEM teachers. More specifically, the project aims to enable teachers to transform their curricula by developing and implementing PBL units that address the grand challenge of sustainable energy in order to help their 6–12 grade students embrace the relevance of math and science in their daily lives. Drawing on work at Purdue's *Center for Direct Catalytic Conversion of Biomass to Biofuels* (C3Bio), the goal is to enable both teachers and students to explore the scientific and technological challenges related to increasing the efficiency by which biomass is converted to fuel (Agrawal, Singh, Ribiero, & Delgass, 2007). Not only does this topic have the potential to engage students in the interdisciplinary nature of research (Wyman, 2009), but it also is likely to be directly relevant to rural students, many of whom have lived or worked on farms that grow soybeans and corn.

Participants

Twenty-one teachers participated in EDCI 62700, *Problem-based Learning in the Science and Math Classroom*, a two-week intensive course offered in summer 2011. Seven of the participants were in-service teachers (3 male, 4 female), currently teaching in rural districts across the state. Thirteen were second-career pre-service teachers (9 male, 4 female), currently completing their master's degrees, and who had been hired by various rural districts to begin teaching the subsequent fall. In general, participants taught more than one subject (e.g., chemistry and physics), and more than one grade level (see Table 2).

In-service teachers were selected via an application process; pre-service teachers comprised the second cohort of the Woodrow Wilson Fellowship Program at Purdue University, which is designed to bring highly qualified STEM teachers into rural secondary schools. In addition, one male

Table 1. Data collection instruments.

Instrument	Data Collected/Measurement	Participants	Research Question
Content Knowledge Test	Teachers' content knowledge related to sustainable energy (pre and post)	21	RQ1
Science Teaching Efficacy Beliefs Instrument (STEBI)	Teachers' content confidence (pre and post)	21	RQ1
PBL Survey	Teachers' PBL confidence and knowledge (pre and post)	18	RQ2
Workshop Daily Reflections	Teachers' changing knowledge and confidence related to both content and PBL	21	RQ2
Focus Group Interviews	Teachers' changing knowledge and confidence related to both content and PBL (post)	11	RQ1 & 2
PBL Unit (developed, in groups, in the workshop)	PBL knowledge (post)	21	RQ2

pre-service teacher participated who, as an undergraduate sophomore, was just beginning his math and science teaching methods courses. Additional demographic details are included in Table 2.

Context: Summer Workshop

Participants met daily over nine days for approximately 6.5 hours each day. The primary goal of the course was to enable teachers to develop a PBL unit, relevant to their designated curricula, which revolved around issues related to the conversion of biomass to biofuels. To support teachers in these efforts, a number of activities were facilitated: teachers participated in a mini-PBL unit, listened to a variety of guest speakers (both content- and PBL-focused), and engaged in activities related to both content (field trips, lab experiments) and PBL (gallery walk, designing rubrics). A majority of the time during the second week was devoted to the development and refinement of teachers' PBL units. Participants worked in self-selected groups of three; as much as possible groups were composed of teachers from the same discipline, although some cross-disciplinary teams were formed. In general, pre- and in-service teachers worked together, although two teams were not mixed.

Table 2. Demographic details for research participants.

Descriptions	In-service (n=7)	Pre-service (n=14)	Total (N=21)
Gender			
Male	3	8	11
Female	4	6	10
Ethnicity			
White/Caucasian	7	13	20
Other	-	1	1
Years Spent Teaching in Current School			
2 years	1	N/A	1
5 years	1	N/A	1
8 years	1	N/A	1
11 years	2	N/A	2
No Response	2	N/A	2
Subjects Taught in Past Year			
Biology	5	4	9
Earth Science	3	2	5
Engineering	-	2	2
Chemistry	1	4	5
Mathematics	1	4	5
Physics	2	2	4
Technology	-	3	3
Other subjects	3	2	5
Grade Levels Taught			
9th grade	4	13	17
10th grade	5	10	15
11th grade	7	11	18
12th grade	7	13	20

The course was co-taught by a content expert and a PBL pedagogical expert, both faculty members. In addition, assistance was provided by a graduate student with expertise in both PBL and chemistry, two graduate students with expertise in STEM content areas (biology, chemistry), an undergraduate student majoring in biology education, and a middle school STEM teacher. As much as possible, the instructors modeled a PBL approach during the course and engaged teachers in the types of activities (use of a driving question, mini-lectures, ongoing formative assessment using detailed rubrics) that the teachers were expected to develop and implement in their own classrooms. Technology was integrated, when appropriate, throughout the workshop (e.g., digital probes, video, Blackboard course site), although little time was given to actually teaching about the technology. Teachers created their PBL units using Google Sites so they could be readily accessed and modified after the workshop.

Table 3 summarizes the key workshop activities. In general, each class session began by debriefing the previous day's activities and addressing any concerns raised in the teachers' reflections. This was typically followed by a specific energy activity and/or fieldtrip. During the first week of the workshop, teachers worked in small groups to explore different types of renewable energy including solar, wind, and water. In the second week, the focus shifted to PBL, with a different component emphasized each day. Guest speakers (content and PBL experts) were included each day during lunch. These guest presentations were followed by a short debriefing session designed to help participants examine how they could apply the information or activities to their own units and classes. Each day also provided time for groups to work on their PBL units.

