Professional Development Through Engineering Academies: An Examination of Elementary Teachers’ Recognition and Understanding of Engineering

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BACKGROUND
K-12 teachers typically lack formal instruction on engineering. To address this issue, the Institute for P-12 Engineering Research and Learning (INSPIRE) developed engineering academies for elementary teachers. During 2006 and 2007, 40 teachers participating in the academies each completed an engineering photo journal.

PURPOSE (HYPOTHESIS)
The purpose of this study was to investigate the influence of week-long engineering summer academies on elementary teachers’ recognition and understanding of engineering in the world around them.

DESIGN/METHOD
The change in teachers’ recognition and understanding of engineering in the world around them was measured by analyzing pre/post academy engineering photo journal entries using the Revised Bloom’s Taxonomy as a framework to code the journal responses. Paired t-tests were conducted and effect sizes calculated to determine change from pre to post academy for each academy year, and for each Revised Bloom’s Taxonomy Cognitive Level.

RESULTS
Results showed teachers demonstrated change in understanding after participation in the engineering academies. Further, 2007 teachers showed greater change than did 2006 teachers. Overall, teachers demonstrated significant changes in the Cognitive Levels of Remember, Analyze, and Evaluate during the academies.

CONCLUSIONS
The photo journal and corresponding coding scheme were used successfully to measure teachers’ change in recognition and understanding of engineering. These tools helped INSPIRE researchers to better understand teachers’ abilities to communicate engineering ideas. These tools will be useful in classroom settings to assess teacher and student ideas and understanding about engineering.

KEYWORDS
Bloom’s Taxonomy, elementary engineering education, teacher professional development

INTRODUCTION
The Institute for P-12 Engineering Research and Learning (INSPIRE) was established at Purdue University to help promote engineering learning in the elementary classroom. During the 2006 and 2007 summers, INSPIRE hosted two engineering academies for local elementary teachers. Both academies focused on enabling teachers to integrate
engineering into their existing school curriculum by helping them become better able to recognize and talk about the presence of engineering in the world around them. This paper investigates teachers' abilities to recognize and understand engineering in everyday life, pre and post, as measured by a coding system based on the Revised Bloom’s Taxonomy (Anderson & Krathwohl, 2001) as well as by teachers’ written journal responses to a photo journal project.

**Background**

The American education system faces an important challenge—preparing future teachers to educate the next generation of graduates to be able to make informed decisions about their academic and career pathways, with particular regard to opportunities in science, technology, engineering, and mathematics (STEM). This challenge will require a pool of teachers who are skilled in STEM subject matter. Studies in science and mathematics indicate that there is a connection between teachers’ preparation with, and attitudes towards, these subjects and students’ achievements and continued pursuit of these subjects (Downing, Filer, & Chamberlain, 1997; Hill, Rowan, & Ball, 2005).

John Brighton, former Assistant Director for Engineering at the National Science Foundation, in his keynote address to the 2004, Salt Lake City ASEE Leadership Workshop, expressed the opinion that, “no one should have to wait until after high school to be exposed to engineering” (as cited in Douglas, Iverson, & Kalyandurg, 2004, p. 4). Brighton implied that engineering education must start earlier in students’ academic careers. Research indicates that students are able to handle scientific subject matter such as physics, programming, and higher order mathematics as early as elementary school (Rogers & Portsmore, 2004). If elementary teachers do not feel adequately prepared to teach STEM subjects in the classroom, and therefore shy away from teaching these subjects, students will lack the exposure necessary to afford them the opportunity to later pursue careers in the STEM disciplines (Douglas et al., 2004).

**Theoretical Framework**

In this study we sought to assess elementary teachers’ abilities to recognize and understand engineering in the world around them, and chose The Revised Bloom’s Taxonomy as our theoretical framework. In 1956, Bloom developed The Taxonomy of Educational Objectives, better known as “Bloom’s Taxonomy,” which consisted of six hierarchal levels focusing on the cognitive domain: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (Bloom, 1956; Krathwohl, 2002). Educators primarily used the taxonomy to aid in the development of educational objectives. In 2001, Anderson and Krathwohl revised the original Bloom’s Taxonomy, and this revised version guided our study. The Revised Bloom’s Taxonomy also has six levels, but the original nouns were changed to verbs: Remember, Understand, Apply, Analyze, Evaluate, and Create.

Since its creation, Bloom’s Taxonomy has been used in a variety of educational settings including helping students learn to add complexity to their graduate level writing and self-evaluate their levels of cognition used in assignments (Athanassiou, McNett, & Harvey, 2003; Granello, 2001). Research indicates that as students move to higher levels of the Taxonomy, they begin to think and write in a more critical and complex manner, i.e., they produce more sophisticated work (Athanassiou, McNett, & Harvey, 2003; Granello, 2001). It was because of the hierarchal nature of Bloom’s Taxonomy, and its utility in education, that we chose to focus on this particular theory as a framework for assessing teachers’ pre and post engineering journal entries.
Research Questions

INSPIRE researchers wanted to understand the change teachers experienced during the engineering summer academies, as measured by their ability to recognize and understand the presence of engineering in the world around them. Therefore, the following three research questions guided this study:

1. Do teachers demonstrate change as measured by their ability to recognize and understand engineering in the world around them after participating in the INSPIRE engineering summer academies?
2. Do greater differences in teachers’ abilities to recognize and understand engineering in the world around them exist for either project year?
3. At which cognitive levels of Bloom’s Taxonomy do the teachers demonstrate change, and what was the nature of the change?

