The effect of professional development on elementary science teachers' understanding and classroom implementation of reform-based science instruction

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Abstract

This investigation characterized changes in teachers' understanding and classroom implementation of problem-based learning (PBL), nature of science (NOS), inquiry instruction, and their students' achievement following participation in the Virginia Initiative for Science Teaching and Achievement (VISTA) Elementary Science Institute (ESI) professional development (PD). The VISTA ESI was aligned with the characteristics of effective PD. The VISTA ESI was assessed through a cluster randomized controlled trials (RCT) design. Treatment teachers (n=199) attended 4-week summer institute with sustained follow-up and coaching throughout the academic year, while control teachers (n=143) received no PD or support. Data included pre-/post-/year-end Perceptions surveys, post-summer institute/year-end interviews, classroom observations, and state student achievement scores. Data were analyzed using multiple methods approach that included systematic data analysis, inferential statistics, and constant comparative approaches. Results indicated the majority of teachers expressed either partially or fully aligned understandings of PBL, inquiry, and NOS instruction following the VISTA ESI. Further analysis of classroom observations indicated the PD improved teachers' implementation of PBL, inquiry, and NOS into their classroom instruction compared to control teachers. Most teachers expressed high levels of satisfaction with the main components of the VISTA ESI; the situated nature of the PD appeared to contribute to the overall effectiveness of the experience. Evaluation of the impact of the VISTA ESI on grade 5 science standards of learning test scaled scores did not reveal a statistically significant difference between treatment and control conditions; however, a comparison of students in the disability subgroup yielded differences. Treatment students with disabilities scored higher than control teachers' students with disabilities when evaluated using a slightly liberal alpha level, $t(86.49) = 1.94$, $p = .056$, favored treatment teachers' students by an average of 11.52 points. The results of this study have the potential to inform PD supporting in-service elementary educators' implementation of reform-based science practices.

Introduction

The *Framework for K-12 Science Education* identifies scientific literacy as a principal goal of science education (National Research Council [NRC], 2012). Yet, achieving scientific literacy is complex, challenging, difficult, and requires students be proficient at: knowing, using, and interpreting scientific explanations of the natural world, generating and evaluating evidence, understanding the nature of and how scientific knowledge is developed, and participating productively in scientific practice and discourse (NRC, 2007). Students develop scientific literacy through student-centered instruction addressing three important aspects of science: scientific knowledge, processes of science, and nature of science (NOS) (NRC, 2012). Effective science instruction should promote students' conceptual understanding and use of science concepts, provide students opportunities to learn about and practice science inquiry and the skills necessary to conduct inquiry, and include explicit instruction about the nature of scientific knowledge (e.g. Lederman, 2007; NRC, 2012). This type of instruction places the teacher in the role of facilitator of learning and provides students with opportunities for collaboration, scientific discussion, and debate (NRC 2012).

Through a randomized control trial, this investigation evaluated changes in teachers' confidence, understandings, and classroom implementation of reform-based practices following participation in the Virginia Initiative for Science Teaching and Achievement (VISTA) Elementary Science Institute (ESI) professional development (PD). As well-prepared teachers have the greatest impact on student achievement and facilitate development of students' scientific literacy (e.g. Bolyard & Moyer-Packenham, 2008; Druva & Anderson, 1983; Heller, Daehler, Wong, Shinohara, & Miratrix, 2012; Roth, Garnier, Chen, Lemmens, Schwille,& Wickler, 2011), documenting PD that facilitates teachers' reform-based science instruction is essential.

Reform-based Science Instruction

Inquiry. Inquiry instruction seeks to help students achieve scientific literacy through active and engaged learning. Asking questions, planning and carrying out investigations, analyzing and interpreting data, constructing explanations, and obtaining, evaluating, and communicating information are some of the key practices described in the *Framework for K-12 Science Education* (NRC, 2012). Taken together, these practices constitute elements of scientific inquiry (Martinez, Borko, & Stecher, 2012). One simplified definition describes inquiry instruction as students analyzing data to answer a research question (Bell, Smetana, & Binns, 2005). Engaging students in scientific inquiry and the scientific practices that support inquiry help students develop scientific literacy (NRC, 2012). Research suggests that engaging students in scientific inquiry can lead to achievement gains in science content understanding and critical thinking and problem solving skills (Bransford, Brown, & Cocking, 2000).

Nature of Science. Another important aspect of scientific literacy is NOS. Instruction about NOS involves teaching students the values and assumptions inherent in the development of scientific knowledge. Researchers have converged on a set of NOS ideas appropriate to teach K-12 students. These ideas include:

(1) Scientific knowledge is empirical, reliable and tentative, based on observation and inference
(2) Scientific theories and laws are different kinds of knowledge; and
(3) Many methods are employed to develop scientific knowledge (Achieve, 2013; Lederman, 2007). Effective NOS instruction makes these ideas explicit to students (e.g. Abd-El-Khalick & Akerson, 2004; Akerson & Hanuscin, 2007; Bell, Abd-El-Khalick, & Lederman, 1998) and research suggests that NOS instruction can enhance students' content knowledge and increase student achievement (Cleminson, 1990; Peters, 2012; Songer & Linn, 1991). A continued debate among NOS researchers is the role context (e.g. history of science, socio-scientific issues, engaging in scientific inquiry, content) plays in supporting NOS instruction. While the Next Generation Science Standards (NGSS) promotes contextualized NOS instruction (NRC, 2012), empirical research is equivocal regarding whether a contextualized approach is more effective than a noncontextualized or continuum approach (e.g. Bell, Matkins, & Gansneder, 2011; Bell, Mulvey, & Maeng, in review; Herman, Clough, & Olson, 2013).

Problem-Based Learning. One instructional model that provides a context for NOS and inquiry to promote scientific literacy is problem-based learning (PBL). Students are challenged to investigate a meaningful, real-world problem and present solutions to the problem based on their findings (Sterling, 2007). PBL incorporates an authentic context, problems with multiple or divergent solutions, inquiry experiences, and collaboration among students (Hmelo-Silver, 2004). Additionally, it facilitates students' real-world application of science knowledge and methods through student-centered instruction (Chin & Chia, 2004). PBL also has the potential to provide opportunities for teachers to explicitly address NOS in instruction, engage students in inquiry-based activities, and increase student achievement (Sterling, 2006; Sterling, Matkins, Frazier, & Logerwell, 2007).

A number of studies suggest the effectiveness of reforms-based science instruction is influenced by teacher characteristics including their understandings, beliefs, and practices. For example, Kanter & Konstantopolos (2010) found teachers' pedagogical content knowledge was positively correlated with improvements in students' science achievement and teachers' use of inquiry-based activities improved their attitudes toward science. In a study of upper elementary teachers, Roth et al. (2011) found reforms-based teaching practices including hands-on investigations, significantly predicted students' science learning.

Changing Teachers' Understandings and Practices

Changing teachers' understandings and practices involves considering both the internal and external factors that influence teachers' instruction. Reform-based approaches to science, such as PBL, represent dramatic shifts from traditional instruction and have proven difficult for teachers to implement (Loucks-Horsley & Matsumoto, 1999) and previous attempts to prepare teachers to teach inquiry and NOS have mixed results (e.g. Gates, 2008; Lederman, 2007; Roehrig & Luft, 2004; Schneider, Krajcik, & Blumenfeld, 2005). Barriers to implementation of reform-based instructional methods such as PBL, NOS, and inquiry can be influenced by teachers' confidence about and understanding of these constructs (Lakshmanan, Heath, Pearlmutter, & Elder, 2011; Ramey-Gassert, Shroyer, & Staver, 1996; Sandholtz & Ringstaff, 2014).

In his Social Learning Theory, Bandura (1986) describes confidence or personal self-efficacy as a component of self-efficacy. The science education literature is replete with studies on the factors that influence elementary teachers' confidence in their ability to effectively teach science, akin to personal science teaching efficacy (e.g. Ramey-Gassert & Shroyer, 1992). Factors that contribute to high personal science teaching efficacy include: strong science background, desire to implement reform-based instruction, and elementary science teaching experience (e.g. Cantrell, Young & Moore, 2003; Enochs, Scharmann, & Riggs, 1995; Mullholland, Dorman, & Odgers, 2004; Ramey-Gassert, Shroyer, & Staver, 1996). In addition, a number of studies suggest elementary teachers' confidence (i.e. personal science teaching efficacy) may influence their reform-based instructional practices (e.g. Lakshmanan, Heath, Pearlmutter, & Elder, 2011; Ramey-Gassert, Shroyer, & Staver, 1996; Sandholtz & Ringstaff, 2014).

In addition to science teacher confidence, barriers contributing to teachers' reluctance to implement reform-based science instruction relate to teachers' knowledge of science content, understandings of NOS, and/or familiarity of pedagogical approaches that support reform-based instruction (e.g. Johnson, 2006, 2007; Lederman, 2007; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010; Supovitz & Turner, 2000). Other barriers to reform-based instruction are institutional (e.g. standardized testing, disconnect between district-mandated content objectives and exploration of concepts through investigation) and technical (e.g. lack of resources or curricular materials) (Arora, Kean, & Anthony, 2000; Bauer & Kenton, 2005; Blumenfeld, Krajcik, Marx, & Soloway, 1994; Johnson, 2006, 2007; Keys & Bryan, 2001; Keys & Kennedy, 1999; Yerrick, Parke, & Nugent, 1997).

Further, effective NOS and inquiry instruction does not come easily for most teachers (e.g. Akerson & Abd-El-Kalick, 2003; Bell, Abd-El-Khalick, & Lederman, 1998; Lederman, 2007; Lederman, Lederman, Kim, & Ko, 2012). For example, some teachers conflate inquiry instruction with hands-on instruction and teaching NOS with inquiry and process skills (Crawford, 2000; NRC, 2000). Still other teachers do not recognize that NOS instruction must explicitly address targeted NOS conceptions through student reflection and discussion to be effective (e.g. Bell, Blair, Crawford, & Lederman, 2003; Bell, Mulvey, & Maeng, 2012; Hanuscin, Akerson, & Phillipson-Mower, 2006; Khishfe, 2008; Scharmann, Smith, James, & Jensen, 2005; Schwartz, Lederman, & Crawford, 2004).

There is clear understanding about the importance of NOS, inquiry, and PBL in science instruction. Likewise, there is sufficient research on the barriers that inhibit teachers from implementing reform-based science practices. However, little is known about how PD programs that support elementary teachers' integration of PBL as a context for classroom implementation of NOS and inquiry practices promote teachers' confidence in implementing reform-based instruction.