Data Collection and Analysis

To answer the knowledge component of research question 1, a 30-item, multiple-choice pre-post content assessment was used. The content assessment was created and validated by the Environmental Literacy and Inquiry Working Group (Bodzin, 2011; Bodzin, Fu, & Peffer, 2012; Bodzin, Peffer, &

Kulo, 2012). Initial review of the instrument by a panel of five earth and environmental scientists and science educators ensured content accuracy, alignment with benchmark ideas drawn from the *AAAS Atlas of Science Literacy Maps* (2007), and construct validity. After pilot testing, the revised instrument was validated in 2010 with 1,043 students in five middle schools in two cities in the northeast. Total score reliability (Cronbach alpha) was .776. For our purposes—measuring changes in teachers' knowledge of sustainable energy—we modified the original instrument by removing nine items that did not relate to topics covered in the course. Cronbach alpha for the modified instrument was .73 at the time of the pre-test and .48 at the time of the post-test. The lower reliability measure at the time of the post-test could mean the instrument is not stable, or may be due to our small sample size. Regardless, interpretations of teachers' content test performance should be made with caution.

The pretest was completed on the first day of the course, prior to engaging in any other course activities. The posttest was completed on the last day of the course after the teachers had presented their final units to their peers. Sample questions included: Which of the following is NOT a renewable biofuel? [4 answer choices provided]; Photovoltaic cells convert [choose one of 4 possible answers] directly into electricity. To compare pre-post differences on the content assessment, responses were scored as 1 (correct) or 0 (incorrect) and summed for a total score. A paired *t*-test was used to examine the statistical differences (if any) between pre-post means.

The confidence portion of our first research question was examined using the *Science Teaching Efficacy Beliefs Instrument* (STEBI) developed by Riggs and Enochs (1990). The STEBI was modeled after scales "designed to measure self efficacy and outcome expectancy beliefs for teaching behaviors in general" (Gibson & Dembo, cited in Riggs & Enochs, 1990, p. 627). There are two versions of the instrument: STEBI-A for in-service teachers and STEBI-B for pre-service teachers. Both versions consist of 22 items, rated on a 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*), with the in-service version referring to actual teacher practices and the pre-service version referring to intended practices. In addition to the 22 similar items, the in-service version had an additional item ("Even teachers with teaching abilities in science/math cannot help some students learn science/math."), which was not included on the pre-service instrument. This study used only the 22 items that appeared on both versions. Items were divided into two subscales reflecting: 1) personal science teaching efficacy (n = 12 items, such as "I will continually find good ways to teach science," and 2) science teaching outcome expectancies (n=10 items, such as "When the science grades of students improve, it is most often due to their teacher having found a more effective teaching approach."). The Personal Science Teaching Efficacy subscale reflects teachers' beliefs about their personal abilities to affect science learning, whereas the Science Teaching Outcome Expectancy subscale reflects teachers' beliefs about whether student learning can be influenced by effective teaching

Table 3. Key workshop activities.

Activity	Description
Content Area Speakers	Scientists described the biology, chemistry, economics, etc. involved in the C3Bio Project
PBL Speakers	K–12 teachers, currently using PBL approaches in their classrooms, shared their experiences and resources
Energy Activities/Fieldtrips	Teachers in the course participated in hands-on activities and fieldtrips
PBL Unit	Websites created by each group included the following PBL components: driving question, objectives and standards, student activities (e.g., investigations, grouping strategies, and scaffolds), materials and resources, implementation management plan (e.g., timeline, debriefing, questioning), evaluation plan and materials
Individual Reflections	Teachers wrote individual explanations of how each of their unit components modeled PBL best practice
Small Group Presentations	Small groups explored a specific renewable energy source and presented their findings to the class
PBL Presentations	Instructors made short presentations and facilitated activities on PBL components (e.g., gallery walk for developing driving questions, brainstorming characteristics that make a specific PBL component effective, evaluating sample facilitation and questioning videos)
Unit Presentations	Teachers presented their group units to the class, as well as invited guests, on the last day
Technology Resources	Instructors modeled various tools and resources throughout; teachers built their units using technology as an implementation tool

(Riggs & Enochs, 1990). Although originally developed for use with elementary teachers, the STEBI has since been used by numerous researchers to examine science teacher efficacy (Anderson, Dragsted, Evans, & Sorensen, 2004; Enochs, 1999; Khoury-Bowers & Simonis, 2004; Lumpe, Haney, & Czerniak, 2000).

Changes in teachers' confidence for using PBL in their classrooms were assessed using a 15-item pre-post survey that had been developed and piloted by the authors the previous summer. For the first 14 items, participants rated their levels of confidence for performing tasks in the PBL environment on a 5-point scale, from 1, not at all confident, to 5, extremely confident. Alpha coefficients were .90 for both the pre-test and posttest, suggesting a highly reliable instrument. The fifteenth item asked participants to rate their perceptions of their current knowledge of PBL on a 5-point scale from 1, extremely low, to 5, extremely high. To examine changes from pre- to post course, participants' responses were summed for a total score and then compared using a paired-*t* test. Although the total score provided a general measure of teachers' overall confidence for using PBL, comparison of pre-post scores on individual items provided a more detailed understanding of teachers' confidence for implementing specific components of an effective PBL unit (e.g., developing a driving question, scaffolding students' inquiry).