Change was defined as teachers’ abilities to recognize and understand engineering in the world around them and measured by movement to higher cognitive levels on the revised Bloom’s Taxonomy. Teachers demonstrated their abilities to recognize and understand engineering in the world around them through participation in a pre- and post-photo journal project in which they took photos of what they considered to be engineering. Then, in a journal, they described the engineering they photographed. We evaluated teachers’ journal entries for increased sophistication and evidence of higher-order thinking about engineering, as indicated by the Revised Bloom’s Taxonomy.

METHODS

INSPIRE, established at Purdue University in 2006, provides teacher professional development with engineering. Through week-long engineering summer academies, INSPIRE provides opportunities for elementary teachers to improve their STEM content knowledge and to learn to incorporate engineering into their existing curriculum. The academies have the following four learning objectives for teachers:

1. convey a broad perspective of the nature and practice of engineering,
2. articulate the differences and similarities between engineering and science thinking,
3. develop a level of comfort in discussing what engineers do and how engineers solve problems with elementary students, and
4. use problem-solving processes (i.e., science inquiry, model development, and design processes) to engage elementary students in complex open-ended problem-solving.

This study focused on the first learning objective, teachers’ abilities to convey a broad perspective of the nature and practice of engineering through the use of a photo-journal project.

Participants

Each summer in 2006 and 2007, a group of teachers spent a week on the Purdue University main campus attending an engineering academy. Teachers for this study were selected from each of the two years of summer academy participants. The study was approved by Purdue’s IRB and each participant signed a consent form prior to participating.

2006 summer academy. Thirty-three teachers and administrators attended the 2006 engineering summer academy, including teachers from grades Pre-K through grade eight. These 33 teachers and administrators came from 11 schools. The average teacher was 49 years of age and had been teaching for 24 years. The age of the 33 teachers ranged from
30–61 years, and 71% of the participating teachers held graduate degrees. For the 2006 INSPIRE academy, there were two curricula taught; one for teachers of grades Pre-K through grade four, and another for teachers of the upper grades. For this study, we elected to focus on data collected from teachers of grades K through grade four, because these teachers all participated in the same curriculum lessons, and all would return to teach in a general elementary classroom setting. We did not include data from the Pre-K teachers or administrators in our study, as these educators do not work in a regular classroom setting, and are not held to the same accountability standards as the K through fourth grade teachers. Additionally, we did not include in our study the data from the upper grade teachers, as they participated in a different curriculum than did the K through fourth grade teachers. This left us with 17 female, K through fourth grade teachers in the sample, who came from nine different schools. They averaged 51 years of age with 26 years of teaching experience. Ninety-four percent of them held graduate degrees.

2007 summer academy. As in 2006, the majority of the teachers (88%) who attended the 2007 INSPIRE engineering summer academy were female. There were 23 teachers who represented six schools, ranged in age from 24 to 58 years, and had an average age of 44 years. Their average number of years teaching was 17, and 58% of them held graduate degrees. All of the teachers who attended the 2007 engineering summer academy participated in the same curriculum lessons. Table 1 shows the number of teachers in this study by grade level who attended the 2006 and 2007 academies and participated in this study.

INSPIRE Academy Facilitators

According to Jeffers, Safferma, and Safferman (2004), many engineering faculty members lack the educational background and skills associated with teaching K-12 students. Therefore, the INSPIRE engineering summer academy staff was comprised of a

<table>
<thead>
<tr>
<th>Grade</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
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<td>3</td>
<td>2</td>
<td>5</td>
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<td>3/4</td>
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<td>4</td>
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<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>23</td>
</tr>
</tbody>
</table>
mixed group of engineers and educators representing both faculty and graduate students. The primary facilitators consisted of two tenured engineering faculty members (one food process engineer [female] and one mechanical engineer [male]), one tenured education faculty member (female), one engineering post-doc (female, 2007 only), two engineering graduate students (one male, one female), two education graduate students (one male, one female), and one practicing teacher (female). This balance of engineering and education experience enabled the academy facilitators to provide the teachers with a sense of both comfort and challenge by establishing a safe environment for the teachers to take risks in their questioning, their creating, and their learning.

The facilitators were responsible for developing the structure of the academies, planning and delivering content to the teachers, leading discussions, and monitoring sessions. Throughout the week, the facilitators conversed with the teachers and reported back to the INSPIRE group any problems or concerns that may have been raised. Additionally, facilitators inquired about the teachers’ comfort level with the pace and activities of the academies.

Treatment Description

To ensure program success, INSPIRE adhered to the six guidelines set forth by the American Society for Engineering Education (ASEE) Engineering K-12 Center for improving engineering education and outreach at the K-12 level (Douglas et al., 2004). These guidelines and how they were considered as part of INSPIRE’s engineering summer academies follow:

1. Hands-on learning: Throughout INSPIRE’s engineering summer academies, teachers collaborated on design tasks. Additionally, many of the activities were client-based, thus emphasizing the real-world connection of engineering.

2. Interdisciplinary approach: The teachers were provided opportunities to use writing, reading/literacy, and journaling, as well as the STEM subjects, to learn about engineering. Additionally, teachers were given opportunities to recognize engineering and technology in everyday items, thus enabling them to appreciate and utilize technology and engineering concepts in every subject area.

3. Standards: Each teacher in the summer academies brought a copy of the state educational standards. As a culminating activity, each teacher wrote science lesson plans that integrated the engineering curriculum taught during the week-long academy. Additionally, the content of the summer academy was based on National Council of Teachers of Mathematics (NCTM) and National Science Education Standards.