Effective Professional Development

The science teacher education community is committed to PD designed to increase teachers' knowledge and classroom implementation of reform-based pedagogy (Johnson, 2006, 2007; Loucks-Horsley et al., 2010; Supovitz & Turner, 2000). Changing teachers' practice is a time-consuming and complex process (Desimone, 2009; Lotter, Harwood, & Bonner, 2006). Thus, the characteristics of effective professional development served as the conceptual framework for the present investigation. The literature indicates that for science teacher PD to elicit desired changes in teachers' practices, it should be *sustained and ongoing* (e.g. Johnson, Khale, & Fargo, 2007; Supovitz, Mayer & Kahle, 2000). This refers to the total hours of the PD and the amount of time over which the PD occurs (Desimone, 2009). Research indicates the length of the PD must be sufficient in order for teacher change to occur (Cohen & Hill, 2001; Supovitz & Turner, 2000).

There is also evidence that *expert coaching* (Loucks-Horsley et al., 2010; Luft et al., 2011) and *coherence* (Birman et al., 2000) can facilitate teachers' implementation of new teaching strategies into their instruction. Coherence is indicative of the ability of PD to be integrated into a program of teacher learning (Birman et al., 2000). In order for PD to be effective it must build on previous activities, be followed with future PD activities, be consistent with teacher goals, and draw teachers into dialogues about their experiences with other teachers and administrators in their own school (Birman et al., 2000). Providing teachers with expert coaching is one way to continue the PD through a program of teacher learning and supports teachers as they attempt new practices (Grierson & Woloshyn, 2013; Luft et al., 2011).

Effective PD also acknowledges teachers' current beliefs and practices, is content focused, provides teachers with opportunities for active learning, and fosters collective participation (Desimone, 2009; Loucks-Horsley et al., 2010; Supovitz & Turner, 2000). *Content focus* refers to the ability of PD to support teachers in understanding subject matter, learners and learning, and teaching methods (Loucks-Horsley & Matsumoto, 1999). Generic PD focusing on methods alone has been shown to be ineffective (Cohen & Hill, 1998; Kennedy, 1998). It is important for PD to focus on content and methods in order to increase teacher learning and skills (Birman et al., 2000; Desimone, 2009; Kennedy, 1999; Loucks-Horsley & Matsumoto, 1999).

Teachers should be engaged in *active learning* during PD (Desimone, 2009). This can take numerous forms including: observing other teachers, observing or videotaping lessons with opportunities for reflection, reviewing and analyzing student work, leading or participating in discussions, developing lesson plans, or practicing a teaching method in a group setting. This list is not exhaustive but highlights the type of activities that can lead to teacher learning (Garet et al., 2001).

A final characteristic of effective PD is *collective participation*. Collective participation occurs when teachers from the same school, department, subject, or grade attend PD together (Desimone, 2009). The presence of teachers from similar arenas can enable conversations and discussions that enhance teacher learning through increased active learning and coherence (Birman et al., 2000; Borko, 2004; Loucks-Horsley & Matsumoto, 1999). Other advantages include the opportunity to develop a professional learning community and for teachers to discuss changes to their curriculum as a group (Birman et al., 2000).

When PD incorporates all of these components, research suggests there is the potential to improve student achievement (Buczynski & Hansent, 2010; Johnson et al., 2007; Wallace, 2009; Whitworth & Chiu, 2015; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). For example, sustained, on-going PD has been directly related to student achievement in science, reading, and mathematics (Yoon et al., 2007). Geier and colleagues (2008) identified coherent PD aligned with district curriculum as having the potential to increase student achievement in science. Furthermore, effective PD has the potential to narrow the achievement gap and increase student achievement in science, especially for ELL, low performing, and low socioeconomic status students (Lee, Deaktor, Enders, & Lambert, 2008). However, little is known about how PD that is sustained, ongoing, and coherent, incorporates a coaching component, and an authentic content-based context impacts teacher understandings and confidence about PBL, NOS, and inquiry and student achievement in science.

The VISTA ESI that served as the context of the present investigation was guided by these key components of effective PD with a goal of increasing student achievement (Desimone, 2009; Loucks-Horsley et al., 2010). The structure of the ESI was informed by two smaller-scale science teacher PD programs that reported statistically significant improvement in science instruction and student performance (Sterling & Frazier 2010; Sterling, Matkins, Frazier, & Logerwell, 2007). Specifically, the ESI had the primary goal of supporting elementary science teachers' inquiry-based and explicit NOS instruction in the context of a PBL instructional model. A second goal was to facilitate a common understanding statewide of reform-based science instruction with the goal of supporting teachers' effective science practices. To support this second goal, principals and science coordinators also participated in some aspects of the ESI PD. The ESI was sustained and ongoing, incorporated expert coaching, provided coherent, content focused, active PD through collective participation as summarized in Table 1.

Table 1
Components of effective PD and strategies for incorporation into the ESI

Component	Strategies for incorporation in ESI
Sustained, On-going	Intense 4-week summer institute, Follow-up sessions, Attendance at state-wide science conference
Expert Coaching	Coaches worked with teachers during the summer and for 22.5 hours throughout the academic year
Coherence	Teachers attend in school teams, Principals and district science coordinators attend summer institute for one day, Coaches assigned, Follow-up sessions, Aligned with Virginia Standards of Learning
Content Focus	Researchers in science fields provide content support and instruction, Implementers situate all pedagogy conversations in content
Active Learning	Teachers experience new pedagogy as students, Practice new pedagogy in a camp setting with students, Observe and provide feedback to one another, Develop unit plans to implement during the academic year
Collective Participation	Teachers attend in school teams

Purpose

While we know that PD that incorporates effective characteristics can positively influence student achievement in general, it is unclear how such PD changes elementary science teachers' understandings and confidence and their students' science achievement. Further, few studies employ rigorous, randomized controlled trial to explore the relationship between professional development and teacher understandings, confidence, and practice. Even fewer studies explore the effects of teacher professional development on the science achievement of their students (Heller et al., 2012). In addition, most studies of the effectiveness of professional development employ teacher self-report data rather than classroom observations of teachers' instruction (Roth et al., 2011). Thus, the purpose of this investigation was to characterize changes in elementary teachers' understanding and classroom implementation of PBL, NOS, and inquiry instruction following a PD experience aligned with the characteristics of effective PD through a randomized controlled trial. We also explored their students' achievement on state end of course assessments. The following research questions guided the investigation:

1) How did teachers' understandings of PBL, inquiry, and NOS instruction change as a result of participation in the VISTA ESI and how did these understandings compare to control group teachers?
2) How did teachers' confidence in implementing PBL, inquiry, and NOS change after participation in the VISTA ESI and how did these teachers' confidence compare to control group teachers?
3) How did teachers' classroom practices of PBL, inquiry, and NOS change as a result of participation in the VISTA ESI and how did these teachers' practices compare to control group teachers?
4) How did treatment teachers' students' achievement on state end-of-course assessments compare to control teachers' students?

Methods

This multiple methods study employed a cluster randomized controlled trial (RCT) design to evaluate changes in participants' confidence, knowledge, and practices and their students' achievement as a result of the VISTA ESI compared to the control group. A qualitative, constant-comparative approach was employed to ascertain participants' perceptions of the key components of the VISTA ESI they perceived as facilitating their confidence, understanding, and practices.

Participants/Context. For each of the two cohorts, school teams of 4th through 6th grade teachers from a mid-Atlantic state were randomized via straight random assignment into treatment or control groups. Retained in the treatment condition across three cohorts of the ESI were 199 teachers from 72 elementary schools. Participants retained in the control condition included 143 teachers from 60 different elementary schools. Demographic data (Table 2) were self-report and all participants were assigned a participant ID.

Table 2
VISTA Elementary Science Institute participant demographic data (Cohorts 1-3)

Condition	Gender		Ethnicity				
	Female	Male	Caucasian	African American	Hispanic	Asian	Native American
Treatment (n=199)	168 (86.2%)	27 (13.8%)	150 (76.9%)	39 (20.0%)	3 (1.5%)	2 (1.0%)	1 (.5%)
Control (n=143)	122 (87.8%)	17 (12.2%)	109 (79.0%)	25 (18.1%)	3 (2.2%)	1 (.7%)	0 (0%)

Note. Not all teachers reported gender and ethnicity information. Percentages reported are for respondents to each demographic question.

Treatment teachers received an intensive 4-week PD with sustained follow-up and coaching throughout the academic year, while control teachers received no PD or support. The 4-week (152 contact hours) summer institute was implemented at four universities. Combining participants across sites and cohorts was warranted as program evaluation documented that the summer institute was planned and implemented consistently and with fidelity across sites and cohorts (Bell, Konold, Maeng, & Heinecke, 2014). Teams of university science educators, scientists, engineers, and science and mathematics specialists, co-planned and facilitated the summer institute. Table 3 identifies how the activities in the ESI were aligned with the characteristics of effective PD.

Table 3

Alignment of the components of effective PD with ESI activities

ESI PD Timeframe	ESI Activities	Corresponding Effective PD Components
Week 1	Teachers attend in school teams	Collective Participation
	Instruction on Inquiry, NOS, and PBL situated within content	Active Learning &
	Modules on integrating math, technology, and engineering	Content-Focused
	Module on utilizing discourse in the classroom	
	Collaborative development of PBL unit for camp	
	Introduced to coaches	Expert Coaching
	All content aligned to Virginia Standards of Learning (SOLs)	Coherence
Week 2 & 3		
Camp Week	Collaborative PBL unit aligned with Virginia SOLs	Coherence
	Teachers practice new pedagogy with students during camp	Active Learning
	Teachers receive feedback from others and coaches	Expert Coaching
Module Week	Field work and content instruction with researchers in the field	Content-Focus
	Modules on literacy integration, teaching science to ELL	Active Learning &
	students, and using simulations	Content-Focused
	All content aligned to Virginia Standards of Learning	Coherence
Week 4	Teachers work with school teams to develop PBL unit for the	Collective Participation
	academic year	Active Learning
	Teachers work with principals and science coordinators	Coherence
	Teachers work with coaches to plan PBL unit	Expert Coaching
Academic Year	Implementation of PBL Unit planned during ESI	Active Learning
	Follow-up sessions (14 hours)	Sustained, On-going
	Attendance at state science teachers' conference	Coherence
	Coaching sessions (22.5 hours)	Expert Coaching

During the first week of the ESI teachers participated in active, content-focused PD around NOS and inquiry within the context of PBL, as well as modules on integrating math, technology, engineering, and discourse into instruction. As a group and with implementer support, teachers co-planned a PBL unit to be taught during a two-week summer camp for high-needs 4th-6th grade students. During the second and third weeks, teachers were split into two groups. During week two one group started the implementation of the PBL for the summer camp component of the ESI, received feedback and reflected through debrief discussions at the end of each day. The other group continued the PD with active, content-focused PD with researchers in the field and experience modules on literacy integration, teaching science to ELL students, and using simulations to teach science. During the third week, the two groups switched places. The fourth week teachers worked in their school teams to plan a PBL unit to be implemented in their own classrooms during the academic year. During this week teachers also had the opportunity to interact with their principals and science coordinators who attended the ESI for a day. Throughout, the four weeks coaches attended three days to work with and support teachers as they developed and planned their units. During the academic year, they participated in at least 14 hours of follow-up sessions and attended the annual state science teachers' conference. Coaches worked with teachers 22.5 hours across the academic year to co-plan, co-teach, observe, promote reflection, and provide feedback on teachers' science instruction. See

Mannarino, Logerwell, Reid, & Edmonson (2012) for a complete description of the VISTA ESI intervention.

