2007

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Abstract: Prior research in both education and cognitive science has identified analogy making as a powerful tool for explanation as well as a fundamental mechanism for facilitating an individual's construction of knowledge. While a considerable body of research exists focusing on the role analogy plays in learning science concepts, relatively little is known about how instruction in the use of analogies might influence the teaching performance of preservice teachers. The primary objective of this study was to investigate the relationship between pedagogical analogy use and pedagogical reasoning ability in a sample of preservice elementary teachers (PTs), a group that has been identified for their particular difficulties in teaching science. The study utilized a treatment/contrast group design in which the treatment group was provided instruction that guided them in the generation of analogies to aid in the explanation phase of learning cycle lessons. A relationship between analogy use and positive indicants of teaching performance was observed and a case study of a low performing preservice teacher who drastically improved teaching performance using analogy-based pedagogy is presented. A notable effect on conceptual understanding of Newton's Third Law as a result of two brief analogy-based demonstration lessons was also observed.

Keywords: physics, pedagogical content knowledge, conceptual change, science teacher education

Published in *Journal of Research in Science Teaching* Vol. 44, NO. 4, PP. 565–585 (2007)
DOI: 10.1002/tea.20167

Submitted 9 September 2005; accepted 10 July 2006; published 8 March 2007.

The early experiences of elementary school students (ES) with science instruction are crucial to their future scientific literacy and potential career choices in science (Bingle & Gaskell, 1994). Yet, many have expressed concern regarding the quality of preservice preparations of elementary teachers to teach science (Trumbull & Kerr, 1993). Elementary teachers are often apprehensive toward science and lack a coherent theoretical framework to view science pedagogy (Duschl, 1983; Peterson & Treagust, 1995). As a result, most elementary teachers either completely avoid teaching science (Tilgner, 1990) or compose lessons around textbook definitions of scientific terms and fail to focus on critical attributes of target concepts (Smith, 1997).

Recent developments in cognitive science have pointed to analogy making as the brain's most fundamental mechanism for building knowledge (Lakoff & Johnson, 1999; Oppenheimer, 1956; Sutton, 1993; Thagard, 1992). The importance of analogies in instruction cannot be underestimated: ''Analogical reasoning is a fundamental cognitive skill, involved in classification, learning, problem-solving, and creative thinking, and should be a basic building block of cognitive development'' (Goswami, 1993). To cognitive scientist and artificial intelligence expert Hofstadter (2000), analogy making is much more than merely one aspect of reasoning—it is the fundamental basis for all human thought. In essence, our minds are composed of tightly bundled sets of analogies. When we think, we unfold these bundles in our short-term memory, comparing one bundle to another. Even the leaps between bundles of analogies are accomplished through an analogical process. In order for us to comprehend the information we receive from our senses, our brains perform nearly instantaneous sub-cognitive searches of long-term memory for analogous bundles of analogies to compare to sensory input (Gentner, 1989; Lawson & Lawson, 1993).

While an understanding of the importance of sub-cognitive analogical processes in human cognition is relatively recent, the use of analogy in education is pervasive throughout human history. Socrates suggested that a person's ability to know oneself is like the eye's ability to see itself (Saunders, 1987). Parables such as ''The Tortoise and the Hare'' are meant to be analogous to situations people find in everyday life (Jose, 1987). Analogies are able to facilitate an understanding of new concepts by comparing and contrasting their structural features to existing conceptual knowledge in the mind of the learner (Duit, 1991). The use of analogies, either deliberate or unintended, is pervasive in science classroom discussions (Goswami, 1993; Lakoff& Johnson, 1999; Stavy, 1993; Sutton, 1993) as well as science textbooks (Glynn & Takahashi, 1998; Harrison, 2001; Iding, 1997; Newton, 2003).

In addition to their role as explanatory devices, analogies have also played major roles in the generation of new scientific discoveries. Archimedes discovered his principle of buoyancy when he compared the displacement of water during bathing to the hypothetical displacement of water by an irregularly shaped object (Stein, 1999). Darwin discovered the process of natural selection through constructing an analogy with the controlled breeding of domestic animals and plants (Venville & Treagust, 1997). Kekule discovered the ring structure of benzene through a dream about a snake biting its own tail (Pinker, 1997). Examples of this type are ubiquitous throughout the history of science (Dreistadt, 1968; Hesse, 1966; Hoffman, 1980; Oppenheimer, 1956). Numerous studies have investigated teaching methodologies based on using broad appeal teacher-constructed analogies as pedagogic tools to facilitate the comparison of unfamiliar target concept attributes to familiar base concept attributes from student's prior knowledge (Castillo, 1998; Clement, 1993; Duit, 1991; Glynn, 1991; Harrison & Jong, 2005; Harrison & Treagust, 2000; Heywood & Parker, 1997). The studies largely agree that, when learners identify strongly with requisite base concepts in teacher-constructed analogies, and when teachers are skillful in the implementation of analogy-based pedagogy, analogies can act as very powerful learning tools. A common theme that is stressed in these methodologies is that, while all analogies are built upon similarity mappings, any successful analogy-based methodology must also take great care to highlight inconsistencies.

In contrast to strategies that rely on learner interpretation of teacher-constructed analogies, some have studied approaches that center on learner-constructed analogies. There is evidence that suggests analogies are much more effective when they are generated by learners rather than teachers (Pittman, 1999). Wong (1993) has studied the capacity of analogy making as a tool to generate inferences about a target concept when learner prior knowledge is incomplete or poorly organized. In Wong's model for introducing analogies in the science classroom, learners use analogies as intermediate and disposable tools that inspire new inferences. Blanchette (2000), using a laboratory setting to research the process by which analogies are generated, has shown that circumstances dictate whether learners use superficial similarity or deep structural features to compose analogies. Stavy (1993) studied the situational components that cause people to perceive disparate domains as analogical. And, Clement (1988) studied how practicing scientists create analogies during problem solving. While research on the many aspects of analogy has produced various analogy-based pedagogies that have demonstrated efficacious effects on student learning, it has also yielded cautions regarding their use (Duit, Roth, Komorek, & Wilbers, 2001; Friedel, Gabel, & Samuel, 1990; Venville & Treagust, 1997). A concern often voiced is the potential for the development of alternate conceptions when learners may erroneously extend analogical mappings for features in a source concept which do not have physical counterparts in the target concept. To mitigate this potential for alternate conceptions, Wong (1993) suggests a technique whereby learners critically assess each mapping in an analogy to gauge its legitimacy. Since target and base conceptual domains must always possess differences, many authors have described approaches where multiple analogies are used to explain a single target concept (Chiu & Lin, 2005; Harrison & Jong, 2005; Spiro, 1989). This approach is exemplified in the field of physics where both wave and particle analogies are routinely used in attempts to explain the behavior of light, which is clearly neither a particle nor a wave.