4. Use/Improve K-12 Teachers: In 2006 and 2007, 40 K through fourth grade teachers local to the university area were engaged in a week-long academy on engineering. As recommended by ASEE, teachers were provided a monetary stipend, granted continuing education credits, and given the opportunity to obtain graduate credits for attending the academy.

5. Make Engineers “Cool”: The teachers met and interacted with a diverse panel of practicing engineers.

6. Partnerships: INSPIRE partners with the College of Engineering, the School of Engineering Education, the College of Education, local and national school districts at the K-12 level, and local and national organizations.

By adhering to these six guidelines, we felt we had provided an environment conducive to teacher learning about the many aspects of engineering in the world around them.
2006 Summer Academy

The 2006 engineering summer academy was hosted by INSPIRE on Purdue University’s main campus for local elementary school teachers from a particular school district. The academy was one week long (Monday through Friday) and teachers participated in academy activities beginning at 7:30 a.m. and ending at 5:00 p.m. each day. In addition to the academy class hours, the teachers were given homework assignments such as reading, lesson planning, and journaling. For the 2006 academy, there was no screening process—the academy was open to all teachers local to the Purdue University area who expressed interest in attending, and who completed an application. Teachers who participated received continuing education credits, classroom materials, as well as a stipend for attending the academy.

During the 2006 engineering summer academy, the primary curriculum components were design activities and Model-Eliciting Activities (MEAs) (Lesh, Hoover, Hole, Kelly, & Post, 2000). The K through fourth grade teachers worked with a design curriculum entitled, “Milton is Missing” (Haines-Allen & Beck, 2006). The theme of this curriculum focused on a camp raccoon mascot, Milton, who was stolen from a rival campsite. The teachers participated in several design activities to help find Milton. One example of an activity that the teachers performed was to design a care package to send treats to Milton. Each team was given a certain amount of money to spend on packaging materials and a bag of potato chips to “mail.” They had to design the package to be the most durable for the least amount of money. These activities promoted the INSPIRE objective of helping teachers to convey a broad perspective of the nature and practice of engineering by providing opportunities to work within constraints, problem-solve, test, evaluate, and improve designs, and communicate ideas with teammates.

In addition to the design activities, teachers worked in teams to solve MEAs. MEAs are thought-revealing activities designed to be solved by teams of students (Lesh et al., 2000). These types of problems require students to work together on a complex problem to develop a mathematical solution. Though each MEA may elicit different solutions from each student team, each solution may prove to be mathematically correct. MEAs emphasize real-life problem solving skills, and stretch students’ mathematical reasoning beyond what is generally offered in mathematical textbooks (Lesh et al., 2000). One MEA that the teachers completed was the “Soccer Ball” MEA. In this activity, teachers were presented with the problem of needing to make as many soccer ball pattern shapes as possible from a fixed amount of material. Teachers were asked to write a procedure for fitting as many identical shapes as possible on a piece of paper (where the paper represented the material and the shapes represented the soccer ball pattern). They were then asked to write a letter to the client that included their procedure to maximize production and minimize waste. This problem focused on engineering principles, geometric principles, procedural writing, and addressed the core principles of MEAs. (For a full description of the curriculum used at the 2006 academy refer to Duncan, Oware, Cox, & Diefes-Dux, 2007). By working through the multiple steps of MEAs, considering different sets of mathematical data, and writing, testing, and revising their procedures, teachers were exposed to multiple facets of engineering.

2007 Summer Academy

In the summer of 2007, a second engineering academy was hosted by INSPIRE on Purdue University’s main campus for teachers local to the university area. In 2007, applications were accepted only from teachers who came in teams from the same school or school district.
district. By accepting “teacher teams,” we sought to provide teachers with peer support upon return to their classrooms. In 2007, the screening process became more selective and teacher participants were selected based on their ability to assemble a “teacher team,” interest in and knowledge of engineering, and willingness to implement engineering into their classroom curriculum.

As in 2006, the teachers completed design activities; however the 2007 INSPIRE engineering summer academy was based on the Engineering is Elementary (EiE) curriculum (Cunningham, 2004). These units each center on one engineering discipline (e.g., Mechanical Engineering or Environmental Engineering) and include lessons in science, language arts, reading, mathematics, and social studies. The teachers at the 2007 engineering summer academy were exposed to two EiE units: Mechanical Engineering and Environmental Engineering. Within each of these two units, the teachers completed a design activity.

For example, when working on the Mechanical Engineering unit teachers completed an activity in which they designed windmill blades. The teachers were asked to design a windmill blade system to attach to a milk carton base that would do the most work possible. The teachers designed blades and then inserted them into a Styrofoam ball attached to a dowel rod in a milk carton. There was a small cup of pennies hanging by a string from the other end of the dowel rod. A fan was turned on (to represent wind) and the device attempted to lift a load of pennies. The load was increased by 10 pennies until the system failed to raise the cup. The blade system that could do the greatest amount of work (raise the most number of pennies) was judged to be the best. Teachers had an opportunity to test their windmill blade systems and then redesign them to see if they could improve on their initial design. As in 2006, this design activity provided teachers with opportunities for problem-solving, teamwork, communication, working within constraints, and testing, evaluating, and improving ideas, all of which promoted the teachers’ abilities to convey a broader perspective of the nature and practice of engineering.