Data Collection and Analysis. Data for all treatment and control teachers consisted of Perceptions surveys administered pre- and post- institute and at the end of the year, follow-up interviews of a subset of VISTA ESI teachers, videotaped classroom observations, and observation forms. The unit of analysis for these data was the individual teacher. In addition, data were collected and analyzed on each school teams' fifth grade students' achievement on the state end of course assessment.

Perceptions surveys. Perceptions surveys were designed to elicit teachers' understanding of key constructs (PBL, inquiry, and NOS instruction) and perceptions of the effectiveness of the VISTA ESI. Face and content validity for the survey was supported by review by a panel of 3 number of experts with backgrounds in science education and research evaluation. These surveys contained both Likert-scale and open-ended items. For Likert-scale items, the scale ranged from 1 (not very proficient) to 5 (highly proficient). Teachers were also asked to define and describe PBL, inquiry, and NOS instruction and indicate the confidence with which they implement these and educational technologies into their science instruction. Common to the post- and year-end Perceptions surveys were additional Likert-scale and open-ended questions designed to elicit teachers' perceptions of the strengths and weaknesses of the VISTA ESI, the quality of the VISTA ESI relative to other PD experiences, and teachers' intent to implement what they learned.

Teachers' pre-, post- PD, and year-end definitions and descriptions of PBL, NOS, and inquiry instruction in the classroom were analyzed using systematic data analysis (Miles & Huberman, 1994) and a multi-part rubric validated for face and content validity (Appendix A). Teachers' responses were coded as not aligned, partially aligned, and fully aligned for definitions and implementation of PBL, inquiry, and NOS instruction. Raters also coded teachers' understanding that effective NOS instruction should be explicit. Two raters independently coded each participant's open-ended responses related to PBL, inquiry, and NOS and inter-rater agreement was established (~90%) by comparing independent analysis across approximately 30% of the data. Examples of coded responses are provided in Appendix A.

Data from Likert scale items on each participant's pre-, post-, and year-end Perceptions survey were analyzed using descriptive and inferential statistics. Univariate analysis of variance was used to compare treatment and control participants' year-end confidence in integrating PBL, inquiry, and NOS into instruction, when outcome scores were controlled for pre-assessment confidence.

Interviews. Following analysis of the pre- and post-Perceptions survey, approximately 20% of teachers (n=40) across cohorts and sites were purposefully selected for a follow-up semi-structured interview about their experience. These participants were selected because their pre- and post-intervention survey responses indicated little, moderate, or great changes in their proficiency of key VISTA objectives (inquiry, PBL, and NOS instruction). Interview questions elicited teachers' perspectives on the most and least valuable aspects of the VISTA ESI, components of the VISTA ESI they planned to implement, and their suggestions for VISTA ESI improvement. These interviews also served as a member-check of survey responses.

Analytic induction as described by Bogdan and Biklen (1992) was used to analyze the open-ended survey responses and follow-up interviews to characterize participants' perceptions of how the key VISTA ESI components aligned with characteristics of effective PD and facilitated their understandings, confidence, and practices. Patterns and common themes in responses were identified in the data set with the goal of characterizing the experiences of teachers. Data were initially coded based on these categories and other categories (e.g. intentions to implement) were added as necessary. Interview transcripts were coded to identify instances in program components supported participants' understanding, confidence, and/or classroom implementation. Multiple coders ensured the codes accurately reflected the data. From these patterns, preliminary categories were developed and refined through comparison with the original data set.

Classroom observations. Classroom observations were conducted four times at regular intervals throughout the academic year, within the same three-week interval for all teachers. Observers visited each teacher's classroom once during each observation period to videotape their science instruction. Observers also collected contextual information regarding the observed lesson per a validated observation protocol. This information included objectives, what lessons occurred prior to the observation, and what teachers anticipated teaching in lessons that followed the videotaped lesson. Classroom observation data were analyzed with a modified and validated version of the CETP-COP observation instrument (Appeldoorn, 2004). The CETP-COP instrument assessed four dimensions or items related to teachers' science instruction (i.e., instructional approaches, classroom engagement, cognitive activity, and quality of lesson). Instruction, classroom engagement, and cognitive activity scores were recorded at 5-minute intervals across the entire lesson duration. For instruction codes, which are reported in the present investigation, the presence (1) or absence (0) of inquiry, explicit NOS instruction, and whether the observed lesson was part of a PBL unit were coded.

School (teacher) team-level analyses. As the unit of randomization was the school team level, analysis of student achievement data (described below) occurred at the school team level. In addition, since the achievement test changed between cohorts 1 and 2, only student achievement for cohort 2 and 3 school teams' students were assessed in this analysis. Therefore, in addition to the individual teacher-level descriptive analyses of confidence, understandings, and practices described above for all teachers in cohorts 1-3, we also conducted school-team level analyses of treatment and control school team differences in these constructs in cohorts 2 and 3 whose students were included in the student achievement analyses. School team means were calculated for each construct and univariate analysis of variance (with pre-score as the covariate) was employed to explore differences between treatment and control teacher teams' year-end understandings of and confidence in implementing PBL, inquiry, and NOS when controlling for pre-understanding. Independent *t*-tests were used to compare differences in treatment and control teacher teams' incorporation of PBL, NOS, and inquiry into instruction each of the four time points. Since each of the three variables (PBL, inquiry and NOS) was coded dichotomously for each teacher on the team, (observed=1) or (not observed=0), teacher team means were calculated and ranged from 0 (no teachers on the team used the instructional approach) to 1 (all teachers on the team used the approach).

Student Achievement Data. State assessments in science are not given in fourth or sixth grade, therefore student achievement data was only available for 5th grade teachers' students. Thus, at the conclusion of the study, 84 teams that included at least one 5th grade teacher remained in the study (N=61 treatment, N=23 control). Baseline balance testing through list-wise deletion of students who did not have both pre-assessment (3rd grade scores) and outcome (5th grade scores) resulted in a working sample of 79 teacher teams (N=57 treatment) and (N=22 control) and 3,556 students. Evaluation of the impact of the VISTA ESI on student level grade 5 science standards of learning (SOL) test scaled scores was examined through a two level model in which students were nested within teacher teams (Appendix C). Hierarchical linear regression was employed with backward selection to determine which potential covariates to include in the model. In this approach, an initial model is fit to the data with all of the potential covariates included as covariates in the model. The covariate with the largest p-value (> 0.20) was dropped from subsequent models. This step was repeated until the only control variables that remained in the model met the $p<0.20$ criterion. Covariates at both student and school level were assessed for inclusion in the final model using this criterion. Potential student level covariates included: minority status, gender, free/reduced lunch program participation, and disability status. Potential school level covariates included: percent limited English proficiency (LEP), 3rd grade science percent pass rate. Potential teacher level covariates (averaged across teachers within a team and included at the school level) included: pre-PD pedagogical content knowledge and years' experience. Ultimately, third grade science SOL test scaled scores, student disadvantaged status, student disability status, and school percent LEP were used as covariates in the final impact model. These school team covariates were selected due to their known linkages to student achievement outcomes. Subgroup analyses were also conducted for at-risk subgroups as defined by the state (i.e. LEP, students with disabilities, and economically disadvantaged students) (Appendix B). The same student level impact procedures described above were also carried out separately for these subgroups.

Results

Below, we describe changes and the components of the ESI participants indicated influenced their in teachers understandings, confidence, and practices. In addition, we discuss outcomes in student achievement for treatment teams' students versus control teams' students. Overall, treatment teachers' understandings and confidence in implementing reform-based practices were significantly greater than those of control teachers after participation in the PD. In addition, treatment teachers implemented reforms-based practices significantly more than their peers in the control group, with the exception of inquiry during the third observation period. Finally, though there were no differences between treatment and control conditions for student achievement, statistically significant differences between treatment teachers' students with disabilities and control teachers' students with disabilities existed that favored treatment students.

Understandings of Reform-based Instructional Strategies

The extent to which participants' pre-, post-, and year-end-VISTA ESI definitions of and descriptions of classroom implementation of PBL, NOS, and inquiry instruction (as defined in Appendix A) were aligned with VISTA constructs was assessed through participants' open-ended Perceptions survey responses (Tables 4 and 5). Results of this analysis indicate treatment participants' knowledge of PBL improved substantially, from 0.5% fully aligned pre-instruction to 34.5% fully aligned post-instruction. Participants' understandings of inquiry and NOS improved less, from 4.1% to 23.7% fully aligned for inquiry and from 0% to 20.1% fully aligned for NOS prior to and following the summer institute. However, these results also indicate participants' made substantial shifts pre- to post-summer institute from not aligned to partially aligned in their understandings of inquiry and NOS. Further, it appears participants' fully-aligned understandings continued to improve for inquiry and NOS understandings from the end of the summer institute to the end of the academic year. Some reversion to not aligned understandings occurred for those expressing partially aligned understandings of NOS. For PBL, summer-end to year-end understandings appeared to revert.

Treatment and control teacher teams' year-end understandings of PBL, inquiry, and NOS understandings and instruction were compared via univariate analysis of variance (Table 6). Results were statistically significant for all indicators (p-values less than 0.001) favoring the treatment group outcomes. Treatment group means approached the middle of the scale (partially aligned) for each construct. The greatest differences were treatment and control groups' understandings of NOS.

Many participants noted how the structure and components of the PD facilitated her understanding of PBL, inquiry, and NOS. Specifically, one participant summarized, "the format for VISTA is easy to participate in and seems functional. I like the way we were learners first, then planned and implemented a PBL to practice, and then had time to work on beginning our own. (E3-T310, Post-Perceptions Survey). Another indicated, "Well, it was easy to learn them because I was doing them. I think if they just taught us what it was, it wouldn't have been as concrete as participating in it and planning it for campers." (E3-T370, Interview). This teacher continued:

> We were given an opportunity to learn the series of it first, and then we were given an opportunity to actually apply what we've learned through a trial and error type thing. And then, even further, we were given an opportunity to assess others who were going through the teaching opportunity, so we got to see it from three different aspects, which really helped give more dimension to the learning process rather than just being in kind of like a direct instruction type role. (E3-T370, Interview).