Contrary to interpreting the inherent conceptual differences which ultimately cause all analogies to break down as problematic, Heywood (2002) views the analysis of these inconsistencies as integral to the derivation of deep meaning by a learner. Furthermore, Heywood argues that the process of analyzing analogies leads teachers toward a deeper appreciation for learning as socially constructed meaning rather than a search for absolute truth. The most important role of analogy in the learning process is then as a catalyst for the critical engagement of teacher and learner in the learning process, rather than as a vehicle to yield successive approximations of reality.

Shulman (1987) has studied the professional development of neophyte teachers as they have struggled to adapt to their new teaching environments. By contrasting their ‘‘stumbles’’ to observations made of experienced teachers in the same situations, Shulman developed a six-stage model called pedagogical reasoning ability to describe the development of a fundamental knowledge base essential to teaching:

comprehension, transformation, instruction, evaluation, reflection, and new comprehension. Each of these stages will be characterized in terms of this study in the methods section.

Others have investigated ways to increase pedagogical reasoning ability in preservice elementary teachers (PTs) through journaling (Peterson & Treagust, 1995), through lesson preparation practices (Van Der Valk & Broekman, 1999), and through analyzing case vignettes (Herman, 1998). While the primary focus of analogy-based instructional strategies has been to increase student learning, there is a strong theoretical rationale for expecting analogy-based pedagogy to impact upon teaching performance by helping teachers develop a meaningful understanding of content knowledge as well as an appreciation for how such meaning is constructed (Heywood, 2002; Heywood & Parker, 2000).

While numerous studies have focused on the efficacy of analogy-based instruction on student learning, the primary objective of this research was to investigate the relationship between pedagogical analogy use and pedagogical reasoning ability in a sample of PTs. The intervention took the form of instruction that guided treatment group participants in the generation of pedagogical analogies to aid in the explanation phase of learning cycle lessons. Shulman's stages of pedagogical reasoning ability were used as a framework to develop a number of positive indicants of teaching performance that were used to assess teaching performance in the sample.

Method

Pilot Studies

Two qualitative pilot studies were conducted in the semester prior to this study to assist in the development of the treatment and data gathering instruments. The first pilot study was conducted with secondary PTs within the context of a science methods course. A preliminary version of the main study treatment was presented to PTs who then worked in cooperative groups to develop pedagogical analogies that could hypothetically be used to teach physics concepts represented in a common demonstration of Newton's Third Law (Freir & Anderson, 1981). Results from this study provided an illustration of the generative analogy technique as well as a powerful learner-generated analogy (‘‘Arocket is like a gun’’) that was later included in a demonstration lesson for the treatment group in the main study. The following excerpt is taken from an interaction that took place within a group of three PTs as they worked in a cooperative group to develop a pedagogical analogy.

> Researcher: ‘‘What do you want to focus your lesson on?’’
> PT1: ‘‘How, according to Newton’s Third Law, the rocket fuel pushes back on the rocket as the rocket pushes on the fuel.’’
> Researcher: ‘‘Can you think of something from your student’s common experience that might be similar?’’
> PT1: ‘‘I don’t know. . . How about shooting a gun? You can feel the kick-back when the bullet is shot out . . .’’
> Researcher: ‘‘Good! So are you thinking that the rocket is analogous to the gun or the bullet?’’
> PT1: ‘‘The rocket is like the bullet.’’
> Researcher: ‘‘So is the fuel like the gun?’’
> PT2: ‘‘I am thinking that the rocket is more like the gun, and the bullet is more like the fuel being shot out. The rocket is a lot bigger compared to the amount of fuel shooting out. So the rocket is like a gun shooting bullets down at the ground.’’
> PT3: ‘‘Yeah . . . But then it would be more like a machine gun shooting lots of bullets . . ..’’

The generation and development of the ‘‘rocket is like a gun’’ analogy sparked a lively discussion within the group about the significance of various features within the analogy. Without further intervention from the researcher, the peer discussion fostered the generation of a number of critical questions regarding salient features in the target concept. Critical questions included: ‘‘How can tiny molecules of gas with almost no mass be like bullets? How could they possibly push an entire rocket?,’’ ‘‘I wonder what the relative speed of the rocket exhaust is compared to the speed of the rocket,’’ and ‘‘Could the speed of a rocket ever exceed the speed of the exhaust?.’’

The peer discussion was not limited to attributes of the target concept. As the PTs considered the analogy, they also became focused on critical questions about the source concept they had never considered. Critical questions included: ''What is the role of the gun barrel in propelling the bullet?,'' ''What actually pushes the bullet out when the gun powder goes off?,'' and ''Could a bullet fire in space where there is no oxygen for combustion?.''

This process of explaining one phenomenon in terms of another clearly compelled the PTs attention away from textbook definitions, toward a deeper understanding of critical relationships between elements within the target concept, the first stage of pedagogical reasoning ability (Shulman, 1987). It might be inferred that teachers who have developed their own critical questions regarding a target concept are more likely to develop lessons that foster the same critical appreciation for conceptual structure. Once this deep focus is realized, the analogy-based pedagogy becomes a useful heuristic device focusing the PTs attention toward a consideration of the prior knowledge of the learner.

In the second pilot study, 7 participants were selected at random from a class of 28 PTs enrolled in an elementary science methods course to be interviewed regarding their prior knowledge of pedagogical analogies. Two analogies were suggested to interviewees: ''An eye is like a camera'' (Glynn, 1993) and ''The moon is like a golf ball'' (Castillo, 1998). While it was found that only one interviewee was familiar with the term ''analogy'' before the interview, all seven interviewees were able to readily develop pedagogical analogies based on the two statements of similarity presented to them. When asked which analogy would be most useful in teaching, all but one respondent identified the eye/camera analogy based on structural similarities. Two respondents suggested that since the moon/golf ball analogy was based on superficial similarities, it might be more appropriate for younger children.

In the week before these interviews were conducted, PTs had completed a class assignment where they were required to delineate critical conceptual attributes of a self-identified science concept they were considering for an upcoming teaching project. Interestingly, while all interviewees demonstrated an intrinsic ability to generate pedagogical analogies when considering the familiar eye and moon concepts, the science concept assignments obtained from all but one interviewee simply contained an enumeration of disparate scientific facts relating to their respective target concepts. The concept attributes shown here are typical of most responses. Main concept: ''How tornados form''; Attributes: ''Tornados occur during a thunderstorm''; ''Tornados are produced by cool air overriding warm air''; and ''A tornado is a funnel that touches the ground.'' The subsequent interview of the PT who had written the above concept description revealed no critical assessment of understanding. The ability to strategize about an approach for instruction that the interviewee had demonstrated with the ''eye is like a camera'' analogy was totally absent with the ''how tornados form'' concept. Why don't the vast majority of thunderstorms produce tornados? How can a cool layer of air overriding a warm layer of air lead to a tornado? Why are tornados shaped like vertical funnels instead of barrels, inverted funnels, or some other shape? The participant had never considered any of these critical questions and could not begin to formulate any connections between the concept attributes for instruction.