The teachers also completed an MEA titled the “Windmill MEA.” In this simulation, the teachers worked for a client known as Pond Savers. Pond Savers was described to them as a small company that distributes windmills to pond owners who are having problems keeping their ponds oxygenated. Pond Savers’ windmill manufacturer quit and the company needed to choose a replacement from a list of five manufacturers. The teachers’ choices were to be based on characteristics such as the number of windmills the manufacturer could produce in a week, durability of windmills, the length of time it took to ship the windmills, and how much the manufacturer charged per windmill. They were asked to write a procedure for choosing the best windmill manufacturer, and they were asked to ensure that the procedure would work even if new manufacturers were added to the list. Then they wrote a letter explaining their procedures to the client, Pond Savers, indicating the best choice for the new windmill manufacturer. Like the MEA that the teachers completed in 2006, this MEA also provided opportunities for procedure writing, testing, revising, communication, cooperation, and data analysis.

During both the 2006 and 2007 engineering summer academies, in addition to the design curricula and the MEAs, the teachers received instruction about the engineering design process and how it relates to the scientific inquiry process. They learned about engineering principles and processes, and ways that engineering is used in the world. The teachers attended a dinner with a panel of practicing engineers with whom they could discuss and ask questions about the education, training, and daily activities of an engineer. Finally, the teachers put into practice what they learned by teaching an engineering lesson to
a group of elementary aged students at a local day camp. These experiences, combined with the hands-on design activities and the challenging MEAs, provided teachers with opportunities to recognize and understand engineering in the world around them. They were able to see, hear about, and experience different aspects of engineering. These qualities of the academy not only aimed to help teachers to recognize and understand engineering in the world around them, but also to fulfill the first objective of the academy: helping teachers convey a broader perspective of the nature and practice of engineering.

Data Collection
Prior to the academies, each teacher was mailed a disposable camera and a blank journal. The letter that the teachers received read: “To document the INSPIRE summer academy participants’ ideas about engineering, the Institute assessment team is asking you to take photographs of scenes (i.e., items or events) that, in your opinion, relate to engineering. You will also record notes about each photograph in a photo journal.” The instructions for the photo journal project were:

1. Using the enclosed camera, have someone take one picture of you holding a piece of paper with your name in large print” (this photo was not used in the analysis).
2. Between now and the first day of the INSPIRE Summer Academy, take ten (10) additional photographs related to engineering. For each photograph, record the following in your journal (enclosed writing pad): the date the photo was taken, a description of the scene (e.g., location, background information), an explanation of how the scene relates to engineering. Note: There are no wrong or right types of photographs, so you do not need to use references.
3. Bring your camera and your photo journal to the INSPIRE Summer Academy. You will use the remainder of the roll of film during the week, and we will collect your camera and journal on the last day of the Academy. (INSPIRE, personal communication, June, 2006, 2007)

In the analysis, these are referred to as “pre” photos, as the teachers took them before engineering instruction. After the first day of the academy, during which teachers received a detailed introduction to engineering, INSPIRE facilitators gave teachers a second set of instructions. To complete the photo journal project, teachers were told:

Between now and the end of the last day of the INSPIRE Summer Academy, take ten (10) additional photographs related to engineering. For each photograph, record the following in your journal (enclosed writing pad): the date the photo was taken, a description of the scene (e.g., description, background information), and an explanation of how the scene relates to engineering. Note: There are no wrong or right types of photographs, so you do not need to use references. (INSPIRE, personal communication, June, 2006, 2007)

In the analysis section, these photographs are referred to as “post” photos, because teachers took them after engineering instruction. Each teacher’s photos were taken on the same disposable camera and the teachers recorded their responses in one journal.

Data Analyses
Coding scheme and inter-rater reliability. Prior to coding the journal text, it was necessary to establish an inter-rater reliability index. Two doctoral students with backgrounds in education and who each had more than two and a half years of training in K through six
engineering education coded samples of journal texts from teachers not included in the study (i.e., pre-K teachers, fifth through eighth grade teachers, administrators). The coders met three times to compute the inter-rater reliability index. During each of the first two meetings, 100 journal entries were coded, and then differences in the codes were discussed. To maintain high standards of reliability, the coders first calculated the reliability, and then had discussions about areas of disagreement (Weller & Romney, 1990). They tested the coding scheme on samples of text, assessed the reliability, and then revised the coding scheme (Weller & Romney, 1990). Because they used the six established cognitive levels of the Revised Bloom’s Taxonomy, the revisions to the coding scheme involved adding further clarifications to the explanations in order to make the coding scheme generalizable.

For the third meeting, 40 journal entries were coded, and these codes were used to compute the inter-rater reliability index. The coders first established an index of 0.80 by using the method suggested by Salkind (2006) and simply divided the agreements by the total number of coded entries (32 agreements/40 coded entries = 0.80 agreement). However, they acknowledged that some of these agreements could have occurred by chance; therefore, to account for this, they used Krippendorf’s alpha to establish inter-rater reliability. Krippendorf’s alpha provides a much more conservative measure of inter-rater reliability (Lombard, Snyder-Duch, & Bracken, 2008), and therefore the reliability index decreased from the original measurement to an index of 0.65. The coders suggest that the true inter-rater reliability lies somewhere in between the liberal measurement of 0.80 and the more conservative Krippendorf’s alpha of 0.65.

Coding. Using the final scheme presented in Table 2, the journal texts of the 40 teachers were coded. A total of 810 journal entries were coded for the analysis (i.e., 389 pre journal entries, 421 post journal entries), with each journal entry averaging one to two paragraphs in length. The coders utilized content analysis when coding the journal text. According to Merriam (1998), content analysis is quantitative in nature and the analysis is inductive. The coders were focused on the communication of the teachers and the frequency of the occurrences of indications of the six different cognitive levels, as provided in the Revised Bloom’s Taxonomy. Weller and Romney (1990) indicated that content analysis takes place on, “text or transcripts of human communications” (p. 10). The content analyzed came directly from the teachers in the form of written journals that accompanied photographs taken by the teachers.