Finally, two data sources were used to triangulate findings related to the sub-questions for research question 2 (that is, teachers' perceptions of comfort and concern for teaching biofuels content using a PBL approach): teachers' daily reflections and focus group interviews. At the end of each day's session, the teachers were asked to respond to two to six questions. Reflections included both general (e.g., What are your thoughts about PBL? Based on today's activities, what additional comments or suggestions do you have?) and specific (e.g., What are the goals of biofuels research and how are they accomplished? What did you learn about the economics of energy?) questions. As illustrated by these sample questions, participants were prompted to think about both PBL and STEM content, as well as to consider how the two could be integrated in their units (e.g., How could you use information from today's biofuels presentation in your PBL unit?). Reflections were analyzed using a simple pattern-seeking approach, that is, we looked for commonalities among responses to each question to illustrate participants' perceptions of the workshop activities and to provide recommendations for changes in future workshops.

Two 75-minute focus groups were conducted by the project's internal evaluator and another staff member at the end of the summer workshop, one for in-service teachers and one for pre-service teachers. Participants (n = 5 pre-service and 6 in-service teachers) were asked to provide their thoughts about the workshop, lessons learned, implementation plans, and perceived benefits and challenges to implementing the PBL biofuels unit. Each session was audiotaped and transcribed. Data were analyzed using open coding, to identify initial themes and patterns, followed by constant comparison methods (Creswell, 2009), to combine codes and create categories of similar themes. An additional researcher, not involved in the initial data analysis, reviewed the codes and themes and collaborated with the internal evaluator to reduce the data into the final categories.

Research question 3 was examined using Pearson correlations. Participants were classified as either a 1 (pre-service teacher) or 0 (in-service teacher), and then the total (e.g., content knowledge) or average (e.g., PBL, STEBI surveys) scores were used for each of the variables under consideration.

Legitimation in Mixed Methods Research

Given that our research methods involved both quantitative and qualitative methods, we examined issues of legitimation, using the framework proposed by Onweugbuzie and Teddlie (2003). According to these authors, researchers continuously strive to assess and document the legitimacy (e.g., "validity, credibility, trustworthiness, dependability, confirmability, and transferability") of their methods and their findings (p. 354). Onweugbuzie and Teddlie noted that mixed methods studies have increased legitimation over pure quantitative or qualitative studies because they integrate data/information from both approaches. This comparison of information across types of sources corresponds to Lincoln and Guba's (1985) description of triangulation, which included the comparison of data from different sources. In this study, we compared findings from our quantitative instruments with the patterns and themes that emerged from our qualitative data sources using a constant comparative approach (Creswell, 2009), with each being used to triangulate or check what the other indicated. In addition to the use of triangulation among different data sources, legitimation of the study was strengthened by triangulation among four different researchers.

Results

Changes in Teachers' STEM Knowledge and Confidence

Changes in STEM knowledge

Results from participants' pre and post-knowledge tests showed an average gain, from pre to post-workshop, of 1.8 points on a 30-item knowledge test related to sustainable energy, which was significant for the combined sample (pre- and in-service teachers) at the .02 level ($t = -2.65$). On the pretest, scores ranged from 10 to 27, with an average of 23.3. Post-test scores ranged from 21 to 30 with an average of 25.1. When analyzing the data separately for in-service and pre-service teachers, the results showed significant pre-post increases for in-service but not pre-service teachers (see Table 4). Interestingly, a one-way ANOVA of group differences in gain scores showed no statistically significant group differences ($F = 0.002$, $p > 0.05$), suggesting that both groups increased in their content knowledge even though the pre-post change was more pronounced among in-service teachers.

Data from the focus group interviews support the observed pre-post significant increases in content knowledge. Both pre- and in-service teachers indicated that the workshop gave them a better understanding of the concepts of sustainable energy, including the conversion of biomass to biofuels, and distinctions among the fuels made from biomass. Participants also reported that they learned important facts about sustainability. However, it is important to note that sample sizes for these focus group interviews were small and thus may not be representative of all participants. A few sample comments, taken from the six in-service teachers who participated in the focus group interview, include the following:

> "I learned a lot about the C3Bio at Purdue and the Chemistry department mainly and in particular how to convert biomass into biofuel."

> "There were some very interesting, specific things about the science side of things that I picked up on that were enjoyable."

> "I didn't know that we were only getting 30% efficiency out of our ethanol, of our corn . . . I didn't realize how much electricity we lost in the power lines, I knew it was inefficient, but I didn't know it was more than 50%."

Sample comments from the five pre-service teachers who participated in the focus group interview included:

> "I knew there was a number, but I didn't have it in mind, but he said by the time [you] load the biomass and drive it, say 80 miles, uh, 50 miles, you've now burned more energy trucking it than is in it."

> "[Prior to this class], I didn't know the difference between biodiesel and biofuels."