The findings from the second pilot study suggest that, while PTs certainly possess the ability to generate and utilize pedagogical analogies, they are unlikely to use these skills when teaching unfamiliar concepts. This second pilot study also highlighted the need to focus on cause/effect relationships as students develop science concept examples in preparation for teaching. The eye/ camera analogy was also adopted as an accessible scheme to explain the development of pedagogical analogies for the treatment group.

Research Design and Sample

The study utilized a treatment/contrast group design where treatment and contrast groups were obtained from two intact sections of a course on methods for teaching science for PTs at a large Midwestern university. The adjunct instructor who taught both treatment and contrast sections was a former elementary school teacher who had no prior experience in science teaching methods instruction.

Both groups received identical instruction and assignments with the exception of two class periods midway through the semester when 5-E lesson planning structure (Marek & Methven, 1991) was introduced. The course instructor presented contrast group PTs with standard instruction in composing 5-E inquiry lessons (Sunal, 2003) and the researcher presented treatment group PTs with instruction in how

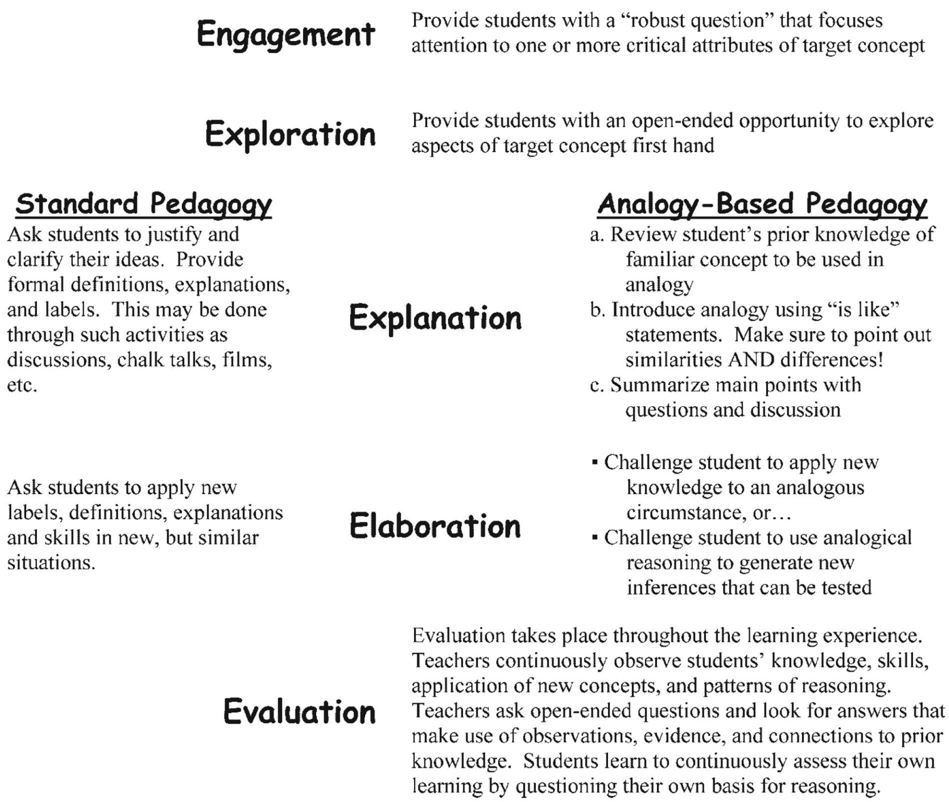

Figure 1. Standard 5-E lesson compared to analogy-based 5-E lesson.

to generate analogies (Wong, 1993) to be used in 5-E learning cycle lessons that employed analogy-based pedagogy (Glynn, 1991) during the explanation and elaboration lesson phases (see **Figure 1**). Data on PT pedagogical reasoning ability was obtained before and after treatment primarily through PT work submitted in completion of a major three part interview/teaching assignment which required all PTs to ultimately present a lesson on force and motion after conducting an interview to identify an appropriate force and motion target concept. A test of force and motion content knowledge known as the Force Concept Inventory (FCI) was administered to both groups at the beginning and end of the semester in order to detect any differences in content knowledge that occurred as a result of the treatment (Hestenes,Wells,& Swackhammer, 1992).

Participating throughout the study were 45 PTs: 23 in the treatment group and 22 in the contrast group. The sample was predominantly female with only two males in the treatment group and three males in the contrast group. Nearly 3 quarters of PTs had taken a prior course in physics: 16 PTs from the treatment group and 18 PTs from the contrast group.

Treatment: The Analogy Workshop

The analogy-based pedagogy was presented in the form of a workshop that took place during two consecutive class periods in week 8 of a 15-week semester. The initial class period was 75 minutes in length and the second-class period was 50 minutes in length.

The researcher began day 1 of the workshop by presenting PTs with a 2-minute video montage containing seven video clips taken from popular movies, television shows, and television commercials demonstrating explicit use of analogies in various real-life contexts. A discussion followed in which PTs determined the meaning and function of the analogies illustrated in each circumstance. In order to further increase awareness of the important role of analogy in everyday life, an interactive PowerPoint presentation was then used to highlight common examples of analogy from humor, psychology, politics, poetry, education, religion, common conversation, children's conversation, and science discovery. (These materials may be downloaded at: http://www.physics.nau.edu/_james/)

PTs were then divided into cooperative learning groups and asked to identify as many analogies as possible that could be found in a brief video clip taken from a natural science documentary about weaver ants. In the clip, more than 15 analogies are alluded to within the brief period of 1 minute. A group discussion followed in which PTs discussed the meaning and structure of the analogies they had identified.

Treatment group PTs were then provided instruction in how to utilize explicitly defined analogical relationships to explain critical attributes of target concepts (Glynn, 1991) during the explanation phase of a 5-E learning cycle lesson (see Figure 1). Two 5-minute analogy-based demonstration lessons were presented to illustrate the technique. The first demonstration lesson focused on the Newtonian Third Law force concepts involved in a tug of war. An explanation was presented which was based on an analogy between a conventional tug of war situation between two PTs and an alternative situation where one PT was sitting on a cart during the tug of war. The second lesson focused on the Newtonian Third Law force concepts involved in rocket propulsion. The explanation that was presented was based on the analogy ''a rocket is like a gun'' that was generated by PTs in the pilot study described earlier. As illustrated in Figure 1, the presentation of the elaboration phase of the 5-E learning cycle was also enhanced with analogy by explicitly instructing treatment PTs to include a question in the elaboration phase that challenged learners to apply new conceptual knowledge to an analogous circumstance.