The same two doctoral students who developed the inter-rater reliability coded the journal texts. They coded each journal entry as a whole text entry (Weller & Romney, 1990), assigning one code, the highest Bloom’s cognitive level demonstrated, to each entry. Weller and Romney indicated that high reliability can be achieved using whole-text coding when the text is short.

To assess if the teachers recognized and understood engineering in the world around them, the coders coded the journal text according to the Revised Bloom’s Taxonomy cognitive levels. They read the journal text and used the corresponding photograph that depicted the engineering scene to verify the journal text. We did not analyze the photos in addition to the journal text because the photos were not central to this study. We looked at the photos for each journal entry in order to understand what was being explained in the journal text; however, for this study, we were interested in the teachers’ abilities to explain, in words, the engineering that they saw in the world around them. As opposed to coding verbatim the words that the teachers used, the coders coded for application. For instance, when coding the Bloom’s cognitive level “Remember,” they were not interested in the
teachers’ use of the word “define,” but rather if the teachers “defined” something about engineering in their journal text. Additionally, within a single journal entry, a teacher may have had more than one Bloom’s cognitive level represented. In this case, though the coders coded each entry in its entirety, they counted only the highest Bloom’s cognitive level represented in each journal entry.

Anderson et al.’s (2001) research provided a framework for the investigation and helped guide discussions regarding the explanations of the Bloom’s cognitive levels, presented in Table 2. The examples of applications in Table 2 came from sources such as journals, books, and Web sites. These documented examples provided clarity and understanding of the teachers’ verbiage in their journals. The explanation column was developed as a result of the coding meetings. These were ways in which distinction was added to the Bloom’s cognitive levels without changing the integrity of the Taxonomy.

## ANALYSIS AND RESULTS

Teachers’ journal responses were coded according to the established coding scheme. Excerpts from the teachers’ journals, shown in Table 3, represent the five Bloom’s cognitive levels that were seen in the teachers’ journals. The Bloom’s cognitive level of “Create” was not demonstrated in the teachers’ journals. The underlined section of the sample of journal text highlights the attributes of the text that warranted coding it at the stated level.

### Table 2

Coding Scheme Based on the Revised Bloom’s Taxonomy

<table>
<thead>
<tr>
<th>Bloom’s Cognitive Level</th>
<th>Definition*</th>
<th>Examples of Applications**</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remember</td>
<td>“Retrieve relevant knowledge from long-term memory.”</td>
<td>Identify, list, define, repeat, name, recognize, recall</td>
<td>Participant offers little to no explanation of concept; simply names, lists characteristics of, or provides a simple definition of the object.</td>
</tr>
<tr>
<td>Understand</td>
<td>“Construct meaning from instructional messages, including oral, written, and graphic communication.”</td>
<td>Explain, express, discuss, describe, infer, summarize, report, interpret, compare, contrast</td>
<td>Participant begins to show understanding of the concept by offering an explanation or description and interpretation of the object, or the participant compares the object to another object (as in showing engineering progress over time).</td>
</tr>
<tr>
<td>Apply</td>
<td>“Carry out or use a procedure in a given situation.”</td>
<td>Apply, develop, use, show, illustrate, implement</td>
<td>Participant indicates a process or procedure (as defined by illustrating a minimum of three steps).</td>
</tr>
<tr>
<td>Analyze</td>
<td>“Break material into constituent parts and determine how parts relate to one another and to an overall structure or purpose.”</td>
<td>Differentiate, deduce, analyze, inquire, scrutinize, discriminate</td>
<td>Participant goes beyond noting the function of the object (describing) to explain the purpose (why the function is important to society).</td>
</tr>
<tr>
<td>Evaluate</td>
<td>“Make judgments based on criteria and standards.”</td>
<td>Appraise, evaluate, defend, judge, organize, plan, support, argue, propose</td>
<td>Participant ventures a personal judgment or critique about the object (e.g., faster, better, easier) in reference to another object, or in reference to how the object has improved/harmed society.</td>
</tr>
<tr>
<td>Create</td>
<td>“Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure.”</td>
<td>Assemble, construct, create, design, develop, formulate, generate, produce</td>
<td>Participant develops his or her own idea or hypothesis in reference to the photo. It could be a way to improve the object, new uses for the object, or an entirely new idea.</td>
</tr>
</tbody>
</table>

* The definitions used to define the Bloom’s cognitive levels are taken from (Anderson et al., 2001, p. 31). ** The examples of applications are taken from multiple literature sources: (Anderson et al., 2001; Krathwohl, 2002; Wilson, 2006).
A series of paired $t$-tests were used to answer the three research questions. Specifically, we used a $t$-test to determine if teachers’ abilities to understand and recognize engineering in the world around them occurred between pre and post occasions for the entire sample. We followed this with $t$-tests for each academy year to determine which of the two years resulted in the greatest pre/post effect. Finally, we used a series of paired $t$-tests to examine changes in the individual five coding categories from pre to post measures. Results follow, presented according to the specific research questions.