Changes in STEM confidence

As reported by the authors (Goodpaster et al., 2012) in a previous paper, statistically significant pre-post increases were observed for the combined groups (in-service and pre-service teachers) on the STEBI Science Teaching Outcome Expectancy (OE) subscale but not on the Personal Science Teaching Efficacy (SE) subscale. ANOVA analyses revealed non-significant group differences (that is, in-service versus pre-service) in gain scores for both subscales (OE: $F = 4.04$, $p = .06$; SE: $F = .11$, $p = .75$). For specific details about these results, please refer to the Goodpaster et al. (2012) report.

Changes in Teachers' PBL Knowledge and Confidence

Changes in PBL knowledge

A two-tailed paired t-test ($df = 17$) indicated a significant increase in participants' ratings of *knowledge* of PBL ($t = 2.83$; $p = .006$) from pre- to post-course. Average ratings of knowledge increased from 3.06 to 3.83 on a 5-point scale. Although separate paired sample t-tests revealed significant increases in pre-post perceptions of knowledge for pre-service and not in-service teachers, a one-way ANOVA showed no statistically significant differences ($F = .35$; $p = .57$) in pre-post gains across groups (see Table 5).

Data from the post-course focus group interviews also suggest that the program enhanced participants' understanding of problem-based learning and how to implement PBL units in their classrooms. In-service teachers indicated that they learned new teaching strategies; for example, they spoke about their excitement in using "exit tickets" to motivate their students to work and check for comprehension at the end of class. Sample comments from the in-service teachers include:

> "I've had an introduction to inquiry-based learning before, but have just had pieces and parts, and it's never been in any kind of order. This was in an order and it encompassed everything that we needed to know in order to carry out a problem-based unit. And everything to plan it and everything to finish it up, just to wrap it

Table 4. Effects of workshop on teachers' biofuels knowledge.

Total score on content test		Pre		Post		Gain	t
	N	M	SD	M	SD	1.8	
All participants combined	21	23.33	3.61	25.14	2.48	1.86	2.65*
In-service teachers	7	24.71	1.80	26.57	2.07	1.86	3.65*
Pre-service teachers	14	22.64	4.13	24.43	2.41	1.79	1.77

Note: Maximum possible score on content test = 30; * = significant at $p < .05$.

up and leave it a neat little package. So that was very helpful."

"I think for me, the fact that we were actually immersed in problem-based learning. It wasn't something we were shown. It's just like what we are going to expect our children to do, our students to do. It was modeled for us and now that our product is just about finished, it's kind of exciting."

Pre-service participants also mentioned that the program enhanced their teaching skills and provided them with practical opportunities to develop lesson units—a skill that is necessary for successful teaching careers. Sample comments from the pre-service teachers include:

"I felt like it was good for me to practice more. I haven't done a lot of unit planning. I didn't do as much as probably they did in their student teaching. So just to have that opportunity to do it and not only do it by myself but to do it with a group of people helped me out."

"We learned, we did a lot of inquiry-based stuff."

"We're all very interested in this type of a program, I think especially some of us with industry experience; this feels more like what we're used to. It's not necessarily what we had in school, but it is more like what we find in the workplace, and this has given us some of the skills and tools to develop this."

Finally, PBL units created by the teachers suggested the ability to apply knowledge gained from the workshop to the development of their own PBL units. While some units were more complete than others, all included the primary components related to the driving question, student activities, implementation strategies, and an evaluation plan. Although we were not able to evaluate teachers' implementation of their units, the final products created by the teachers indicate sufficient knowledge of PBL to allow effective implementation.

Changes in PBL confidence

Scores on the 14 items of the PBL confidence survey were added and averaged to account for those with missing values on one or more of the items. A two-tailed paired *t*-test ($df = 17$) indicated a significant increase in participants' ratings of overall *confidence* for implementing PBL in their classrooms ($t = 7.61$; $p < .000$) from pre- to post-workshop. Average ratings of confidence increased from a mean of 2.98 ($SD = .36$) to 3.99 ($SD = .18$) for the combined sample (see Table 5).

Separate analyses of pre-post changes in total scores for in- and pre-service teachers also showed statistically significant gains in confidence for both groups. A one-way ANOVA examining possible group differences in average gains in confidence showed no statistically significant differences ($F = 3.34$; $p > 0.05$). This suggests that the impact of the program on PBL confidence was similar for both pre- and in-service teachers.

To explore pre-post differences further, a paired samples *t*-test was conducted to examine differences in pre-post responses to confidence ratings on individual items, as shown in Table 6. The results revealed statistically significant differences for all 14 items for the combined group. Post-participation confidence ratings were significantly higher than pre-participation ratings.

Confidence and Concern for Implementing Specific PBL Components

As illustrated by PBL confidence scores listed in Table 6, participants rated their post-confidence at the highest levels ($M = 4.00$ or greater on a 5 point scale) for items related to using the Internet to find PBL materials ($M = 4.61$) as well as to access state and national standards ($M = 4.89$). This indicates that the technology-embedded approach utilized in

Table 5. Changes in teachers' knowledge and overall confidence for implementing problem-based learning.