The analogy workshop culminated in an exercise on day 2 where treatment group PTs worked to develop practice lessons based on analogies they constructed. PTs were asked to identify a personally meaningful target concept in force and motion that could be used as the focus of an exploration in a hypothetical lesson. To aid PTs in their search for a hypothetical target concept, PTs were provided with an illustrated handout that depicted 30 common physics demonstrations (Freir & Anderson, 1981) that could be used as the basis of explorations in the practice lessons. After picking a target concept and exploration, PTs were asked to imagine source concepts familiar to ESs that could be used to form an analogy with their target concept. The PTs worked in cooperative learning groups to develop hypothetical analogy-based explanations which they recorded on worksheets that were submitted for grading. An illustration of the generative analogy technique is found in the pilot study section of this study.

During the two class periods where treatment group PTs were participating in the Analogy Workshop described above, contrast group PTs received instruction by the course instructor in 5-E lesson planning structure which did not explicitly utilize techniques based on analogy (see Figure 1). Where treatment group PTs were taught to develop explanations by pointing out similarities and differences in analogical relationships, contrast group PTs were taught to develop explanations by eliciting student ideas in a discussion of the exploration activity and then incorporating those ideas into a scientific account of the concept. Where treatment group PTs were taught to challenge learners to apply new knowledge to an explicitly analogous circumstance in the elaboration phase, contrast group PTs were taught to ask learners to apply labels and features of the explanation to a similar example. During the introductory lecture on day 1, contrast group members were presented with sample 5-E lessons from the course textbook on tree growth and rock classification (Sunal, 2003). PTs then worked in cooperative groups to develop hypothetical 5-E lessons on force and motion concepts found in the interview/teaching assignment. On day 2, instruction for the contrast group focused on developing evaluation questions at the various levels of Bloom's taxonomy.

Data Sources

The primary data source for the study was PT work submitted in completion of a major three-part interview/teaching assignment for the methods of teaching elementary science course. In part 1 of the assignment which was completed prior to treatment, PT's performed an analysis of their own understanding of Newtonian force and motion concepts by providing cause/effect examples to illustrate various force and motion conceptual categories adapted from the Hestenes et al. (1992) Force Concept Inventory. PTs were encouraged to pose their concept examples in the form of if /then statements in an effort to focus attention toward critical relationships between elements within a target concept. All force and motion concept categories were compatible with national content standards for grades 4 through 8 (National Research Council, 1996). After completing an analysis of Newtonian force and motion conceptual understanding, PTs then developed questions for each Newtonian force and motion conceptual category in preparation for an interview with an ES to gauge the student's prior knowledge of these concepts.

In part 2 of the assignment, which was completed in the week following treatment, each PT used the questions they had composed in part 1 to conduct a 10–15 minute interview on force and motion concepts with an ES from grades 4 to 8. Each PT generated a transcript of their interview from a tape recording. Based on an analysis of their interview transcript, PTs then prepared a 20-minute 5-E instructional intervention (Marek &Methven, 1991) designed to build on the prior knowledge of their interviewee as well as to remediate any alternate conceptions that had been identified.

In part 3 of the assignment, each PT met once again with their respective ES to teach the lesson he/ she had composed. PTs then generated transcripts of their lessons from tape recordings. Pedagogical reasoning ability was analyzed in PT submissions for parts 1 and 3 of the interview/teaching assignment using coded indicants of the six levels of pedagogical reasoning developed by Shulman (1987).

The Force Concept Inventory (Hestenes et al., 1992) was administered at the beginning and end of the semester to gauge differences in content knowledge of Newtonian force and motion concepts which may have occurred as a result of treatment. The test, targeted at the level of high school seniors and university freshmen, is composed of 30 five-answer multiple-choice questions with only 1 correct Newtonian response. The authors used a qualitative analysis of interviews and more extensive non-multiple-choice test questions to validate each item in the FCI test. A false negative, the probability of a Newtonian thinker failing to identify a correct Newtonian response, was found to be much less than 10%. The probability of false positives was found to be much higher. The authors do not identify a statistic for false positives, however, the authors sought to minimize the occurrence of false positives by providing powerful non-Newtonian multiple-choice alternatives in each question designed to reflect common alternate conceptions that had been identified in novice populations.

In order to triangulate findings, interviews were conducted with a sub-sample of five PTs from the treatment group and five PTs from the contrast group. Each group sub-sample was purposefully obtained to include a diversity of PT ability as measured by the coded indicants of pedagogical reasoning ability described below.

Coding Pedagogical Reasoning Ability

Qualitative indicants of pedagogical reasoning ability found in PT work on the interview/ teaching assignment were coded for analysis. The coding procedure was blind to group affiliation. The items that were analyzed on the basis of pedagogical reasoning ability included PT generated concept examples, PT generated interview questions, unstructured reflection papers, PT/ES interview transcripts, and PT/ES teaching transcripts. Pedagogical analogy use in PT/ES lesson transcripts was also coded. A second coder was trained in the coding system and coded 30%of all data items independently of the primary coder. An overall interrater reliability coefficient was established at 0.94 (Pearson's r). A summary of pedagogical reasoning indicants coded for this study is found in **Table 1**. A discussion of the key indicants used in the analysis of stages of pedagogical reasoning ability follows.

Table 1. Pedagogical reasoning ability codings from interview/teaching assignment

Level of Pedagogical Reasoning Ability	*Coded Indicant*	*Data Source*
Comprehension and transformation	*Alternate conception*: concept in conflict with Newtonian conception of force and motion *Confused*: ambiguous conception *Trivial*: concept with insufficient detail to distinguish between Newtonian and non-Newtonian conception *Jargon*: question or comment that relies on prior knowledge of abstract scientific terms *Meaningful*: a statement that did not contain an alternate conception, confused, trivial, or jargon response	Concept examples, interview questions, teaching transcript
Instruction	*Observation*: a statement where an ES was directed to make or recall a critical observation *Explanation*: a statement where a PT attempted to explain, or help an ES construct an explanation, of a physical phenomenon. Each explanation coding was additionally coded for comprehension using one of the five indicants listed above	Teaching transcript
Evaluation	*Application question*: a question where an ES was asked to apply new knowledge to a novel situation	Teaching transcript
	Evaluation comment: a statement where a PT reflected upon some aspect of ES learning	Unstructured reflections
Reflection	*Change comment*: a statement where a PT reflected upon changes that could be applied to future lessons	Unstructured reflections

Comprehension: The 1st Level of Pedagogical Reasoning Ability. Shulman defines the most fundamental level of pedagogical reasoning ability as the ability to articulate the extent of one's knowledge of content to be taught. An examination of the force and motion concept examples provided by PTs in part 1 of the interview/teaching assignment revealed three categories of inexpert comprehension responses: alternate conception responses, confused responses, and trivial responses. A composite category labeled ''meaningful'' was defined as a concept example that was not coded as alternate conception, confused, trivial, or jargon (jargon is discussed in the following section relating to transformation).