This participant specifically mentioned the opportunity to observe other teachers teaching in the camp setting and teaching in the camp setting herself, as facilitating her understanding of PBL, inquiry and NOS. This evidences the importance of including coherent, active learning opportunities for teachers in the PD. The active learning of practicing new pedagogy in a content-focused camp allowed teachers to experience, observe, and provide feedback to one another providing coherence and an opportunity for expert coaching within the intensive ESI. Another participant indicated that working with other teachers who taught in different types of school from herself was beneficial to her learning, and specifically mentioned the camp as facilitating the development of her understanding of reforms-based strategies:

> It's cool to work with different teachers that come from a different building with a different demographic of children. And being able to work with different practices and strategies with them. Especially working in groups [during camp weeks], the teachers that I had to work with teach my unit, all come from different schools. I would put that high on the list too also, with being able to work with the kids [during camp] before we left. (E2-T267, Interview)

Participants universally acknowledged the value of the sustained, on-going PD model that emphasized active learning through collective participation situated within a coherent context. Regarding opportunities to practice what she learned in an authentic context, one participant explained, "Many of the concepts and strategies have been explicitly introduced, modeled, and practiced" (E3-T387, Post-Perceptions survey).

Table 4

Treatment Participants' Understandings of PBL, Inquiry, and NOS Instruction (Cohorts 1-3)

	Pre-Instruction (n=197)			Post-Summer Institute (n =194, 98.5% responding)			Year End (n = 192, 97.5% responding)		
	Not Aligned	Partially Aligned	Fully Aligned	Not Aligned	Partially Aligned	Fully Aligned	Not Aligned	Partially Aligned	Fully Aligned
PBL	178 (90.4%)	18 (9.1%)	1 (.5%)	80 (41.2%)	47 (24.2%)	67 (34.5%)	100 (52.1%)	57 (29.7%)	35 (18.2%)
Inquiry	122 (61.9%)	67 (34%)	8 (4.1%)	64 (33%)	84 (43.3%)	46 (23.7%)	50 (26%)	82 (41.6%)	60 (31.3%)
NOS understandings	184 (93.4%)	13 (6.6%)	0 (0%)	56 (28.9%)	99 (51%)	39 (20.1%)	76 (39.6%)	72 (37.5%)	44 (22.9%)

Table 5

Treatment Participants' Understanding That Effective NOS Instruction Is Explicit (Cohorts 1-3)

	Pre-Instruction (n=197)		Post-Summer Institute (n = 194, 98.5% responding)		Year End (n =192, 97.5% responding)	
	Implicit	Explicit	Implicit	Explicit	Implicit	Explicit
NOS instruction	197 (100%)	0 (0 %)	120 (61.9%)	74 (38.1%)	129 (67.2%)	63 (32.8%)

Table 6

Cohort 2 and 3 School-team level understanding of key constructs

	Pre-PD Group Means		Year-end Group Means		
	Treatment (n=56)	Control (n=37)	Treatment (n=56)	Control (n=37)	Sign.
PBL	1.06 (.19)	1.14 (.24)	1.66 (.67)	1.05 (.15)	**<.001**
Inquiry	1.44 (.38)	1.66 (.60)	2.12 (.54)	1.61 (.54)	**<.001**
NOS Understandings	1.08 (.17)	1.21 (.31)	1.93 (.55)	1.09 (.23)	**<.001**
NOS Instruction	1.00 (.00)	1.00 (.00)	1.36 (.37)	1.06 (.20)	**<.001**

Note. Adjusted = Year end (delayed post) means adjusted for school team baseline pre- measure, school % Ell, % school-level science pass rate, average team teacher years' experience, school % FRLP, % minority. For PBL, inquiry, and NOS understandings, scale ranges from 1 = not aligned to 3 = fully aligned. For NOS instruction, scale is dichotomous: 1 =implicit, 2 = explicit.

Most participants perceived that they had a good understanding of the concepts. For example, one participant described the process through which the facilitators introduced the concepts:

> We practiced a PBL scenario and of course we set one up for the students, and we practiced all of that and then the same for the NOS… we were actually practicing it ourself…. I definitely have a better understanding now… I've always kind of put inquiry and hands-on as being synonyms. And now I can see that the inquiry is where the students are actually asking the questions themselves and using evidence, rather than the teacher just generating everything. (E3-T310, Interview)

This participant clearly perceived value in the structure of how the concepts were introduced during the ESI and indicated that following the ESI she had a better understanding of the constructs as a result.

Confidence in Teaching PBL, Inquiry, and NOS

The ESI program participants' confidence levels in incorporating PBL activities, inquiry-based activities, and explicit NOS instruction improved prior to and following the ESI (Table 7). Paired sample t-tests indicated that for all assessed indicators, treatment teachers exhibited a statistically significant change in their confidence implementing PBL, inquiry, and NOS (all p values < 0.05) pre- to post-PD.

Table 7

Paired Samples t-tests for Treatment Participants' Pre-ESI/Year End Confidence (Cohorts 2-3, n=50)

Paired Indicator (Pre-ESI/Year End)	Pre PD	Year-end PD	t	Sign.
PBL activities	2.44 (.74)	3.11 (.94)	10.38	**<.001**
Inquiry-based activities	2.59 (.80)	3.38 (.97)	10.03	**<.001**
Explicit NOS instruction	2.15 (.85)	3.20 (1.1)	12.07	**<.001**

Univariate analysis of variance tests indicated teacher teams in the treatment group reported significantly greater confidence than their peers in the control group for all constructs; when year-end outcome group means were adjusted for pre-measure scores, all p-values were <.001 (Table 8).

Table 8

Cohort 2 and 3 School Team Confidence in Incorporating Key Constructs

	Year-end Group Means		
Construct	Treatment (n= 50)	Control (n= 38)	Sign
PBL activities	3.62 (.68)	2.40 (.81)	**<.001**
Inquiry-based activities	3.01 (.61)	2.63 (.91)	**<.001**
Explicit NOS instruction	3.93 (.54)	2.17 (.79)	**<.001**

Note. Likert scale ranges from 1 = not confident to 5 = very confident. Adjusted = Year end (delayed post) means adjusted for baseline pre- measure

Qualitative data of PD observations may explain these findings. For example, during the ESI, facilitators provided teachers definitions of PBL, inquiry-based instruction, and NOS and explicitly taught these concepts. Participants repeatedly discussed how specific components of the ESI were important in facilitating their confidence in implementing reform-based science instruction into their own practice. For example, one teacher described how many of the effective characteristics of PD (active learning, collective participation, expert coaching) of the ESI facilitated her confidence:

> I really enjoyed the camp and being able to practice what we were learning about, what we were taught, I think that was crucial to be able to become more comfortable with what we were going to be doing in our classroom this coming year. And I also liked the time we had to plan and plan with other teachers from other areas in order to come up with a cohesive plan. (E3-T337, Interview)

As the above example illustrates, implementing a PBL unit at camp not only provided participants with an opportunity for active learning, but also a chance to get feedback on their teaching. Participants observed one another teaching at camp and following each teaching experience, participants debriefed with each other and ESI facilitators, receiving expert coaching and feedback. Participants cited the time to reflect and receive feedback as valuable because it increased learning and because time to reflect and material resources are not typically features of other PD or teaching during the academic school year. Active learning, collective participation, and expert coaching are all key characteristics of effective PD.

Another participant pointed out the collective participation in the PD facilitated her confidence in implementing what she learned into her own instruction:

> I LOVE that we have had the chance to work with another teacher from our school and to build that team-type relationship. VISTA is the ONLY experience that has taught me a new technique, let me practice that new technique, let me reflect on my implementation of that new technique and supported me to this extent. I feel as though with all of the support and materials and experiences given it is literally IMPOSSIBLE to fail in implementation during the upcoming year. (E3-T385, Year-end Perceptions Survey)

Like E3-T385, many participants attributed their new confidence with the unique aspects of ESI, namely being able to work with their colleagues and other teachers to plan and implement a PBL unit at camp, where they had opportunities to practice the teaching strategies they learned at ESI in camp. Again, this indicates the importance of aligning PD with characteristics of effective PD, specifically collective participation and active learning.

Coaching was another component of the ESI many participants' perceived as a valuable aspect of the ESI that supported their capacity to translate what they learned during the summer into their instruction. For example, participant E3-T348 described her interactions with her coach:

> From her very first visit to our classroom, [my coach] became a part of our community. Along with the relationship she was forming with me, she cared about connecting with the students. She was always extremely helpful and was very flexible. She brought a wealth of knowledge and experience to this position, and she offered ideas in a very professional way. She was often very affirming, with both verbal and non-verbal ways. (E3-T348, Year-end Perceptions Survey)

Another echoed the support provided by her coach:

> She even came to our school before school started. She helped us plan our lessons for science at times and offered us suggestions on how to keep our students engaged. When she wasn't at our school, she was busy helping us by sending us great resources to use for each unit we taught this year. (E3-T332, Year-end Perceptions Survey)

As evidenced by the above comments, participants' perceived coaches as supporting the transfer of what they learned during the summer ESI into effective implementation in their own classroom.

Overall, participants repeatedly mentioned how participating in VISTA changed their perspective of how to teach science and how this developed their confidence in implementing the key constructs learned in VISTA, as exemplified by the following comments:

> [After participating in VISTA] I now see science instruction as an active practice that doesn't involve a warehouse of facts and knowledge. [VISTA] has driven me to be more invested in the act of exploration, and I hope my students adopt that mindset in the coming school years. I am glad I have knowledge of PBL and inquiry to take with me. I now know how to develop a

> problem-based exploratory unit and take the steps necessary to plan it. (E3-T334, Post-Perceptions survey)

Participants largely perceived the unique opportunities for collective participation, active learning, and expert coaching provided during the ESI resulted in their improved confidence.

Importantly, participants discussed how they perceived they could translate what they learned during the ESI into their own classroom instruction. One teacher explained, “Even during units that are not my PBL that I designed at VISTA, I will be incorporating the same guiding principles and ideas throughout the entire year.” (E2-T239, Post-Perceptions Survey). Another discussed how she planned to transfer what she learned in VISTA to other elementary content she taught. She noted:

> I have participated in some other science professional development but it was not nearly as in depth and immediately applicable to my classroom. I can see how what I learned will impact my teaching of not just science, but all subjects. (E3-T318, Post-Perceptions Survey)

The coherent, contextualized nature of the VISTA ESI appeared to facilitate teachers’ understandings and confidence in implementing PBL, NOS, and inquiry into their own classroom science instruction.