	N	Pre		Post		Gain	t
		M	SD	M	SD		
Average knowledge score							
Combined sample	18	3.06	1.11	3.83	0.71	0.78	2.83*
In-service teachers	7	3.29	0.95	3.86	0.90	0.57	1.08
Pre-service teachers	11	2.91	1.22	3.82	0.60	0.91	2.89*
Average confidence score							
Combined sample	18	2.98	0.908	4.00	0.43	1.02	7.61***
In-service teachers	7	2.92	0.59	4.23	0.41	1.30	5.25**
Pre-service teachers	11	3.02	0.64	3.85	0.39	0.83	6.29***

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

the workshop helped participants feel more confident using technology to prepare their lessons. Teachers also rated their confidence at relatively high levels for using questions to prompt higher-order thinking ($M = 4.06$) and facilitating student questioning in an ill-structured environment ($M = 4.00$). As noted by one pre-service teacher in her Day 3 reflection: "Group discussion is critically important in order to link content with the 'messing about' activity. How questions are asked is also important. Let students answer rather than answering as the teachers." Another pre-service teacher noted the impor-

Table 6. Pre-post changes in teachers' confidence for implementing individual components of PBL.

Items	N	Pre		Post		t
		M	SD	M	SD	
Developing problems for student-based inquiry	18	2.89	0.90	3.78	0.65	5.78***
Developing driving questions	18	2.72	0.90	3.86	0.72	6.68***
Mapping inquiry activities to unit objectives	18	2.94	0.94	3.89	0.59	4.27**
Using Internet to find PBL materials	18	3.44	1.25	4.61	0.61	4.51***
Using Internet to find state/national standards	18	4.39	0.78	4.89	0.32	2.70*
Developing scaffolds to support students' content learning	17	2.53	0.87	3.88	0.70	5.28***
Developing scaffolds to support students' inquiry	18	2.44	0.92	3.81	0.71	5.34***
Developing scaffolds to support students' metacognition	18	2.39	0.85	3.78	0.73	5.15***
Effectively facilitating PBL discussion	18	2.72	1.07	3.78	0.65	4.04**
Using questions to prompt higher order thinking	18	3.39	0.85	4.06	0.64	3.69**
Facilitating student questioning in ill-structured environment	18	2.61	0.92	4.00	0.77	8.44***
Providing ongoing formative feedback to students	18	3.28	0.83	3.83	0.77	2.23*
Creating rubrics to assess learning	17	3.18	0.95	3.88	0.93	3.17**
Developing/implementing alternative assessment measures	17	2.76	1.15	3.85	0.82	4.11**

Note: t = T statistic; PBL = problem-based learning; * = significant at $p < .05$; ** = significant at $p < .01$; *** = significant at $p < .001$.

Table 7. Group differences in gain scores on confidence of implementing PBL components.

Items	Combined		Pre-service		In service		F
	M	SD	M	SD	M	SD	
Developing problems for student-based inquiry	0.89	0.68	0.64	0.50	1.29	0.76	4.83*
Developing driving questions	1.14	0.72	0.96	0.78	1.43	0.53	1.94
Mapping inquiry activities to unit objectives	0.94	0.94	0.64	0.92	1.43	0.79	3.50
Using internet to find PBL materials	1.17	1.10	0.91	1.22	1.57	0.79	1.61
Using internet to find state/national standards	0.50	0.79	0.46	0.82	0.57	0.79	0.90
Developing scaffolds to support students' content learning	1.35	1.06	1.00	1.00	2.00	0.89	4.16+
Developing scaffolds to support students' inquiry	1.36	1.08	0.96	1.06	2.00	0.82	4.91*
Developing scaffolds to support students' metacognition	1.39	1.14	0.82	0.75	2.29	1.11	11.28**
Effectively facilitating PBL discussion	1.05	1.10	1.09	1.30	1.00	0.82	0.03
Using questions to prompt higher order thinking	0.67	0.77	0.63	0.67	0.71	0.95	0.04
Facilitating student questioning in ill-structured environment	1.39	0.70	1.18	0.60	1.71	0.76	2.75
Providing ongoing formative feedback to students	0.56	1.06	0.46	0.72	0.71	1.50	0.25
Creating rubrics to assess learning	0.71	0.92	0.82	0.60	0.50	1.38	0.45
Developing/implementing alternative assessment measures	1.09	1.09	1.14	1.14	1.00	1.10	0.06

Note: M= Mean; SD= Standard deviation; *= $p < .05$; ** = $p < .01$; + = $p = 0.059$; F= ANOVA F statistic.

tance of debriefing: "Debriefing after a project is very important so students get a chance to reflect about what they did."

At the time of the posttest, participants showed the lowest levels of confidence ($M = 3.78$) on three items related to 1) developing problems for student-based inquiry, 2) developing scaffolds to support student metacognition, and 3) effectively facilitating PBL discussions. This may simply be a function of the relatively low levels of confidence participants had for these specific PBL components at the time of the pretest ($M =$ 2.89, 2.39, and 2.72, respectively). Although the participants made significant gains by the end of the course, there was still room for growth.

Table 7 presents results of a series of ANOVA tests conducted to examine group differences in the confidence change scores (i.e., post minus pre-test scores) for implementing individual PBL components.