An alternate conception response was tabulated when a PT articulated a concept in conflict with currently accepted Newtonian conceptions. In the following response, PT33 articulates a conception of inertia where a force is exerted on a passenger in the direction of motion when a moving car stops. In the Newtonian conception of this situation, the motion of a passenger has a natural tendency to continue when a car stops without the imposition of an external force in the direction of motion. PT33: ''If a car stops suddenly, then a force is exerted on a passenger towards the windshield, but the seat belt provides another force to prevent the passenger from hitting the windshield [alternate conception].'' The following two excerpts illustrate meaningful concept examples which are consistent with a Newtonian conception of inertia. PT34: ''If a car hits a wall, the person in the car continues moving forward while the car stops [meaningful].'' PT43: ''If you are riding in a school bus and the bus turns left, your body will lean right [meaningful].''

A confused response was tabulated when a PT articulated an idea that was ambiguous, or did not possess an internally coherent structure. In the following response from part 1 of the interview/ teaching assignment, PT48 began with an example of Newton's First Law that was apparently compatible with the scientific view. However, the second half of the response introduces an ambiguity regarding the PTs use of ''applied'' force and ''constant'' force. PT48: ''Aball that has a velocity of zero will not move without force being applied, because the force exerted on the ball will be constant [confused].'' The following concept example illustrates a coherent conception of zero net force acting on a ball. PT2: ''If a ball is sitting on a desk, gravity is pulling the ball downward and the desk is pushing the ball up [meaningful].'' A trivial response was tabulated when a PT articulated a concept without sufficient detail to distinguish a Newtonian response from a non-Newtonian response. The following examples illustrate trivial responses. PT14: ''When a bullet hits a still block of wood, the block of wood gets knocked off [trivial].'' PT39: ''If I am going to mow the lawn, I will push the lawn mower forward [trivial].''

At the end of each of the three parts of the interview/teaching assignment, PTs were asked to provide unstructured reflections. Many PTs spontaneously reflected on their level of comprehension of the force and motion concepts. An expression of confidence in content

Table 2. Comprehension indicants in interview/teaching assignment

	Total Meaningful Response Ratio		*AC + Jargon + Trivial + Confused Responses*		*Net Concept Affect Comments in Reflections*	
	(Part 1)	(Part 3)	(Part 1)	(Part 3)	(Part 1)	(Part 3)
PT47	18.9%	100.0%	30	0	-3	-1
Treatment group mean	50.7%	65.6%	15.4	4.6	-0.58	-0.32

knowledge was coded as positive concept affect, and an expression of concern was coded as negative concept affect. The net concept affect reported in **Table 2** is the difference between positive and negative concept affect comments. The following excerpts are typical of positive and negative concept affect, respectively. PT50: "I think I learned more about these subjects from this assignment, then [sic] I did in my Physical World class [negative concept affect]." PT02: "What I am most worried about when I conduct my interview is not being able to answer a question that my student might ask [negative concept affect]."

Transformation: The 2nd Level of Pedagogical Reasoning Ability. Shulman defines the second level of pedagogical reasoning ability as the ability to logically organize content knowledge in preparation for teaching. As part of the interview preparation assignment, PTs were required to formulate hypothetical interview questions based on their Newtonian concept examples using non-scientific language that their ES interviewee would easily understand. An examination of the questions compiled by PTs in part 1 of the interview teaching assignment revealed that a significant number of questions focused on definitions of scientific terms or relied upon prior knowledge of potentially unfamiliar scientific terms. Such comments or questions indicate an inability to organize knowledge coherently for a target learner and were tabulated as jargon responses. In the following excerpt, PT33 assumes that a fifth grade ES would have prior knowledge of Newton's second law and acceleration. PT33: "According to Newton's second law of motion, distinguish whether a sports car or a locomotive would be able to accelerate more easily [jargon]." The following question would have been coded meaningful had it simply focused on an analysis of a physical event rather than requiring an interpretation of an event in the context of a potentially unfamiliar scientific law. PT48: "According to Newton's Law, does a ball thrown in space travel forever [jargon]?." Here, PT12 provides a question based on the same concept without using jargon: "What would happen to a baseball if you were to throw it straight up in space [meaningful]?" The following excerpt illustrates a meaningful question designed to probe for ES understanding of the force of friction and its role in slowing a skater. PT38: "If you were roller skating and you stopped moving your feet, why do you think you would eventually slowdown and stop [meaningful]?" Some PTs submitted questions similar to those they may have encountered in a fact-oriented physics course as illustrated in the following excerpt. PT48: "Which of Newton's laws explains blood rushing from your head to your feet while quickly stopping when riding on a descending elevator [jargon]?"

In the culmination of the interview/teaching assignment, PTs submitted transcripts of the one-on-one lessons they taught to individual ESs. Each sentence uttered by a PT that contained a question relating to the lesson content was coded as either an alternate conception, confused, trivial, jargon, or meaningful using the same rules that were applied to interview questions found in part 1 of the assignment. PTs had been instructed to always ask specific content oriented questions when probing for understanding rather than generically asking "*Do you understand?*" Instances of "*Do you understand?*" or "*Isn't that correct?*" that occurred in transcripts were not coded. Questions included in transcripts that did not relate to lesson content, such as attempts to develop rapport by asking about family members or vacation plans, were not coded.

Instruction: The 3rd Level of Pedagogical Reasoning Ability. Shulman defines the third level of pedagogical reasoning ability as the ability to translate organized knowledge into an instructional strategy. Two codings providing evidence of a rudimentary instructional strategy were used in the analysis of PT teaching transcripts. When a PT directed an ES to make a critical observation, the sentence containing the direction was coded as an observation interaction. The following excerpt illustrates an observation coding. PT50: "OK, I want you to look at this picture and tell me how fast you think the car is moving [observation]." If the direction to make an observation was posed in the form of a question, that sentence was also coded as question according to the rules for interview questions indicated previously.

Any sentence where a PT attempted to explain, or helped to construct an explanation, was coded as an explanation interaction. Each explanation coding was additionally coded for comprehension using the coding scheme described in the comprehension section. The following excerpt illustrates two meaningful explanation sentence codings which occurred in the same passage. PT50: ''So the crash dummy is not so lucky [explanation]. Since he is not wearing his seat belt and is not connected to the car, he continued moving at the same speed the car was [explanation].''