Classroom Practices

Across sites and cohorts, participants indicated they intended to implement the knowledge and skills they learned during the ESI. According to the post-ESI Perceptions survey, participants said they were very likely to implement the material learned from the course (M = 4.88 on 5 point Likert scale, SD = .36).

For example, one participant described her plan for implementing the key ideas she learned during the summer ESI:

> I will be starting off my year with a lot of hands-on, inquiry-based activities to get my students to start thinking like a scientist, as well as to help develop a strong classroom community. I am very excited about implementing my PBL, and am happy that I will get to teach it 3 times to 3 different groups of kids. I think this will allow me to tweak anything that may not be working, as well as to add on to it if possible. (E3-T343, Post-Perceptions survey)

Not only did this participant indicate an intention to implement PBL into instruction following the summer component of the ESI, but she also reflected that she would have opportunities to extend and modify the PBL unit after teaching it. Another participant reflected on her intentions to implement inquiry and NOS:

> We have designed a PBL that we plan on using this fall that will address Water and Matter. The NOS standards will be emphasized the entire year, but will be highlighted even more during my Space unit. We are currently working on another PBL to teach the measurement unit we do for the Math department in our school during the late winter. I can see using inquiry and the NOS standards to address my units on weather and energy. With the strategies we have learned in this experience, I can see my whole outlook in how I teach science changing. I need to become a much less "sage on the stage.” (E3-T384, Post-Perceptions survey)

This participant indicated that she planned to use a PBL unit developed during the summer institute for instruction and has continued to develop PBL units using the skills learned during the summer.

Analysis of classroom observations with the modified CETP-COP instrument provided evidence of the extent to which ESI participants’ actually incorporated PBL, inquiry, and NOS into instruction (Table 9). When comparing treatment teacher teams’ outcomes to control teacher teams’ outcomes for PBL and NOS, significantly more treatment teachers incorporated these constructs than control teachers across all observation windows. Integration of inquiry was also statistically different, favoring integration by treatment teachers for inquiry during the first, second, and final observation windows.

Table 9
Cohort 2 and 3 school team inclusion of PBL, NOS, and Inquiry (mean, SD)

	PBL			NOS			Inquiry		
	T	C	Sign	T	C	Sign	T	C	Sign
Fall 1	.538 (.44)	.080 (.24)	<.001	.675 (.38)	.160 (.35)	<.001	.831 (.28)	.627 (.43)	**.015**
Fall 2	.594 (.43)	.123 (.30)	<.001	.569 (.44)	.116 (.25)	<.001	.849 (.30)	.591 (.40)	**.003**
Spring 1	.415 (.48)	.104 (.29)	.003	.684 (.39)	.116 (.25)	<.001	.759 (.33)	.640 (.43)	.194
Spring 2	.391 (.45)	.14 (.34)	.016	.427 (.42)	0 (0)	<.001	.664 (.38)	.432 (.44)	**.021**

Note: T= treatment, C = control. Scale ranges from 0 (no teachers on team included construct) to 1 (all teachers on team included construct)

Student Achievement

Evaluation of the impact of the VISTA ESI on grade 5 science standards of learning test scaled scores was assessed through a two-level model with students nested within school (teacher) teams. Evaluation of the impact of the VISTA ESI on grade 5 science standards of learning test scaled scores did not reveal a statistically significant difference between treatment and control conditions, t(363.76) = 1.28, p = .20. Controlling for model covariates, the average SOL test scaled score of students exposed to treatment team teachers was 4.33 points greater than that of students exposed to control team teachers and Hedges g=.07. No significant difference existed for models that explored the interaction between treatment condition and LEP status (t(3518.93) = 0.19, p = .85) or treatment condition and disadvantaged status (t(630.52) = 0.60, p = .55). Statistically significant differences between treatment teachers' students with disabilities and control teachers' students with disabilities existed when evaluated in relation to a slightly liberal alpha, t(86.49) = 1.94, p = .056, that favored treatment students by an average of 11.52 points on the grade 5 science standard of learning test. Hedges g = .20. In this case, the liberal alpha is warranted since, "Effect sizes of 0.20 or smaller are often of policy interest" when they are based on student achievement measures (Hedges & Hedberg, 2007, p. 77).

In summary, results from three cohorts of participants suggest teachers in the VISTA ESI made gains in their understanding of pedagogical approaches that support reform-based science instruction. The majority of teachers expressed either partially or fully aligned understandings of PBL, inquiry, and NOS instruction following the VISTA ESI. Results also indicate teachers' made substantial shifts from not aligned to partially aligned understandings of inquiry and NOS. In addition teachers' confidence in implementing these reform-based practices improved following participation in the VISTA ESI and was significantly greater for teachers in the treatment group for all constructs. Teachers in the treatment group also incorporated more PBL, inquiry, and NOS than those in the control group across most observation points. Participants indicated the specific components of the PD facilitated their confidence, understanding, and intention to implement the reform-based practices they learned. Evaluation of the impact of the VISTA ESI on grade 5 science SOL test scaled scores did not reveal a statistically significant difference between treatment and control conditions for the overall model, LEP status or disadvantaged status but did reveal a statistically significant difference between treatment and control conditions for disability status.

Discussion and Implications

This randomized controlled trial explored the effectiveness of the VISTA ESI in improving elementary science teachers' knowledge of and confidence in implementing PBL, inquiry, and NOS into their classroom instruction. It also explored their students' science achievement after their participation in the ESI. The results of this investigation make three major contributions to the literature. First, the randomized controlled trial research design, which is uncommon in science education research, allowed us to measure statistically significant positive changes in treatment teachers' understandings, confidence, and practices related to PBL, inquiry, and NOS and attribute these to the PD. Second, the components of effective PD that characterized the VISTA ESI appeared effective in promoting positive changes in teachers' understandings, confidence, and reforms-based instructional practice. Finally, embedding PBL, NOS, and inquiry into science instruction appears to have a positive impact on students with disabilities. Each of these contributions are described below.

Changes in Knowledge, Confidence, and Instructional Practice

Knowledge. ESI participants made significant gains in their understanding of NOS, inquiry, and PBL instruction following their participation in the ESI and these gains were significantly greater than those of control group teachers. The majority of teachers expressed either partially or fully aligned understandings of PBL, inquiry, and NOS instruction following the VISTA ESI. Results also indicate teachers' made substantial shifts from not aligned to partially aligned understandings of inquiry and NOS.

ESI participants expressed moderate knowledge in teaching NOS after PD; however, they retained their conception that students would learn about NOS through implicit approaches. This finding is consistent with a large body of literature that teachers do not incorporate explicit NOS instruction (e.g. Bell, Abd-El-Khalick, & Lederman, 1998; Bell, Blair, Crawford, & Lederman, 2003; Lederman Lederman, Kim & Ko, 2012). Further, participants in the present study learned about NOS instruction through both contextualized and noncontextualized activities such as an investigation in which teachers made observations and inferences about a rock then gathered more evidence and discussed NOS ideas (creativity, empirical evidence, tentative) that they used during the investigation. Thus, the findings of the present study support the assertion of Clough (2006), who argued in a theoretical article for the implementation of explicit NOS instruction along a continuum from noncontextualized to highly contextualized and contribute to the ongoing debate over the role context plays in NOS instruction facilitates teachers' capacity to learn and transfer this knowledge to their own classroom instruction (e.g. Bell, Matkins, & Gansneder, 2011; Bell, Mulvey, & Maeng, in review; Herman, Clough, & Olson, 2013). While it is notable that treatment teachers' understandings of NOS were more aligned than control teachers' following the PD, the results of this investigation raise questions as to the efficacy of a continuum approach during a summer institute is sufficient in supporting teachers' understandings that NOS instruction must be explicit to be effective.

Research suggests many science teachers do not have accurate conceptions of inquiry (e.g. Johnson, 2006, 2007). For example, some teachers conflate inquiry instruction with hands-on instruction and teaching inquiry with teaching NOS and process skills (Crawford, 2000; NRC, 2000). While these non-aligned conception was present among some of the teachers in the present study prior to the VISTA ESI, desired shifts in treatment teachers' understandings of inquiry (from non-aligned to partially and fully aligned understandings occurred pre- to year-end and were significantly greater than those of control teacher teams. Treatment participants' knowledge of PBL improved the greatest of the three constructs pre- to post-PD. However, some reversion a number of teachers' summer-end to year-end understandings of PBL appeared to revert. One explanation for this reversion relates to teachers' PBL instruction, which was observed predominately in the fall semester. It is possible that because they did not employ PBL consistently throughout the academic year, as was observed with inquiry and NOS instruction, their understandings of this complex construct diminished over time. While many studies espouse the success of PD programs that specifically target teachers' inquiry (e.g. Kanter & Konstantopoulos, 2010; Lotter, Harwood, & Bonner, 2007) or NOS understandings (e.g. Ackerson, Cullen, & Hanson, 2009; Ackerson & Hanuscin, 2007) most of these investigations utilize a pre-/ post-intervention design, are quasi-experimental, or are qualitative in nature. This study supports the findings of these previous investigations through a randomized controlled trial. Further, it extends these studies through exploration of not only inquiry and NOS, but also teachers' understandings of PBL following a PD that embedded inquiry and NOS within a PBL context.

Confidence. In the present investigation, participants' confidence in targeted reforms-based practices increased significantly pre- to year-end and their confidence was greater than those teachers in the control group. Similar findings exist for other investigations of professional development to support inquiry (e.g. Brand & Moore, 2011; Duran, Ballone-Duran, Haney, & Beltyukova, 2009; Lakshmanan, Heath, Pearlmutter, & Elder, 2011; Sandholtz & Ringstaff, 2014). However, the majority of these studies employed a qualitative, pre-/post-, or quasi-experimental design and focus on preservice teachers or secondary teachers. Thus, the results of the present investigation substantiate these findings among elementary teachers. Notably, the present investigation also extends the body of literature on PD to support development of science teachers' confidence by exploring their confidence in developing and implementing NOS and PBL instruction.

Instructional Practices. The present study explored participants' reforms-based practices during four observations windows spread throughout the academic year. While results indicated only approximately 50% of participants were observed integrating the targeted reforms-based practices, it may be that this is an underestimate of the actual number of participants who implemented these practices, as some may have integrated these pedagogical approaches outside the observation windows. Despite this potential limitation of the study, overall, results indicated teacher teams who participated in the VISTA ESI integrated targeted reforms-based practices (i.e. NOS, inquiry, and PBL) significantly more frequently than their control group counterparts across all observation windows except inquiry during the first spring observation window.