Overall, in-service teachers showed greater gains in confidence for implementing the various components of PBL than pre-service teachers (see Table 7). These differences were significant between groups on three items: 1) developing problems for student-based inquiry ($F = 4.83$; $p < .05$), 2) developing scaffolds to support student inquiry ($F = 4.91$, $p < .05$) and 3) developing scaffolds to support student metacognition ($F = 11.28$, $p < .01$). On all three items the in-service teachers made greater gains than the pre-service teachers. As noted by one pre-service teacher in his Day 4 reflection: "It's challenging developing activities that properly scaffold and allow students to construct their own knowledge while keeping the scope reasonable." Another pre-service teacher described being worried that "PBL won't fly without preparing the students to do inquiry, basic lab methods, and safe practice." A third pre-service teacher expressed concern that "students need to get the content out [of the activity] and not just have fun." It is clear from these teachers' reflections that they were not yet completely comfortable developing a unit that would effectively support students' learning within a PBL framework.

On three different items, pre-service teachers showed a higher, but insignificant, gain than the in-service teachers. These items included 1) creating rubrics to assess learning, 2) developing and implementing alternative assessment measures, and 3) effectively facilitating PBL discussions. One in-service teacher noted in her Day 5 reflection: "It's challenging creating a question that is ambiguous enough for students to form their own investigative question but focuses enough to ensure mastery of the targeted content/curriculum."

Relationship among Variables

In addition to teachers' PBL knowledge, PBL confidence, and content knowledge, we also collected pre-post data on teachers' science teaching self-efficacy beliefs, using the STEBI instrument described earlier (Riggs & Enochs, 1990); our findings regarding pre-post changes in science teaching efficacy have been reported elsewhere (Goodpaster et al., 2012). For the current study, we conducted correlation analyses to examine relationships among participants' specific science content knowledge, their science teaching efficacy, perceptions of PBL knowledge, overall PBL confidence (i.e., average on all 14 PBL confidence items), and teacher classification (i.e., pre- versus in-service teachers).

Students' classification as a pre-service or in-service teacher was not significantly correlated with any of the other measures. Although one might predict that in-service teachers would have greater content knowledge or confidence for using PBL or for teaching science, that was not the case in this study. There were no significant relationships between a participant's "classification" and any of the other variables examined in this study.

At the time of the pre-test, significant correlations were found between participants' ratings of their PBL confidence and their ratings of their PBL knowledge ($r = .60$; $p < .01$, see Table 8). In general, those who rated themselves as having greater levels of PBL knowledge also rated themselves as having higher levels of confidence for implementing PBL in their classrooms. This is not surprising as ratings of confidence are often determined by how knowledgeable you judge yourself to be in a given domain (Schunk, 2000). Also, at the time of the pre-test, a significant correlation ($r = .76$; $p < .01$)

Table 8. Correlation among variables: pre-test.

Variables	Classification	PBL Confidence	PBL Knowledge	Content Knowledge	Outcome Expectancy	Personal Efficacy
Classification	1.00					
PBL Confidence	-0.08	1.00				
PBL Knowledge	0.17	0.60**	1.00			
Content Knowledge	0.28	-0.01	0.14	1.00		
Outcome Expectancy	-0.39	0.18	0.01	-0.17	1.00	
Personal Efficacy	-0.13	0.76**	0.32	0.05	0.07	1.00

Note: Classification = pre- versus in-service; * = significant at $p < .05$; ** = significant at $p < .01$.

was found between PBL confidence and the STEBI Personal Science Teaching Efficacy subscale (i.e., teacher's judgments of their abilities to affect student science learning). Those who felt more confident implementing PBL also rated their abilities to impact students' science learning at higher levels. This possibly suggests that, at the time of the pre-test, participants judged that PBL teaching skills and science teaching skills were similar in nature, feeling relatively confident in their ability to be effective in both domains.

At the time of the post-test, there were no significant correlations among any of the variables examined (see Table 9). Only one variable, content knowledge, had a strong, but non-significant, relationship to a participant's "classification" (r = .42; p = .059). In general, in-service teachers were more likely to have greater content knowledge than pre-service teachers at the time of the posttest.

To get a better picture of how the participants changed over the duration of the course, we conducted an additional correlation using gain scores (see Table 10). There was a significant correlation between gains in teachers' ratings of PBL confidence and gains on the two subscales on the STEBI (r = .52, p < .05 on the Outcomes Expectancy Subscale; r = .68, p < .01 on Personal Efficacy Subscale). Participants with higher confidence for using PBL methods also tended to have higher confidence for affecting science learning and for believing that effective teaching can positively influence student science learning.

Discussion

Changes in Teachers' Content Knowledge and Confidence

Results indicated a significant gain in energy content knowledge for the combined sample of pre- and in-service teachers at the end of the workshop. Furthermore, pre-post changes were more pronounced for the in-service teachers. Some of the reasons for this effect may relate to the increased teaching experience and expertise of our in-service teachers. Others have observed relationships between content knowledge and both teaching experience and expertise, specifically within the context of biology (Gess-Newsome & Lederman, 1995; Khalick, 2006). In addition, the in-service teachers were less diverse than the pre-service teachers in terms of the subjects taught the previous year (see Table 2), perhaps providing them with a more developed framework, or a deeper content knowledge representation, upon which to build. However, as stated earlier, the results from this test must be interpreted with caution since the sample size was small and the reliability score suggested that the instrument could be unstable. Based upon the use of this instrument and demonstrated reliability from other studies (Bodzin, 2011; Bodzin, Fu et al., 2012; Bodzin, Peffer et al., 2012), the reliability scores obtained were more likely reflective of the small sample size.