Evaluation: The 4th Level of Pedagogical Reasoning Ability. Shulman defines the fourth level of pedagogical reasoning ability as the ability to assess student understanding. There were two indicants of evaluation that were coded in the teaching transcripts. When a PT asked an ES to apply new knowledge gained from the lesson to a novel circumstance in an effort to assess learning as in the following excerpt, the interaction was coded as an application question. PT17: ''OK, so you just showed me how a cannon ball would move because of gravity . . . If there were no gravity, can you tell me how the cannon ball would move [application]?'' And, an evaluation comment was tabulated in unstructured reflections whenever a sentence contained a comment on aspects of ES learning. The following two excerpts illustrate evaluation codings from unstructured reflections. PT31: ''While I was working on part 2, I found that it was hard to determine if the student had a misconception or if they just did not understand what I was asking them [evaluation].'' PT10: ''Even though Billy was able to tell me that the steeper the incline, the more weight is required to move an object, I think the lesson failed in helping Billy understand how an incline makes work easier [evaluation]. By reading his answers to my questions, I realize that he never really answered this question [evaluation].''

Reflection: The 5th Level of Pedagogical Reasoning Ability. Shulman defines the fifth level of pedagogical reasoning ability as the ability to articulate constructive changes that could be applied to future lessons. A statement in PTs unstructured reflections was coded as a change comment if it referred to changes that could be implemented to improve future lessons, or changes that could be implemented to improve the interview/teaching assignment. A typical change comment is provided in the following excerpt. PT68: ''Perhaps if I could have found a scooter board that one would have been able to properly stand on with both feet, then the child would have been able to properly balance on the scooter board instead of focusing on trying to hold tightly onto the handle bars while performing the activity [change].''

New Comprehension: The 6th Level of Pedagogical Reasoning Ability. Shulman defines the sixth level of pedagogical reasoning ability as the ability to identify the extent of one's conceptual gains that have taken place as a result of the teaching process. Many PTs reflected in a general way upon knowledge gained from the teaching experience in their unstructured reflections. However, since sufficient detail that could allow coder to assess the validity of such claims was typically not provided, these statements were not coded for new comprehension. Therefore, no indicant of new comprehension was coded in this study.

Coding Pedagogical Analogy Use in Teaching Transcripts

A pedagogical use of analogy was coded in teaching transcripts whenever a PT introduced an explicit similarity or difference between two disparate concepts as part of the lesson. The following examples are typical of pedagogical analogy use by PTs in this study: PT49: ''Ok, if this toy figure is representing you in a car in real life, what would this piece of ribbon represent [pedagogical analogy use]?'' PT17: ''When we throw a paper wad up, and it comes back down, and it travels in a parabola (you already know that), do you think it changes speed the same way that the gumball did when you rolled it on the tilted board [pedagogical analogy use]?'' PT23: ''Ok, now I am going to give you these things to play with and you need to try and think of something you could do with those things that will show me the same thing that happens with a ball in a car when the car stops [pedagogical analogy use].''

Results/Discussion

Use of Analogies in Lessons

Of 45 PT lessons coded, 19 were found to contain at least 1 explicit analogy usage, 10 from the treatment group and 9 from the contrast. While the frequency of analogy-based interactions observed in the

Table 3. Pearson correlations between analogy use and various indicants

N=45	*1*	*2*	*3*	*4*	*5*
1. Frequency of analogy use	—	0.459**	0.462**	0.535**	-0.350*
2. Overall meaningful interaction ratio		—	0.608**	0.490**	-0.328*
3. Number of explanation interactions			—	0.591**	-0.233
4. Number of application questions				—	-0.353*
5. Fraction of interactions with jargon					—

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

interview/teaching assignment lesson transcripts was not significantly correlated with treatment/contrast group identity [$F(1,43)=0.838$; $p=0.365$], the frequency of pedagogical analogy use which occurred in transcripts from both groups was significantly correlated with three positive indicants of pedagogical reasoning ability. An examination of the Pearson correlation matrix shown in **Table 3** reveals that the frequency of analogy use in PT lesson transcripts was significantly correlated with the frequency of explanation interactions and application questions. The overall meaningful interaction ratio (the fraction of interactions which did not contain jargon, alternate conceptions, confused conceptions, or trivial conceptions) was also significantly correlated with the frequency of analogy use. Further, a significant inverse correlation existed between frequency of analogy use and frequency of jargon responses.

Interviews conducted with two analogy implementers from treatment and contrast groups, respectively, support the conclusion that the use of pedagogical analogies in teaching transcripts was mostly unintended. Of the four analogy implementers interviewed, only one PT (from the treatment group) had deliberately included analogies as part of the lesson planning process. Indeed, the two interviewees from the contrast group who had used pedagogical analogies in their lessons were not even familiar with the term "analogy." Since analogy-making is undeniably a basic and implicit cognitive process that all humans share (Hofstadter, 2000), the interview results coupled with the correlations illustrated in Table 3 can be interpreted to suggest that those PTs who possessed a meaningful understanding of their target concepts were more likely to spontaneously utilize analogies to assist in explanations. Conversely, PTs who had less comprehension of their target concepts were less likely to use accustomed techniques of explanation and instead, relied more heavily upon the recitation of textbook definitions and jargon in their lessons. While it cannot be concluded that analogy use caused increased levels of pedagogical reasoning ability for most subjects of this study, the remarkable association between analogy use and positive indicants of teaching performance cannot be dismissed. The important question of whether analogy use can influence pedagogical reasoning ability in students who deliberately choose to implement analogy-based pedagogy is addressed in the case study of PT47 which follows this section.

PT47 Case Study

While the course instructor did not require the use of analogy-based pedagogy in the interview/teaching assignment, a small number of treatment group PTs did intentionally utilize the technique in their lessons with ESs with great effect. The case of PT47 is particularly striking since, as a direct consequence of the analogy-based pedagogy instruction, the participant's scores on indicants of pedagogical reasoning ability went from the 3rd percentile before treatment (the lowest score in the treatment group), to the 84th percentile after treatment (see Table 2). This remarkable change after treatment was particularly notable in regard to indicants of comprehension. PT47's low level of prior knowledge of concepts of force and motion, in spite of having two previous courses in introductory physics, is exemplified here in excerpts from PT47's self-analysis of force and motion conceptual understanding submitted in part 1 of the interview/ teaching assignment: ''The equal forces of gravity and the upward push of the ground on our feet, keeps us from lifting off the ground [alternate conception],'' ''If you push a wheelbarrow, it will move [trivial],'' ''If two people are exerting equal energy on each other, they will remain stationary [confused],'' and ''When you are driving a car at a fast pace and you come to a sudden stop, your weight is thrown forward [alternate conception].''