To answer Research Question 1, “Do teachers demonstrate change as measured by their abilities to recognize and understand engineering in the world around them after participating in the INSPIRE engineering summer academies?” we analyzed the data using a
paired $t$-test to determine if teachers demonstrated a change in understanding after participating in the INSPIRE engineering summer academies. To test our coded data using a $t$-test, we converted the Revised Bloom’s Taxonomy cognitive level categories assigned to each pre and post picture taken by teachers to numeric data. This was done by assigning the value of “1” to each “Remember” response, the value of “2” to each “Understand” response, the value of “3” to each “Apply” response, the value of “4” to each “Analyze” response, and the value of “5” to each “Evaluate” response. This conversion resulted in data similar to Likert and Likert-type data, which according to Floyd and Widaman (1995) are appropriate for use with quantitative methods requiring interval data and has been used by other researchers for the purpose of assigning value to the Bloom’s cognitive level categories (Almerico & Baker, 2004). Researchers widely use response-scale data in quantitative analyses (Gable & Wolf, 1993). Therefore teachers’ individual mean scores were the sum of their response scores divided by the number of codes (or pictures taken) pre and post.

We addressed Research Question 2, “Do greater differences in teachers’ abilities to recognize and understand engineering in the world around them exist for either project year?” in the same manner as Research Question 1. To follow-up the findings from Research Question 1, a paired $t$-test was run for each program year (i.e., 2006, 2007). These results are presented in Table 4, and means and standard deviations are presented in Table 5. Figure 1 presents a graphical representation of the differences in the means for the INSPIRE academies.

As indicated in Table 4, the teachers demonstrated statistically significant change in their abilities to recognize and understand engineering in the world around them after attending the INSPIRE engineering summer academies. Additionally, when Cohen’s $d$ was calculated, it became evident that these results are not only statistically significant, but also practically significant, with change in understanding approaching a full standard deviation ($d = 0.91$). As depicted in Table 5, the entire sample of teachers averaged 1.82 on the pre measure, or between Remember and Understand on the Revised Bloom’s Taxonomy when they explained their initial pictures. After participating in the academies, they averaged 2.41, or between Understand and Apply on the Revised Bloom’s Taxonomy.

Because we found significant changes in the teachers’ abilities to recognize and understand engineering when we combined the academy years for analysis, and because the curriculum differed each year, we followed up this initial finding with tests for each of the two program years. These results are also depicted in Tables 4 and 5. The teachers demonstrated significant change in both 2006 and 2007. However, the effect was much larger in 2007 than in 2006 as indicated by the Cohen’s $d$ effect size estimates (i.e., 2006, $d = 0.65$; 2007, $d = 1.28$).

### Table 4
Teacher Change in Understanding After Participation in the INSPIRE Academies

<table>
<thead>
<tr>
<th>Sample</th>
<th>$n$</th>
<th>$t$</th>
<th>$p$</th>
<th>$d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 &amp; 2007</td>
<td>40</td>
<td>-6.590</td>
<td>&lt;.0001</td>
<td>0.91</td>
</tr>
<tr>
<td>2006</td>
<td>17</td>
<td>-2.493</td>
<td>.0240</td>
<td>0.65</td>
</tr>
<tr>
<td>2007</td>
<td>23</td>
<td>-7.506</td>
<td>&lt;.0001</td>
<td>1.28</td>
</tr>
</tbody>
</table>
In 2006, post scores averaged 1.98 with only a 0.37 mean difference, and on the scale this difference indicated teachers’ mean Bloom’s cognitive level remained below Understand. Whereas in 2007, teachers’ mean scores grew from 1.98 pre to 2.72 post, indicating change in understanding of 0.74 or almost an entire Bloom’s cognitive level category change from just below Understand to just below Apply.

For Research Question 3, “At which cognitive levels of Bloom’s Taxonomy do the teachers demonstrate change, and what was the nature of the change?” we examined differences among the coding categories from pre to post to determine which cognitive levels of Bloom’s accounted for the changes in teachers’ understanding. To analyze these data, we converted teachers’ coded responses to percentages for each code for pre and post data. For example if a teacher took 10 pre photos as instructed and five of these photos were coded Remember, then 50% of this teacher’s pre photos were in the Remember category. We could then test each category pre and post using a paired \( t \)-test to determine whether statistically significant changes existed from pre to post for this sample of teachers. The paired \( t \)-test

<table>
<thead>
<tr>
<th>Sample</th>
<th>n</th>
<th>Pretest M</th>
<th>Pretest SD</th>
<th>Posttest M</th>
<th>Posttest SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006 &amp; 2007</td>
<td>40</td>
<td>1.82</td>
<td>0.51</td>
<td>2.41</td>
<td>0.74</td>
</tr>
<tr>
<td>2006</td>
<td>17</td>
<td>1.62</td>
<td>0.39</td>
<td>1.98</td>
<td>0.70</td>
</tr>
<tr>
<td>2007</td>
<td>23</td>
<td>1.98</td>
<td>0.55</td>
<td>2.72</td>
<td>0.61</td>
</tr>
</tbody>
</table>

**FIGURE 1.** Pre/post comparisons of means from the INSPIRE Academies
t-tests were conducted using ratio percentage data for each of the five Bloom’s cognitive levels (Remember, Understand, Apply, Analyze, Evaluate) represented in the teachers’ journals for pre and post content analysis using data combined from each of the academy years. Although the teachers were instructed to take 10 pre photos and 10 post photos, the number of photos they actually took varied, ranging from 8 to 11 (pre), and 7 to 16 (post). To convert these counts to percentages, we divided the number of responses for each category (pre and post) by the number of pictures the teachers took and multiplied this ratio by 100. This enabled us to test changes for each category from pre to post occasions to determine which categories contributed to the overall results seen in the analyses. Because we ran multiple t-tests on the same data set (i.e., five analyses), we adjusted our alpha measure using a Bonferroni adjustment and set alpha at 0.01 rather than the traditional 0.05, as we recognize that multiple tests can inflate alpha. Additionally, we reported and examined effect sizes to further explain the meaningfulness of our results. The results for the paired-sample t-tests are presented in Table 6 and the pre and post means and standard deviations are contained in Table 7.