Table 9. Correlation among variables: post-test.

Variables	Classification	PBL Confidence	PBL Knowledge	Content Knowledge	Outcome Expectancy	Personal Efficacy
Classification	1.00					
PBL Confidence	0.26	1.00				
PBL Knowledge	-0.05	0.22	1.00			
Content Knowledge	0.42⁺	0.04	-0.16	1.00		
Outcome Expectancy	-0.11	0.29	0.10	0.03	1.00	
Personal Efficacy	0.10	0.24	0.14	0.26	0.16	1.00

Note: Classification = pre- versus in-service; * = significant at p < .05; ** = significant at p < .01 and += p = 0.059

Table 10. Correlation among variables: gain scores.

Variables	Classification	PBL Confidence	PBL Knowledge	Content Knowledge	Outcome Expectancy	Personal Efficacy
Classification	1.00					
PBL Confidence	0.42	1.00				
PBL Knowledge	-0.15	0.39	1.00			
Content Knowledge	0.01	0.04	-0.11	1.00		
Outcome Expectancy	0.44	0.52*	-0.01	-0.10	-1.00	
Personal Efficacy	0.08	0.68**	0.31	0.19	0.34	1.00

Note: Classification = pre-versus in-service; * = significant at p < .05; ** = significant at p < .01

In addition, as reported by Goodpaster et al. (2012), significant gains were observed in STEM confidence, as measured by the outcome expectancy subscale (but not the self-efficacy subscale) of the STEBI (Riggs & Enochs, 1990). As stated by Bandura (1997), and discussed by Cantrell, Young, and Moore (2003), personal self-efficacy is the "belief in one's capabilities to organize and execute the courses of action required to produce given attainments, whereas outcome expectancy is a judgment of the likely consequence such performances will produce" (p. 177). Our results suggest that the teachers believed their units would produce strong learning outcomes for their students but were less convinced of their abilities to effectively teach the PBL units. It is quite possible that the two-week workshop was insufficient to produce a significant change in self-efficacy because participants did not have the opportunity to implement their units with students. Perhaps if the STEBI were administered after classroom implementation, we would observe an impact on the self-efficacy subscale. This would support the observations of Cantrell et al. (2003) who found larger effect sizes in science teaching efficacy when participants had spent time actually "teaching science to children in an elementary classroom" (p. 188). Others have reported that variables such as gender, number of science courses taken, and positive school science experiences can impact science teaching efficacy (Bleicher, 2004). Since the pre-and in-service teachers were diverse, these variables may also have impacted the results we obtained.

Changes in Teachers' PBL Knowledge and Confidence

At the end of the two-week workshop, participants rated their knowledge of PBL at a significantly higher level than at the beginning of the workshop. Engaging participants in the PBL process and requiring them to apply their knowledge to the development of their own units appeared effective in increasing their perceived understandings of "how to do PBL." This is not surprising as best practices in teacher professional development emphasize the importance of engaging teachers in both active and collaborative design work (Garet, Porter, Desimone, Birman, & Yoon, 2001; Koehler & Mishra, 2005). Specifically, results from a recent meta-analysis demonstrated that PBL is effective when participants engage in design problems (d = 0.74; Walker & Leary, 2009). In this study, participants engaged in the design problem of developing an authentic PBL unit for their own students. Using a similar approach, Walker et al. (2011) reported significant gains in teachers' PBL knowledge after participating in a professional development workshop in which they designed and later implemented PBL units.

Overall confidence for implementing PBL also increased significantly from pre- to post-workshop. However, participants' responses to individual items uncovered nuances in ratings of confidence. For example, at the time of the posttest, participants' ratings ranged from 3.78 to 4.89 on a 5-point scale, suggesting that they felt more confident implementing some aspects of PBL than others. Although a lot of time was spent during the workshop helping participants learn how to facilitate student inquiry, including the development and use of specific scaffolds, it is likely that in the two-weeks timeframe teachers did not gain sufficient understanding to enable them to feel as confident implementing these aspects. Previously, Ertmer and Simons (2006) reported the difficulties teachers face transitioning into these types of facilitative roles. In addition, in this study, teachers did not get the opportunity to *practice* facilitating student inquiry, thereby giving them less concrete information on which to base their confidence ratings. As noted by Bandura (1997), one of the best ways to increase confidence is by engaging participants in actual mastery of the task. Unfortunately this was not possible in the summer workshop setting.

In addition, there were noted differences between the pre- and in-service teachers on individual confidence ratings. On all but three items, the in-service teachers showed greater gains at the time of the post-survey. It is plausible that the in-service teachers' prior classroom experiences and existing pedagogical content knowledge (Shulman, 1987), enabled them to glean more from the workshop than the pre-service teachers. According to Crawford, (1999) "pre-service teachers typically struggle with many pedagogical issues" (p. 176). However, it is noteworthy that the workshop was able to help both groups of teachers grow in confidence regarding pedagogical skills that could be transferred to a variety of settings.