PT47's level of anxiety regarding a lack of conceptual understanding before treatment was reflected in comments made in the participant's unstructured reflections at the end of part 1 of the interview/ teaching assignment: ''I found that I do not remember as much as I should from my physics classes [negative concept affect]. I also found that my understanding of these concepts might match the fourth grade level [negative concept affect]! I fear that when I conduct my interview, my child will be absolutely clueless as to what I am asking of her [negative concept affect].''

The analogy-based lesson demonstrations subsequently performed by the researcher as an illustration of how to implement pedagogical analogies profoundly influenced PT47's conceptual understanding of Newton's Third Law. As indicated in the following excerpt from PT47's unstructured reflections in part 2 of the interview/teaching assignment, this participant was inspired to adapt the analogy-based lesson for teaching: ''I plan to use tug of war and a skateboard to help teach my ES about action/reaction pairs. I had a difficult time understanding this concept until this strategy was used to teach me. I was also a volunteer in class for the tug of war so I learned first hand. My ES will be allowed this same opportunity to learn.''

The following teaching excerpt is taken from the transcript PT47 provided in part 3 of the interview/teaching assignment. The analogy that formed the basis for PT47s lesson was: ''The loosing team in a tug of war is like a person on a skateboard pulling on a rope.''

PT47: ''First, I want you to stand on a skateboard and hold one end of this rope and I will hold the other end. I am going to pull on my end and you pull on yours and we'll see what happens. *(Pulled on rope)* So what happened?''

ES47: ''You pulled me toward you.''

PT47: ''And why did that happen?''

ES47: ''Because I'm on wheels.''

PT47: ''Right. Now I'm going to get on the other skateboard and we're going to have another tug of war, but this time I will also be on a skateboard.'' *(We did so and the skateboards slowly met in the middle.)* ''We met in the middle because we are on wheels and had no way of stopping ourselves without hopping off the skateboard, right?''

ES47: ''Yeah.''

PT47: ''So, you can see that we were pulling with the same amount of force and there was no winner or loser. The only way you can win a tug of war is having your feet firmly placed on the ground. In any tug of war, the same amount of force is placed on the rope from both sides. So if I'm pulling with a force of 10 lbs. on this rope, with what force are you pulling?''

ES47: ''10 lbs.''

PT47: ''Good, let's look at that another way. If we're both holding on to one end of the rope and pulling, what force will be acting on the rope if you let go?''

ES47: ''None.''

When compared to other PT lesson transcripts, PT47's lesson is quite remarkable. PT47 directs the learner to make observations of critical attributes during exploration. PT47 engages the learner in an interactive explanation of the phenomenon using age appropriate terminology. The participant continually probes for understanding, and later in the lesson, challenges the learner to apply the new knowledge about forces and motion to a novel circumstance. Table 2 compares PT47's comprehension scores before and after treatment to those of the treatment group. PT47's total meaningful response ratio increased from 18.9% before treatment to 100% in her lesson transcript. PT47's net inexpert comprehension responses went from 2.0 standard deviations above the group mean before treatment, to 0.94 standard deviations below the group mean on in her teaching transcript. And while PT47's unstructured reflections before treatment included three statements indicating negative affect regarding her level of content knowledge, her unstructured reflection submitted with the teaching transcript included only one negative affect comment referring to her concern about questions that could have arisen during her lesson that were not directly related to her target concept. PT47: ''I personally do not feel I am an expert on action/ reaction pairs and was a little nervous when I asked Shana to come up with other examples [negative concept affect].''

PT47's content knowledge relating to Newton's 3rd Law before instruction was extremely incoherent and fragmented. All of PT47's concept examples submitted to illustrate Newton's 3rd Law in part 1 of the interview/teaching assignment were scored as confused, alternate conception, or trivial (three excerpts are provided in the first paragraph of this section). Similarly, PT47's pretest score on 3rd Law related FCI multiple choice questions was only 20% (See **Table 4**).

Table 4. FCI pre/posttest sub-category means

	3rd Law Subset Mean		*Non-3rd Law Subset Mean*	
	(Pretest)	*(Posttest)*	*(Pretest)*	*(Posttest)*
PT47	20.0%	100.0%	24.0%	16.0%
Treatment group	27.6%	53.8%	22.4%	27.4%
Contrast group	30.0%	40.8%	22.6%	27.2%

The transcript of PT47's lesson demonstrates that the brief analogy-based lesson that was presented by the researcher at the beginning of the analogy workshop acted as a catalyst for this learner to construct a coherent framework of knowledge to interpret Newton's 3rd Law concepts. PT47's perfect posttest score on 3rd Law related FCI multiple choice questions bears out a consistent gain in content knowledge. PT47's score on FCI posttest questions not related to the topic of her lesson remained well below the treatment group mean after treatment.

Treatment /Contrast Group Differences

Many researchers have noted the formidable difficulties learners face in changing their alternate conceptions (Clement, 1993; Duit & Treagust, 2003). Indeed, an analysis of FCI pretest scores highlights the challenges that this population faces in learning science by revealing no significant difference between PTs who had previously taken one or more physics courses and those who had never taken a college physics course [$F(1,47)=0.314$; $p=0.578$]. This result implies that for most PTs in this sample, the successful completion of a physics course was not enough to impact long term learning of the fundamental aspects of Newtonian force and motion concepts. As part of the treatment of this study, the treatment group observed two 5-minute Newton's 3rd Law analogy based lesson demonstrations performed by the researcher. While the demonstration lessons had been designed to illustrate the pedagogical use of analogies, not as instructional interventions, an examination of the 3rd Law subcategory of FCI posttest scores revealed a treatment group mean significantly higher than the contrast group mean after controlling for pretest in an analysis of covariance, [$F(1,50)=4.41$; $p=0.041$]. There was no significant difference between treatment and contrast group means on the FCI posttest questions which did not deal with Newton's 3rd Law after controlling for pretest in an analysis of covariance [$F(1,50)=0.01$; $p=0.932$]. It is noteworthy that the posttest was administered 7 weeks after instruction.

A statistical difference between treatment and contrast groups was also found in the evaluation indicant of Shulman's 4th stage of pedagogical reasoning ability. An examination of PT part 3 unstructured reflections revealed that the frequency of comments regarding the evaluation of student learning was significantly higher in treatment group PTs [$F(1,43)=14.58$, $p=0.000$]. The mean number of evaluation comments (with standard deviation in parentheses) for treatment and contrast groups was 1.95 (1.67) and 0.43 (0.89), respectively. Students in both groups received identical instructions regarding the expectations for their unstructured comments. Interviews after the completion of the study were used to rule out possible alternative explanations for this extraordinary group difference. The frequency of comments regarding changes which could be implemented in future lessons, an indicant of Shulman's 5th stage of pedagogical reasoning ability, was also somewhat higher for the treatment group [$F(1,43)=3.49$; $p=0.068$]. These results can tentatively be interpreted as indications that participation in the analogy workshop predisposed preservice teachers to become more conscious of their elementary student's prior knowledge and degree of learning.