As shown in Table 6, the paired t-test results indicated that statistically significant differences existed between the pre and post scores for three of the five Bloom’s cognitive levels (i.e., Remember, Analyze, Evaluate). Effect size calculations of Cohen’s $d$ indicated these results were practically significant, with the largest effect occurring for Analyze ($d = 0.78$), next largest for Evaluate ($d = 0.67$), and the smallest effect for Remember ($d = 0.53$), which was still an important finding. Essentially, after participation in the academies, teachers offered more explanations of their photographs that were judged at the Analyze and Evaluate levels, and they offered fewer explanations judged at the Remember level. Other levels, Apply and Understand, were non-significant. Figure 2 graphically displays the changes in average percentage for each of the five categories from pre- to post-test occasions.

**DISCUSSION**

INSPIRE was established to help promote engineering learning in the elementary classroom. During the summers of 2006 and 2007, elementary teachers participated in engineering academies and completed photo journal projects. These teachers, through their abilities to portray engineering through pictures and words, showed significant changes in the cognitive areas of Remember (negative change), Analyze, and Evaluate. This happened after their week-long exposure to engineering through design activities.

<table>
<thead>
<tr>
<th>Code</th>
<th>$n$</th>
<th>$t$</th>
<th>$p$</th>
<th>$d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remember</td>
<td>40</td>
<td>3.461</td>
<td>.001</td>
<td>0.53</td>
</tr>
<tr>
<td>Understand</td>
<td>40</td>
<td>0.441</td>
<td>.662</td>
<td>0.09</td>
</tr>
<tr>
<td>Apply</td>
<td>40</td>
<td>-1.732</td>
<td>.091</td>
<td>0.34</td>
</tr>
<tr>
<td>Analyze</td>
<td>40</td>
<td>-4.400</td>
<td>&lt;.0001</td>
<td>0.78</td>
</tr>
<tr>
<td>Evaluate</td>
<td>40</td>
<td>-3.385</td>
<td>.002</td>
<td>0.67</td>
</tr>
</tbody>
</table>
modeling activities, intense engineering instruction, collaborating with teammates, journaling, developing and teaching an engineering lesson, and interacting with practicing engineers.

Overall, when teachers participated in the INSPIRE engineering summer academies, they demonstrated changes in their abilities to recognize and understand engineering as evidenced by their explanations of engineering they wrote in their journals before and during the academies. Since there were changes made to the academy structure between the 2006 and 2007 academies, we wanted to know whether there were greater differences (pre/post) for either project year. Results revealed that teachers demonstrated greater change in understanding in the 2007 academy than they did in the 2006 academy. There are a few explanations for the greater level of change in 2007. First, INSPIRE changed from a curriculum created in-house with limited piloting in 2006 to a research-based,

<table>
<thead>
<tr>
<th>Code</th>
<th>n</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remember</td>
<td>40</td>
<td>37.51</td>
<td>31.22</td>
<td>19.86</td>
<td>34.79</td>
</tr>
<tr>
<td>Understand</td>
<td>40</td>
<td>51.61</td>
<td>27.73</td>
<td>49.19</td>
<td>28.28</td>
</tr>
<tr>
<td>Apply</td>
<td>40</td>
<td>2.62</td>
<td>6.94</td>
<td>5.59</td>
<td>10.23</td>
</tr>
<tr>
<td>Analyze</td>
<td>40</td>
<td>7.51</td>
<td>10.66</td>
<td>21.05</td>
<td>22.12</td>
</tr>
<tr>
<td>Evaluate</td>
<td>40</td>
<td>0.48</td>
<td>0.88</td>
<td>4.31</td>
<td>8.04</td>
</tr>
</tbody>
</table>

**FIGURE 2.** Teachers' change in understanding by Bloom cognitive level.

TABLE 7
Means and Standard Deviation Scores for Each Code Pre and Post
standards-driven, and classroom-tested curriculum, Engineering is Elementary (Cunningham, 2004), in 2007. Another possible explanation for the greater change in 2007 is that the 2007 teachers were recruited in teams from the same school or school district. This was done to help facilitate communication and collaboration between the teachers post-academy, as well as provide consistent working-groups during the academy. The teacher teams were not implemented in 2006, so this academy feature may have influenced the change demonstrated in the teachers' journal entries, as collaboration may have influenced a greater, shared understanding of engineering during this academy (Blumenfeld, Krajcik, Marx, & Soloway, 1994). Finally, 2006 was the first academy year, so by the start of the 2007 academy, the INSPIRE facilitators had time to rethink the structure of the academy, integrate suggestions made by 2006 academy teachers, and discuss better ways to deliver the engineering content and concepts.

There are a few explanations for why the teachers did not show significant gains in the categories of Understand and Apply. Some teachers demonstrated change in their understanding by starting in the Remember category and moving to Understand (and some even higher). Others started in Understand and moved to Apply (and even higher). Since the category of Understand was a starting point for some teachers and an ending point for others, it’s not surprising that this category did not reflect teacher gains.

The teachers also did not reflect significant gains in the category of Apply. One possible reason for this may be due to the coding definitions. The coding definition for Apply requires the teacher to demonstrate a process or procedure. This definition is more narrow and specific than some of the other definitions. In addition, if a teacher goes on to describe the usefulness of the process or procedure to society, the entry could be coded as Analyze instead of as Apply. Another possibility is that the teachers, though they both followed and developed procedures during the academy, may not realize that this is an aspect of engineering. However, overall, though not significant, the teachers did show positive change in this category.