Relationships among Variables

At the time of the post-test, a significant correlation was noted between gains in overall PBL confidence and gains on the two subscales on the STEBI (see Table 8), suggesting that as teachers gain confidence in one area (e.g., implementing PBL in the classroom), they also feel more confident that their students' learning will benefit from effective science teaching (outcome expectancy) and that they have the *personal* ability to positively impact their students' science learning (personal efficacy). Although judgments of efficacy are commonly believed to be context-specific (Henson, 2002), Bandura (1997) argued that efficacy judgments *may* transfer between domains, especially if those domains share common characteristics. In this study, participants learned about PBL while also learning new STEM content. One of the main goals of the workshop was to simultaneously increase teachers' knowledge of both STEM and PBL so that they, in turn, could use the same methods to teach STEM content to their students. In this way, efficacy for effective STEM teaching and for using PBL may have become intertwined. That is, specifically demonstrating/modeling how to teach science and math content via PBL methods may have led to simultaneous increases in teachers' confidence for both using PBL and for teaching STEM. Confidence is known to increase by observing effective models (Schunk, 2000). Furthermore, according to Henson (2002), teachers with high efficacy/confidence tend to "experiment with methods of instruction, seek improved teaching methods, and experiment with instructional materials" (p. 128). Similar results have been reported for pre-service teachers (Tribble, cited in Henson, 2002). As such, increases in teaching efficacy may correspond to increases in efficacy for using new instructional methods, including PBL.

Limitations and Suggestions for Future Research

Given the relatively small number of participants in this study, results are not readily generalizable. In order to verify these results, a larger sample is needed. In addition, our participants were all teachers assigned to teach, or currently teaching, in rural schools. It is unclear whether or how this specific teaching context impacted our findings. Comparisons with teachers assigned to urban or suburban schools would shed additional light on this question. Finally, we were unable to capture observation data to verify the extent to which teachers actually implemented their PBL units in their STEM classrooms. Gathering follow-up observation data would enhance our understanding of how the knowledge and confidence gained during the 2-week workshop translated into classroom practice. Future studies are also needed to gather *student* data to verify how K-12 rural students engage in these PBL units, as well as the impact of these units on their STEM learning and their motivation for learning future STEM content and/or for pursuing STEM careers.

Implications and Conclusions

The results of this study have implications for the professional development of rural STEM teachers. Engaging pre- and in-service teachers in a professional development experience that integrates STEM content and PBL methods has the potential to simultaneously increase their knowledge of both STEM content and PBL. In addition, this approach can increase teachers' confidence for being effective science teachers. According to the Carnegie Commission on Mathematics and Science Education (CCMSE, 2009), "no school factor is more important to learning than the quality of their teachers" (p. 34). If we are to improve STEM learning for all our students, we must "increase the supply of teachers who have strong working knowledge of mathematics and science *and* the pedagogical techniques necessary to teach math and science effectively" (p. 35). Based on the results of this study, a two-week PBL/STEM integrated workshop offers a promising method for achieving both increased content knowledge and increased understanding of effective pedagogical techniques among STEM teachers.

Traditional approaches to teaching science typically have involved learning facts about science (CCMSE, 2009), as opposed to engaging in science. However, the National Research Council (1996) has long stressed the importance of engaging learners in "inquiry into authentic questions generated from students' experiences" (pp. 32–33). In this study, participants learned new STEM content by engaging in the kind of experiences they were expected to provide for their students. This, then, increases the likelihood they will employ similar techniques in their own classrooms (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). As noted earlier, making STEM instruction relevant to rural students' lives increases the likelihood they will pursue STEM majors and careers (Avery & Kassam, 2011). Helping teachers experience these kinds of engaging activities, themselves, is a critical first step in effecting the kind of changes recommended for the K–12 classroom. According to CCMSE (2009), students and parents give high marks to teachers who use engaging instructional practices, such as PBL. Furthermore, students who rate their science teachers highly are more likely to see math and science in their futures.

Although pre- and in-service teachers both gained STEM and PBL knowledge through the two-week workshop, there were differences among groups, suggesting that professional developers should consider their individual, in addition to, shared needs. According to Crawford (1999), inquiry-based instruction challenges even "the most expert of teachers" (p. 175). As noted by Dexter, Anderson, and Becker (1999), "For teachers to implement any new instructional strategy, they must acquire new knowledge about it and then weave this together with the demands of the curriculum, classroom management, and existing instructional skills" (p. 223). Given that pre-service teachers are novices in all aspects of classroom instruction, they are more likely to require additional mentoring and support as they implement innovative approaches in their STEM classrooms. This is not to suggest that in-service teachers will not struggle, only that they are likely to face different challenges, perhaps related to changing from traditional or comfortable approaches to those with which they are less familiar and/or confident. It is important that professional developers be prepared to support teachers' various needs in ways that are most relevant to them.

Given the severe shortage of highly qualified STEM teachers in classrooms today, as well as noted weaknesses in terms of both content and pedagogy for many career teachers in STEM fields (CCMSE, 2009), it is important to empower our future STEM teachers to make STEM learning exciting, accessible, and challenging for all students. As stated by Carnegie/Institute for Advanced Study (2011), “tools are needed that deepen teachers’ STEM knowledge and help them deliver personalized, rigorous STEM learning to all students” (p. 12). An integrated PBL/STEM approach may offer one of best tools available at this time.

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