Previous research suggests effective NOS and instruction does not come easily for most teachers (e.g. Akerson & Abd-El-Kalick, 2003; Bell, Abd-El-Khalick, & Lederman, 1998; Lederman, 2007; Lederman, Lederman, Kim, & Ko, 2012). In the present investigation, treatment teachers incorporated significantly more explicit NOS into their instruction than control teachers across all four observation points. In fact, for all time periods except the late spring window, the mean number of teachers on a treatment team who implemented NOS instruction was more than half of the teachers on the team. This suggests that not only were teachers integrating explicit NOS into instruction to a substantive extent, but they were doing it more consistently across the year than some might expect. Often, NOS is taught near the beginning of the year during instruction on scientific methodology. Results indicated treatment teacher teams implemented inquiry to a greater extent than control teacher teams across all observation windows except the first spring window. These findings extend previous studies, most of which do not look at snapshots of teachers' instruction over the entire academic year, but often observe teachers during an instructional unit or abbreviated timeframe.

Classroom observations revealed teachers incorporated PBL more frequently in the fall semester, in closer proximity to when they learned it, than in the spring, whereas participants tended to incorporate NOS and inquiry more consistently throughout the year. These differences are not unexpected given that inquiry instruction was more familiar to participants and is a more straightforward pedagogical approach to implement than developing and implementing and entire PBL unit. The modest improvements in PBL instruction are not unexpected for a number of reasons. First, designing and implementing PBL into instruction is a complex process. It relies heavily upon students' exploration and synthesis of multiple science concepts within a coherent instructional unit to solve a problem with multiple possible solutions (Center of Excellence in Leadership of Learning, 2009; Sterling et al., 2007; Thomas, 2000). Thus, the process of designing and implementing PBL may be especially difficult for elementary teachers who may not be science content experts as previous research suggests some degree of content knowledge expertise may be necessary but insufficient to facilitate teachers' effective science instruction (Abell, 2007). Several explanations for why PBL integration was not sustained throughout the academic year among treatment participants exist. It is possible the support treatment group participants received during follow-up sessions and via coaching was insufficient to engender year-long integration of complex instructional strategies such as PBL. In addition, the final observation window occurred just prior to state-mandated testing. Therefore, participants may have been focused on reviewing previously-learned content during that observation window; spring may be a more difficult time to implement extended PBL units due to the end of school year focus on state testing. Finally, developing PBL units requires additional planning time. Participants may not have found opportunities to plan additional PBL units beyond those developed during the ESI. It is possible additional and more instructionally sustained PBL implementation would be observed in subsequent years.

Taken together, the results of this investigation indicate that the VISTA ESI was effective in facilitating desired changes in treatment teachers' knowledge, confidence, and practices related to the reforms-based pedagogical approaches of NOS, inquiry, and PBL and that these teachers' changes were significantly greater than those of control teachers. These findings contribute to our understanding of the complex relationships between understandings, confidence, and practices and suggest that patterns in these relationships may be different for NOS, inquiry, and PBL. First, a number of studies indicate elementary teachers' confidence influences their reform-based inquiry and NOS instructional practices (e.g. Lakshmanan, Heath, Pearlmutter, & Elder, 2011; Ramey-Gassert, Shroyer, & Staver, 1996; Sandholtz & Ringstaff, 2014). The present investigation extends these findings by exploring relationships between understandings, confidence, and practices for PBL. Second, though significantly less than those teachers in the control group, many of the treatment participants' still expressed the non-aligned understanding that effective NOS instruction could be implicit. However, treatment teachers incorporated explicit NOS instruction to a greater extent than their understandings that NOS instruction needs to be explicit indicated. Thus, a disconnect between teachers' understanding of explicit NOS instruction and their explicit NOS instructional practices observed appeared to exist. This finding supports previous research that teachers' practices may not reflect their understandings about NOS (e.g. Bell, Abd-El-Khalick, 2000; Lederman, 1999; Lederman, 2007; Schwartz & Lederman, 2002); however, those studies focused on preservice and in-service secondary teachers and found that while teachers' accurate conceptions of NOS were present, their instructional practices did not include extensive explicit NOS instruction. Thus, our findings for elementary teachers warrant further exploration. Finally, while the relationship between understanding and practice is well-documented for inquiry and indicates that teachers' understandings and confidence positively influence their practices (e.g. Brand & Moore, 2011; Lakshmanan, Heath, Pearlmutter, & Elder, 2011), the relationship between teachers' understandings of PBL and their classroom implementation of PBL has not been well-studied. From the results of the present investigation, it appears that this relationship may more complex than that between understanding and practice for inquiry and NOS.

Efficacy of Embedded Components of Effective PD

The embedded components of effective PD that characterized the VISTA ESI appeared to contribute to the overall changes in participants' understandings, confidence, and practices. For many participants, active learning opportunities incorporating inquiry and NOS instruction, opportunities to practice PBL, NOS, and inquiry instruction in the context of camp prior to implementing these constructs in their own classrooms facilitated transfer to their own instruction. Participants also cited collaborating with peers when designing instruction, receiving feedback from coaches and instructors, as encouraging integration of reform-based practices into their instruction. The incorporation of these active learning opportunities and requirement of collective participation appeared to promote participants' transfer of what they learned in the ESI into their own reform-based instruction.

The summer institute constituted only one component of the VISTA PD experience. Participants were provided support throughout the academic year through follow-up sessions and coaching, which provided sustained, on-going, coherent PD with expert coaching. Follow-up and coaching sessions were designed to reinforce what participants initially experienced during the summer institute and promote transfer to the classroom environment. These longitudinal and contextualized features of the VISTA ESI are often cited as essential features of effective PD (e.g. Desimone, 2009; Johnson et al., 2007; Supovitz & Turner, 2000). Results of the present study support inclusion of these features into PD for elementary science teachers as participants' retained their understandings of PBL, inquiry, and NOS instruction across the year. In addition, participants integrated these constructs relatively consistently across the year, with slightly higher integration in the fall. Therefore, the results of the present study provide further support for the importance of including longitudinal components such as coaching, collective participation, active learning, coherence, in content-focused PD (Desimone, 2009; Loucks-Horsley et al., 2010). However, ascertaining the extent to which each of these components of effective PD contributed to participants' understanding, confidence, and practice is one area for future research.

Finally, given the significant and numerous barriers to reforms-based instruction documented elsewhere in the literature (e.g. Arora, Kean, & Anthony, 2000; Bauer & Kenton, 2005; Johnson, 2006, 2007; Keys & Bryan, 2001; Keys & Kennedy, 1999; Lakshmanan, Heath, Pearlmutter, & Elder, 2011; Lederman, 2007; Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010; Sandholtz & Ringstaff, 2014; Supovitz & Turner, 2000), it is possible that the components of effective PD (e.g. coherence, opportunities for participants' active learning, collective participation, and expert coaching) embedded within the VISTA ESI facilitated participants in overcoming these barriers to implement the targeted reforms-based practices in their instruction to the extent observed in the present investigation.

Student Achievement

Previous research suggests that reform-based practices including PBL, inquiry, and NOS instruction have the potential to improve student achievement (e.g. Bransford, Brown, & Cocking, 2000; Cleminson, 1990; Peters, 2012; Songer & Linn, 1991; Sterling, 2006; Sterling, Matkins, Frazier, & Logerwell, 2007). Contrary to the findings of those investigations, results of the present study indicated no changes in student achievement between treatment and control 5th grade teachers' students. There are a number of possible reasons for these results. First, though participants incorporated inquiry and NOS relatively consistently across the year, most treatment group teachers taught one or two PBL units across the entirety of the academic year, and these were typically taught in the fall. Given that the assessment focused on an entire year's science content knowledge and was administered in the spring, it is possible that the assessment was not sensitive enough to capture changes attributed to instructional methods in one or two instructional units. Second, previous research suggests that using student achievement on a state exam as a measure of the effectiveness of a PD is challenging because the effectiveness of PD on student achievement is mediated by changes in teacher knowledge and instructional practices (e.g. Yoon, Duncan, Lee, Shapley, 2008). Finally, somewhat of a mismatch between teachers' reform-based instruction taught during the PD and the content in the standardized state test utilized to measure student achievement existed. The ESI did not specifically target improving teachers' content knowledge, rather it emphasized reforms-based practices including scientific investigation skills, PBL, and NOS. Despite this potential mismatch, no difference in students' content knowledge achievement was observed between treatment and control group teachers; the robust reform-base science instructional practices utilized by the treatment group teachers did not negatively impact their students' content knowledge in science relative to students of control group teachers who did not employ these reforms-based strategies. This suggests that embedding reforms-based practices that encourage critical thinking and solving complex, real-world problems is an appropriate instructional approach that is not detrimental to students' achievement on content-based standardized tests. Further, interview data suggest both teachers and students were excited by the science instruction espoused by the ESI. These issues raise questions about the alignment of reform-based science teaching and standardized, content-based end-of-course achievement assessments commonly used as indicators of the success of PD programs. Until the assessment matches the reform-based approaches, an accurate measure of the effectiveness of a program on student achievement cannot be realized.

Our results suggest reforms-based science instruction has the potential to benefit all science students. Students with disabilities in treatment teachers' classrooms significantly outperformed students with disabilities in control teachers' classrooms. Special education instruction in science often emphasizes content-oriented approach with an emphasis on vocabulary acquisition (e.g. Scruggs & Masteropieri, 1993). McGinnis and Stefanich contend, in their 2007 review of the literature, that multimodality is important in facilitating students' with disabilities science learning. Taken together with the literature on special education in science, our results suggest combining content-oriented instruction and PBL, in which students are using the vocabulary they are learning to solve meaningful problems through scientific inquiry and presenting their findings in a culminating product may be effective in supporting science learning by students with disabilities. That is, it appears that incorporating reforms-based practices, including NOS, inquiry, and PBL instruction may be effective in supporting students' with disabilities science learning as measured on end-of-course science achievement tests that emphasize content knowledge.

Given these caveats, along with the positive outcomes related to teacher understanding, confidence, and practice, we contend that documenting PD that facilitates teachers' reform-based science instruction at the school level through randomized controlled trials is essential, as well-prepared, effective teachers have the greatest impact on student achievement (e.g. Bolyard & Moyer-Packenham, 2008; Druva & Anderson, 1983; Heller, Daehler, Wong, Shinohara, & Miratrix, 2012; Roth, Garnier, Chen, Lemmens, Schwille,& Wickler, 2011). That students with disabilities in treatment teachers' classrooms outperformed their peers in control teachers' classrooms is a notable finding and suggests that including reforms-based instruction has the potential to better help science teachers meet the goal of scientific literacy for all students. Finally, the results of this study have the potential to inform PD supporting educators' implementation of reforms-based instruction by in-service elementary science teachers. Our results support the efficacy of PD designed with coherence that includes opportunities for participants' active learning and collective participation to facilitate changes in in-service elementary teachers' understandings, confidence, and practices.