This study provides evidence that teachers demonstrated change in their understanding of engineering. Through the INSPIRE engineering academies, we introduced ways for teachers to see and experience engineering in the world around them, then developed a tool to measure the resulting changes. The next step involves determining whether teachers translate such changes in understanding into their classroom practices and content. The nature of the photo journal project required teachers to recognize engineering in the world (through a photograph), then discuss (in a written journal) why the photograph represented engineering. Since teachers improved pre to post in their ability to Analyze and Evaluate the engineering around them, we feel they are better prepared to discuss with their students the nature of engineering and what engineers do.

LIMITATIONS

Several limitations exist in this study, including a small sample size of Midwestern teachers who used a specific curriculum, each of which affects generalizability. Thus, the results should be viewed with the specific context of this research in mind.

Another potential limitation of this study was that coding the journal entries did not reveal the Bloom's cognitive level “Create” in the teachers' writings. This assignment did not explicitly lend itself to eliciting a “Create” cognitive level response, as this level requires a teacher to take an existing engineering idea and build upon it in an effort to improve the
object, or to form a new idea in reference to the object. The teachers, as indicated by the activity instructions, wrote about the objects in their photographs. During the academy, the teachers learned about creating during design activities, so it could be expected to see a teacher make the connection between engineering in the world and a new idea. However, as mentioned, this sample was small and this response did not occur. We would be interested to see if the “Create” cognitive level emerged when using this assessment with a larger sample.

Another limitation is the time-frame of the study. Teachers received a camera prior to their attending the academy, therefore their pre photos and accompanying journal entries were already completed by the time the teachers arrived at the INSPIRE academy. However, after the first full day of the academy, the teachers received instructions to complete the photo journal project (take 10 more photos and complete the journal entries) by the end of the week. If a teacher were to “get this assignment out of the way” and take all of his or her photos on day two of the week-long academy, the teacher’s full change in understanding of engineering in the world around them may not be captured by the assessment. In addition, without further study, we are not sure to what extent our academy teachers retain their new knowledge, nor the extent to which they use their knowledge with their students.

An additional limitation with the post photos is accessibility. Since the academies were held on a campus of a university known for engineering, teachers had opportunities to take post engineering photographs that they did not have when taking their pre photos. This made the conditions different for the pre and post photos.

We chose to use the Revised Bloom’s Taxonomy cognitive levels to code teachers’ journal responses due to its hierarchal nature (Almerico & Baker, 2004). The Bloom’s cognitive levels are viewed as cumulative with each level becoming more complex (Almerico & Baker; Granello, 2001). Thus, we treated hierarchical, ordinal data as interval data to enable analyses and investigation into the teachers’ changes in understanding of engineering. This is similar to the common treatment in research of data from Likert and Likert-type scales as interval data (Floyd & Widaman, 1995; Gable & Wolf, 1993), but presents a limitation as using the Revised Taxonomy in this manner is novel and warrants more research.

A final limitation is the pre-measure. We sent the cameras to the teachers prior to the academy in an effort to see what they know about engineering prior to being exposed to any sort of engineering instruction. However, we do not know whether the teachers did any research (e.g., Internet, asking friends or co-workers, reading books) to learn about engineering prior to taking their photos. Therefore, some of their photos, while still taken before a formal engineering professional development academy, may not be fully representative of the teachers’ true pre-engineering knowledge.

**CONCLUSIONS**

Through the use of a photo journal and our coding scheme based upon the Revised Bloom’s Taxonomy cognitive levels, we were able to assess teachers’ changes in their abilities to recognize and understand engineering in the world around them after participating in an engineering academy. The photo journal project was a successful method of gathering information about teachers’ ideas about engineering. The change in understanding demonstrated by the teachers in their photo journals indicated higher levels of sophistication in their abilities to discuss the nature and practice of engineering. They became more proficient in their abilities to identify and discuss engineering pre to post academy. By both
taking photos and then journaling about them, it allowed the teachers to freely express their ideas about engineering without the bounds of a traditional paper and pencil test. One of INSPIRE’s goals is to help prepare elementary teachers to be able to discuss engineering. Through the use of the photo journal project we saw that, during the INSPIRE engineering summer academies, teachers’ levels of understanding of engineering changed and their ability to convey engineering messages moved from Remember to two higher Bloom’s cognitive levels of Analyze and Evaluate. We used an established theoretical taxonomy as the basis for our coding scheme, thus tying this innovative use of Bloom’s Taxonomy to extant educational literature.

With the numerous engineering initiatives and classes occurring across the country, the results from this project indicate that a photo journal project could be an effective way to gather information about students’ ideas about engineering. This type of project could be appropriate for use with students in elementary, middle, or high school. Additionally, college professors could use this type of project to gain insight into their students’ ideas about engineering. Using the developed coding system, educators can detect changes in understanding and note changes in students’ sophistication of journal responses. Since the coding scheme developed to accompany the photo journal project is transferrable to a classroom setting, it could provide information about students’ change in understanding in other academic areas as well.

Further research is needed to determine whether teachers transfer their engineering knowledge to their students, and if in doing so they affect their students’ attitudes about or knowledge of engineering. Therefore, future studies might focus on the engineering achievement and attitudes of the participating teachers’ students. This research would provide additional evidence about whether the change in engineering understanding among teachers documented in this study transfers to their teaching practices and affects their students’ academic performance and aspirations toward engineering. Further research is also needed to continue this current research with larger and more diverse samples.

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REFERENCES


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