Considering that the entire treatment of this study was limited to a two class-period workshop that received no further attention by the course instructor, it is perhaps not surprising that there were no significant differences found between treatment/contrast groups (alpha=0.05) in most indicants of pedagogical reasoning ability observed in PT lesson transcripts. The average number of meaningful comprehension codings in lesson transcripts was 65.6% in the treatment group and 62.5% in the contrast group [$F(1,43)=1.819$; $p=0.184$]. The mean difference between positive and negative content knowledge affect comments coded in teaching reflections in the treatment group was _0.32. This mean was not significantly different than the mean content knowledge affect of _0.52 observed in the contrast group [$F(1,43)=0.249$; $p=0.620$]. And, as detailed previously, the frequency of analogy-based interactions observed in the teaching assignment lesson transcripts was not significantly correlated with treatment/contrast group identity [$F(1,43)=0.838$; $p=0.365$].

Conclusions and Implications for Future Research

Preservice teachers who have limited prior knowledge of the concepts they intend to teach very often fail to focus on critical attributes of target concepts by composing their lessons around textbook definitions of scientific jargon. Many researchers have studied the efficacy of using analogies to increase comprehension of science concepts. While an objective of this study was not to replicate these findings, a remarkable difference in posttest measures of Newtonian conceptual understanding was found as a result of two extremely brief demonstration lessons that were presented to the treatment group to highlight the use of pedagogical analogies. The fact that the posttest was administered 7 weeks after instruction suggests that the statistical difference in posttest scores reflected a profound learning experience. This statistical difference in posttest scores relating to concepts covered in the two demonstration lessons not only further demonstrates the power of using analogies in teaching, but also has implications for teaching college physics. If 15 minutes of analogy-based instruction could produce a statistical effect 7 weeks after instruction, what sort of effect could be realized in an entire course based on analogy?

An important objective of this study was to investigate the potential efficacy of analogy-based pedagogy in improving the teaching performance of PTs. PT47's case is particularly striking since, as a direct consequence of the analogy-based pedagogy instruction as evidenced in her written reflections, PT47's scores on indicants of pedagogical reasoning ability went from the 3rd percentile before treatment, to the 84th percentile after treatment. PT47's pre/posttest scores on content knowledge demonstrate that her comprehension of Newton's 3rd Law also increased dramatically as a result of the analogy-based lesson planning instruction. PT47's lesson transcript was comparable to the best work found in either group. Before treatment, PT47 was extremely anxious about her ability to teach science. Her frequency of comments reflecting apprehension about physics content knowledge was the second highest in the treatment group and her frequency of alternate conception, confused, trivial, and jargon responses on the pretreatment conceptual self-analysis was the highest in the treatment group. The use of analogy as a teaching tool, as well as a mechanism for metacognition, provided PT47 with a means to approach teaching science that enabled her, for the first time, to conceive of teaching meaningful scientific ideas without relying on empty recitations of scientific facts and terms. PT47's success using the analogy-based pedagogy demonstrated that it is possible for a PT with virtually no prior content knowledge in science to utilize this technique to develop and present a meaningful science lesson.

The use of analogies in teaching transcripts was strongly correlated with other positive indicants of pedagogical reasoning ability (meaningful interactions, number of explanations, number of application level questions, and less use of jargon). When teachers are using analogies, they are by definition focusing on conceptual relationships between elements within the target concept. The correlations reported in Table 3, in conjunction with the gains in pedagogical reasoning ability realized by PT47 as a result of explicitly implementing the analogy-based technique, form a persuasive rationale for including explicit instruction in the generation and implementation of pedagogical analogies as a nominal part of PT instruction. The remarkable group difference between treatment and contrast groups that was observed in the number of unstructured reflections regarding the evaluation of student learning can tentatively be interpreted as indications that participation in the analogy workshop predisposed preservice teachers to become more conscious of their elementary student's prior knowledge and degree of learning. A future study focusing specifically on the impact of analogy-based pedagogy on PTs ability to assess student learning could explore this connection.

The first-year methods course instructor who taught both treatment and contrast group sections was not comfortable requiring the use of analogies in the interview/teaching assignment. Consequently, most treatment group PTs did not intentionally employ the analogy-based explanation/assessment technique in their 5-E lessons. The group differences that were observed between treatment and contrast groups are quite compelling given the brief fraction of class time that was allotted to the treatment and the absence of subsequent endorsement of the methodology by the treatment group course instructor. How might students benefit from a methods course that utilized analogies throughout the semester as an integral element of lesson design? A future study in a methods course where an analogy workshop like the one described here is followed-up by regular practice and analysis throughout the semester could incontrovertibly demonstrate the efficacy of this approach.

PT47's success in using the analogy-based pedagogy would have been even more compelling if the participant had implemented a learner-constructed analogy instead of adapting the teacher constructed analogy that had been used in a demonstration lesson. However, consistent with findings from cognitive science research that identify analogy making as a fundamental aspect of cognition we all share, nearly half of the PTs in this study demonstrated the capacity to creatively develop their own pedagogical analogies for use in teaching. Further, the frequency of analogy use in PT teaching transcripts was found to be significantly correlated with positive indicants of pedagogical reasoning ability. As demonstrated in the interviews conducted in the pilot study, even PTs who were not aware of the term "analogy" were nonetheless able to spontaneously elaborate upon and assess the pedagogical worth of analogies based on a single statement of similarity between familiar concepts. The challenge of science education is then to assist preservice teachers to use analogies when teaching science in the same way they have learned to spontaneously use analogies in their everyday lives. The generative analogy case study provided an example of how the analogy-based technique presented here could be used in a cooperative environment to assist PTs in developing their own critical questions and instruction based on the prior knowledge of learners.

Several improvements could be implemented to enhance any future studies. Additional instruction in the basic structure of analogies and the generation of physical models as exploration devices would certainly enhance the ability of preservice teachers to develop their own pedagogical analogies. Furthermore, additional work needs to be done on how to instruct preservice teachers in methods to critically assess the value of the analogies they create. Preservice teachers would benefit from a systematic methodology that could be routinely administered to help gauge the relative merits of generated analogies. Adaptations of this study could help generalize findings to other populations such as secondary preservice teachers as well as in-service teacher populations.

We are thankful to Dr. Emmett Wright for his guidance in developing the interview/ teaching assignment protocols, Dr. John Staver for his contributions to the study design, and to Dr. Julie Gess-Newsome for her insightful critiques of initial drafts of this manuscript.

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