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Appendix A: Perceptions Open-ended Response Coding Rubric

Description of Use

This rubric was developed to assess the extent to which VISTA participants' responses express views of problem-based learning, inquiry, and nature of science aligned with VISTA constructs. This rubric will be used to assess VISTA participants' responses to the following questions on the VISTA Perceptions survey:

1) Define problem-based learning.
2) Describe what teachers and students are doing during a typical lesson/activity that emphasizes problem-based learning.
3) Define science inquiry.
4) Describe what teachers and students are doing during a typical lesson/activity that emphasizes science inquiry.
5) Define nature of science.
6) Describe what teachers and students are doing during a typical lesson/activity that emphasizes nature of science.

Coding Understandings and Implementation of Problem-based learning and Inquiry.

Evidence of italicized components must be present for a response to be coded at this classification level. In general, coding of the definition and application to the classroom (teacher and student actions) provided by participants should be weighed in coming up with a classification for the response on a given dimension. If there are discrepancies between coding of the definition and explanation, the application component should carry more weight. For example, if the participant gives the VISTA definition verbatim (**fully aligned**), but their description of classroom application does not reflect aligned implementation, coding should err toward the response of the description of how this approach is enacted in the classroom.

Note: Non-aligned perspectives of the nature of science (e.g. "proving," overemphasis on "the" scientific method) in responses about PBL and inquiry should be taken into account when coding participants' NOS understandings.

	Non-aligned	Partially Aligned	Fully Aligned
Problem-based Learning (PBL)	Responses lack crucial elements of the VISTA definition. Definitions and examples align better with hands-on science or inquiry. Response may define hands-on instruction or inquiry without acknowledging the following: role of authentic context, the open-ended nature of the task, meaningful problem, and duration or response explicitly indicates participant doesn't know.	Definitions and examples suggest a partial understanding of PBL and its key features. Response indicates a **role for inquiry and authentic (real world) context** in PBL and may acknowledge *a subset of the following:* meaningful problem for students to solve, open-ended nature of the task or the extended duration of such lessons. Examples may overemphasize the teacher as the information provider.	Definitions/ examples accurately reflect the VISTA definition: *A form of **inquiry** in which students solve a meaningful problem with multiple solutions over time, as a scientist would in a **real world context**. The problem and context must be meaningful to students*. Essential components that may be included in response: theme, problem, student roles, scenario, resources, culminating project/assessment, safety.
Inquiry	Responses lack crucial elements of the VISTA definition (i.e. indicates only a role for questioning or hands-on, no indication of analysis of data on the part of students) or response is expanded to include PBL or response explicitly indicates participant doesn't know.	Definitions and examples suggest a partial understanding of inquiry and its key features. It may indicate that **students** do only one of the following: (1) *analyze data, (2) solve problems, (3) answer questions through investigation.* Participants may cite students conducting "investigations" without elaboration. Response may indicate inquiry <u>must</u> be hands-on or overemphasizes "the" scientific method and experimentation. Examples may overemphasize the teacher as the information provider.	Definitions/ examples accurately reflect the VISTA definition: *asking questions*, *collecting and analyzing data*, *using evidence to solve problems*. Key components that may be included in response: learners engage in scientifically oriented questions, gives priority to evidence, formulates explanations from evidence, connects explanation to scientific knowledge, communicates and justifies explanations.

Examples of Coded Responses: Problem-based Learning.

Non-Aligned	**Partially Aligned**	**Fully Aligned**
My thinking is that problem based learning and science inquiry are interchangable terms. A problem or question is given for the students to try to discover an answer by investigating and being able to explain their answer. The teacher would give some background information and then propose a question or problem for the student to discover. The student would work in small groups to discover how to solve the problem or question. The teacher would walk around and listen and or guide students. *[Response indicates PBL and inquiry are the same, example doesn't include any components of PBL, but only describes "investigation"]*	Problem based learning is when you combine a real-world scenario with learning in science. Which is when students act and do what real-world scientists actually do. Students do hands-on activities dealing with real-world science tools. Students are learning about a problem and then researching more on a topic. Through their own research, with the teacher mostly facilitating, students will learn to ask questions and think like a scientist. Ultimately, students will come up with a solution for the presented problem and what they think the solution should be and why. In a PBL setting, there is more the students doing all the work and finding out the possible problems that are posed and also finding solutions to that problem through research, asking other specialists or scientists, and possibly testing with real-world science tools. Students can take up several days to find out solutions and then make a culminating product from their findings and present it either in power point, skit, in a model, song, rap/rhyme, or other types of presentation. *[Response implies inquiry (testing, doing what real scientists do), finding solutions and supporting them with evidence, and indicates the importance of a real-world scenario and an extended duration, but does not indicate a need for the problem or scenario to be meaningful to students.]*	PBL is students solving a problem with multiple solutions in a real-world context the way a scientist would. A teacher would present a problem to students as a scenario. She would have them generate questions that they would want to find out as a result of the scenario. For example, a teacher presents the problem to students about how to design an eco-friendly theme park. She gives them a scenario and guiding questions (how is the park currently operating? What should our theme park offer? What does eco-friendly mean? What resources are out there?) to help them solve the problem of how to design a more eco-friendly theme park. They do research on computers and hands-on activities in the classroom to arrive at multiple solutions to this one problem. *[Response elaborates on the VISTA definition with an aligned example]*
Problem-based learning is when students solve a problem with multiple solutions over time like scientists in a real world context, must be meaningful to students. During a problem-based lesson/activity the teacher is the facilitator while the students are doing the activities. *[Though other components of the VISTA definition are present, response does not indicate a role for inquiry]*	Solving a real world problem with multiple solutions in a way that is similar to how a scientist would work. The teacher is facilitating the learning of the students by asking questions and explaining how they are working like a scientist. The students are working in small groups to investigate situation using inquiry or hands-on	Problem based learning is a process where students work through to answer a larger problem. The problem is usually a broad scientific problem that students can relate to. They are given a scenario and a role. Students then conduct experiments and make observations in order to get closer to a solution set for the given problem. The teacher serves as a facilitator and a reminder of the bigger problem. The lessons are driven by the teacher planning but also by student curiosity. Students complete some kind of culminating project to show their learning. The goal is deep learning and understanding of as scientific topics rather than memorization of facts and terms. Students will acquire more information about the nature of science and the scientific method by investigating real world topics. *[Response indicates a role for inquiry, authentic context, the importance of a meaningful scenario, and extended duration]*

	experiences to solve a problem presented in a scenario. *[Response is indicates the role of inquiry, authentic (real world) context, and the open-ended nature of PBL but does not address the extended duration of PBL]*	

Note: Bracketed, italicized comments provide a rationale for coding at this level. Hi-lighted components were used in making judgement for categorization of response.

Examples of Coded Responses: Inquiry.

Non-Aligned	Partially Aligned	Fully Aligned
My thinking (at this time) is that problem based learning and science inquiry are interchangable terms. Science inquiry learning is when students inquire, are curious, about something then they will explore to find the answers to their curiosities. Thus learning about what they are curious about. All modalities of learning can be address in activities for scientific inquiry. The teacher presents the students with a problem/ question and some activities that will help the students find answers to the problem. The students will complete a variety of activities to help them learn about the information they are seeking. They will present this information to the class. *[Response does not indicate a need for analysis of data.]* Science inquiry is a method by which students can find their own answers by asking questions; I think this is similar to the Socratic method. When I teach a science class, I like to take an inquiry-based approach: "What do you notice about the surface of the moon and the surface of the earth? How are they alike? How are they different? Could we say that the moon is rockier than the earth? Could we say that the earth has more water? What do you think could have caused this?" Science inquiry is finding answers by asking questions...this may bring up more questions, but that's okay! *[Response does not indicate a role for data analysis by students.]*	Science inquiry is about curiosity and student investigation. Inquiry is **hands-on** and has students using real world objects and scientific tools. When students are engaged in inquiry they are testing their hypotheses. Students are collecting data, making observations, and testing hypotheses. Students are formulating further research and questions for **more experiments** and activities. *[Some of this definition is aligned, but the bolded parts indicate a response that overemphasizes that inquiry has to be hands-on and experimental.]* Inquiry is where students research, question, probe, and investigate to satiate curiosities and observations. **Inquiry can be as simple as creating a hypothesis.** It can be giving them a problem and having them come up with the materials and procedures necessary to investigate. Or it can be the teacher providing materials and allowing students to come up with their own investigation. **I see it also as real world situations**. *[Some of this definition is aligned, but the bolded parts indicate that inquiry could exist in situations where s. are not analyzing data.]*	Science inquiry uses carefully posed questions to lead students to explore ideas and form strong understandings on their own rather than being told the answers to questions they may have. Students have a question that they want to answer and are guided through various levels of questioning to investigate then make inferences and draw conclusions. *[Response indicates the role of data analysis on the part of students and doesn't overemphasize experimentation.]* Science inquiry is investigating a scientific question looking for evidence to support inferences made through the investigation. Students are investigating on science oriented questions. Students are focusing on finding evidence to support explanations. Students use evidence to connect explanations to scientific knowledge. Students should be leading much of the investigating. There should be a good deal of student to student interaction. The teacher is acting as a facilitator. *[Response indicates the role of data analysis on the part of students and doesn't overemphasize experimentation.]*

Coding Nature of Science Understandings and Instruction

This two-part component of the rubric was developed to assess the extent to which VISTA participants' responses express tentative and revisionary view of the nature of science and the extent to which they understand that these aspects of the nature of science must be explicitly addressed in science teaching. This rubric will be used to assess VISTA participants' responses to the following questions on the VISTA Perceptions survey:

1) Define nature of science.
2) Describe what teachers and students are doing during a typical lesson/activity that emphasizes nature of science.

Responses will be coded based on the degree of alignment between participant responses and the VISTA description of understandings of the nature of science (below). Participants' responses to these two questions will be analyzed holistically.

Description of VISTA Understandings of the Nature of Science

Responses reflect absolutist conceptions of scientific knowledge. Responses indicate a lack of clear understanding of how evidence is used in science, that science is an social endeavor, and/or refer to THE scientific method or one scientific method. Responses indicate that scientific knowledge is made up mainly of the results of experiments and that scientific knowledge is inherently unbiased.	Responses reflect tentative and revisionary conceptions of scientific knowledge. While scientific knowledge is empirically-based, it is not derived directly from observation alone. Rather, inferences, theories, and social/cultural factors all play a role in the development of scientific knowledge. Science seeks to limit personal bias, often through formal processes; however, science can never totally eliminate subjectivity. Nor is totally eliminating subjectivity always a goal because of the important roles of imagination and creativity in science. Scientists do not follow a rigid algorithm but rather use a multitude of creative approaches to answer questions of interest. There is no single scientific method.

Absolute → **Revisionary**

(not aligned) **(partially aligned)** **(fully aligned)**

Coding Understandings of the Nature of Science.

	Non-aligned	**Partially Aligned**	**Fully Aligned**
Nature of Science (NOS)	Response includes statements that reflect absolute views of science. <u>or</u> Response does not address any key elements of the VISTA description of NOS <u>or</u> Response indicates the participant does not know.	Response indicates a partial understanding of the tentative and revisionary nature of science. Response lists key elements of NOS taught in VISTA without any elaboration. <u>or</u> Response does not include all of the key elements of the VISTA description of NOS. <u>or</u> Response includes all key aspects but includes misconceptions about these aspects.	Response reflects tentative and revisionary views of science consistent with the aspects of NOS taught in VISTA. Response <u>**must**</u> include the following key elements of the VISTA description of NOS: Scientific knowledge is tentative and revisionary. Scientific knowledge is empirically-based. Social/cultural factors play a role in the development of scientific knowledge.

Examples of Coded Responses: Understandings of the Nature of Science.

<table>
<tr><th>Non-aligned</th><th>Partially Aligned</th><th>Fully Aligned</th></tr>
<tr>
<td>…everything is related to world of science. Teachers and students are making connections to the real world. [Vague; doesn't address any VISTA aspects of NOS.]

The natural world is everywhere and science is the study of the relationships/interactions/ happenings in our world (not just the physical world). [Only addresses one aspect – natural world is understandable]

Nature of science is how one would investigate a problem in a scientific manner to arrive at an unbiased solution. [Expresses an absolute viewpoint, bolded]</td>
<td>The nature of science is one that is always growing and changing. We will always be throwing away old conclusions and understandings, and adopting new ideas. [Addresses tentativeness - in an incomplete way, doesn't address the role evidence plays in adopting new ideas in science, doesn't address social/cultural aspects.]

The nature of science is seven tenets that are essentially seven "truths" about science that may be accepted as universal concepts. They include: 1. Our world is scientifically understandable 2. All ideas in science have a basis (empirically based) 3. Science is social 4. If you're going to say something, prove it! Provide evidence (science demands evidence) 5. Science is a product of logic and imagination (or creativity) 6. Science does not discriminate [All key aspects of NOS are expressed. Responses indicate the participant still holds some absolute views of science, bolded]

The nature of science is what a scientist does. It is the things that make science science. Some of the things involve data collection and reporting. The nature of science is social and collaborative. The nature of science is to hold some truths but to be willing to adapt definitions. [Addresses tentativeness & social/cultural influences, doesn't address role of evidence in adopting new ideas in science.]</td>
<td>One of the main focuses I remind my students is that science is always changing and adapting as technology changes, and as new information is gathered. Science also relies heavily on evidence (empirically based). Also, some concepts take a while for people to accept. [Addresses role of evidence in the development of scientific knowledge, implies a societal component (technology) and expresses an appropriately tentative perspective]

When defining the nature of science, it is important to know that science is logical, and understandable. Furthermore, science demands evidence, and because new evidence is always being discovered, science is always changing. Finally, science is a social activity in which people work collaboratively work together to test make hypotheses, determine understandings, and adopt theories. [Appropriately tentative

response addresses and elaborates on all key elements of NOS taught in VISTA.]

Science is used to understand the natural world. It is social and creative, with scientists working together to understand problems. Science is based on evidence collected through observation and inference. Scientific knowledge is dynamic and changing over time. [Appropriately tentative

response addresses and elaborates on all key elements of NOS taught in VISTA.]</td>
</tr>
</table>

Coding Nature of Science Instruction Understandings. With regard to teaching the nature of science, responses will either be coded as implicit, if the response indicates that students will learn about the nature of science from implicit approaches or explicit if the response indicates explicit instruction is required to effectively teach the nature of science.

Implicit	**Explicit**
Responses indicate that nature of science is taught effectively through implicit approaches and instruction. Responses indicate students will develop accurate conceptions of the nature of science as a byproduct of learning historical episodes of scientific knowledge and/or participating in authentic scientific investigations.	Responses indicate that nature of science is taught effectively through explicit instruction. Responses indicate students will develop accurate conceptions of the nature of science through instruction that intentionally draws attention to targeted aspects of the nature of science through such methods as discussion, reflection, and questioning.

Examples of Coded Responses Nature of Science Instruction Understandings.

Implicit	**Explicit**
Having students observe, journal, and discuss their real science experiences. *[Implies S. learn NOS by doing science]*	Students and teachers are discussing science topics. Usually, a new idea or technological advance is emphasized, and then I ask students to imagine what things were like before that idea or advancement. Then the students discuss with one another and/or share with the class their ideas. After that, we talk about how science is always changing and then may discuss any current events or possibilities that could change our knowledge of science as we know it today. *[Addresses the importance of explicit instruction]*
Students are encouraged to study real-life issues and collect data in the same way that a real scientist would. They should also be given the chance to collect data using real instruments whenever possible. *[Implies S. learn NOS by doing science]*	During a lesson/activity that emphasizes the nature of science, teachers are explicitly teaching and pointing out the seven components of the nature of science. *[Addresses the importance of explicit instruction]*
The teacher is there to remind the students what "good scientists" do. This means allowing them to realize the ways in which the students ask questions, develop experiments, support/ reject notions, discuss findings, draw conclusions, propose new questions, makes them "real scientists." When presented with these opportunities, the students **discover** that science is logical, understandable, is subject to change, demands evidence, and is a social activity, etc. When presented with these ideas, throughout a year, students are able to make better sense of their own thoughts. They are able to make more scientific based hypotheses, and understand the process for coming up with their own conclusions. They will be able to take these understandings with them into the "real-world." *[Response doesn't indicate that the teacher needs to actively link the process skills students are using as "real scientists" to corresponding nature of science understandings]*	There are 7 different beliefs: The nature of science is understandable, **scientific knowledge is durable**, scientific knowledge uses logic and imagination, **scientific knowledge demands evidence, science requires complex and social thinking**, ***scientific knowledge avoids bias***, and **scientific knowledge is subject to change**. These elements need to be explicitly taught and experienced throughout PBL units and throughout science investigations, in general. *[This response would be coded as explicit for instruction. It was coded as partially aligned for understandings as all key elements of NOS are expressed (bolded), but the responses indicate the participant still holds an absolute view of science, bolded and italicized]*

Appendix B

State Definitions for Student Sub-group Analyses

Variable Description: Limited English proficiency

"Students A) who are ages 3 through 21; (B) who are enrolled or preparing to enroll in an elementary school or a secondary school; (C) (who are i, ii, or iii) (i) who were not born in the United States or whose native languages are languages other than English; (ii) (who are I and II) (I) who are a Native American or Alaska Native, or a native resident of the outlying areas; and (II) who come from an environment where languages other than English have a significant impact on their level of language proficiency; or (iii) who are migratory, whose native languages are languages other than English, and who come from an environment where languages other than English are dominant; and (D) whose difficulties in speaking, reading, writing, or understanding the English language may be sufficient to deny the individuals (who are denied i or ii or iii) (i) the ability to meet the state's proficient level of achievement on state assessments described in section 1111(b)(3); (ii) the ability to successfully achieve in classrooms where the language of instruction is English; or (iii) the opportunity to participate fully in society. [P.L. 107-110, Title IX, Part A, Sec. 9101, (25)] (From http://www.doe.virginia.gov/federal_programs/esea/title3/guidance/definitions/definition_lep.pdf) The valid values: Y = Yes N = No

Variable Description: Students with Disability

> "Child with a disability" means a child evaluated in accordance with the provisions of this chapter as having an intellectual disability, a hearing impairment (including deafness), a speech or language impairment, a visual impairment (including blindness), a serious emotional disability(referred to in this part as "emotional disability"), an orthopedic impairment, autism, traumatic brain injury, another health impairment, a specific learning disability,deaf-blindness, or multiple disabilities who, by reason thereof, needs special education and related services. This also includes developmental delay if the local educational agency recognizes this category as a disability in accordance with 8VAC20-81-80 M.3. If the related service required by the child is considered special education rather than a related service under Virginia standards, the child would be determined to be a child with a disability. (§ 221-213 of the Code of Virginia; 34 CFR 300.8(a)(1) and 34 CFR 300.8(a)(2)(i) and (ii)) (From: http://www.doe.virginia.gov/special_ed/regulations/state/regs_speced_disability_va.pdf) The valid values: Y = Yes, N = No"
>
> Note: Code 15 (504 plan) was not included in the dataset.

Variable Description: Economically Disadvantaged

> "A flag that identifies students as economically disadvantaged if they meet any one of the following: 1) is eligible for Free/Reduced Meals, or 2) receives TANF, or 3) is eligible for Medicaid, or 4) identified as either Migrant or experiencing Homelessness. The valid values: Y = Yes, N = No."

Appendix C

2-level model used in analysis of student achievement data

Model equations for the primary/confirmatory research question:

What is the impact of the VISTA professional development for 5th grade science teachers on the science achievement of their students?

Level 1 Model: Student Level

$$Y_{ij} = B_{oj} + B_{1j}\left(X_{ij}\right) + \sum_{m}^{M} B_{mj} X_{mij} + r_{ij}$$

Where;

Y_{ij} = 5th grade state science SOL outcome score,

B_{oj} = conditional mean 5th grade state science SOL outcome score for control students in school team j,

B_{1j} = average 3rd grade-5th grade state science SOL slope for students in school team j

X_{ij} = 3rd grade state science SOL score for student I in school team j,

X_{mij} = M additional potential student-level covariates representing demographic characteristics of student I in school team j (e.g., White/non-White, gender, FRPL or other indicator of socioeconomic status, IEP or other indicator of disability).

B_{mj} = M coefficients corresponding to additional potential student-level covariates,

r_{ij} = random effect representing the difference between student ij's score and the predicted mean score for school team j, r_{ij}~ND(0, σ^2).

Level 2 Model: School Teams

$$\beta_{oj} = \gamma_{oo} + \gamma_{01} W_j + \sum_{q}^{Q} \gamma_{oq} W_{qj} + U_{oj}$$

Where;

γ_{oo} = conditional mean 5th grade science SOL achievement score for control school teams,

γ_{01} = treatment effect (i.e., the conditional mean difference between treatment and control school teams),

W_j = 1 if school team j is an intervention school, and 0 if control

W_{qj} = Q additional potential school team level covariates (e.g., Pre summer institute pedagogical content knowledge, years' experience, percent school ELL, percent of students passing 3rd grades science SOL at school level).

γ_{oq} = Q coefficients corresponding to additional school team level covariates,

U_{oj} = deviation of school team j's mean from the grand mean, conditional on covariates, U_{oj}~ND(0, τo^2)

Note. This is a two level model in which students are nested within teacher teams. Random assignment occurred at the level of school (teacher) teams.