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Engaging Students in Gathering, Reasoning, and Communicating through Evidence: Findings from the Partnership for Effective Science Teaching and Learning

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Abstract

The Partnership for Effective Science Teaching and Learning (PESTL) brings together five school districts and two universities to provide sustained and comprehensive science professional development with the goal of improving student learning, interest, and achievement in science. The PESTL program focuses on teachers development of the knowledge, skills, and dispositions to effectively engage students in gathering science information, reasoning to develop explanations supported by evidence, and communicating science explanations using models and arguments supported by evidence.

The PESTL program is a three-year professional development program for teachers in grades 3-6. The program is currently in year three with the second cohort of 120 teachers. Teachers annually participate in over 100 hours of science professional development with the following objectives:

1. *Increase teacher pedagogical content knowledge in science specific to disciplinary core ideas, crosscutting concepts, and science and engineering practices;*
2. *Develop teachers' use of effective instructional strategies in science;*
3. *Develop deep understanding of science standards;*
4. *Refine alignment of instructional resources and formative assessment tasks to the science and engineering practices, crosscutting concepts, and disciplinary core ideas;*
5. *Develop meaningful and useful understanding of the nature of science;*
6. *Increase teachers' interest in and enjoyment of science learning.*

The PESTL program includes a five-day summer seminar, two after school instructional alignment sessions and an annual content course specific to each teacher's grade-level (two Saturday sessions and online modules). These components of the professional development are linked through structured science professional learning communities (PLCs) facilitated at each school by a teacher facilitator who has received additional preparation. The approaches to instruction presented in the PESTL professional development program are strongly influenced by the research presented in the National Academies of Sciences, Taking Science to School.

Sustained professional development changes classroom instruction. Instructional strategies to engage students in using evidence to support explanations showed significant differences from students in classrooms of teachers not receiving professional development. The changes were significant after two years and the trend continued after three years. Structuring the science practices in ways that lead to communicating science reasoning provides a useful platform for teachers to engage students in developing skills across the literacy expectations of the Common Core State Standards for English Language Arts. Engaging students in meaningful science performances requires instructional strategies and structures to examine phenomena, classroom expectation for student engagement in reasoning, and norms for communicating through writing and oral discourse.

Introduction

The science practices are powerful ways for students to engage in reading, listening, speaking, and writing. Providing teachers with a structure for the practices supports students' engagement in science and engineering performances described in the National Research Council's *A Framework for K-12*

Science Education (Framework) [1] as well as the literacy components associated with the Common Core State Standards for English Language Arts (CCSS ELA) [2]. Professional development organized around science practices specific to gathering, reasoning, and communicating is a meaningful structure to improve science teaching and learning.

Preservice preparation alone cannot fully prepare teachers of science to implement instruction consistent with the vision of science described in the *Framework* and the Next Generation Science Standards (NGSS) [3]. Professional development is necessary to inspire and empower teachers to implement the vision with fidelity in classroom instruction. The Partnership for Effective Science Teaching and Learning (PESTL) program provides a clear vision of the scientific and engineering practices, crosscutting concepts, and disciplinary core ideas closely linked to teachers' classroom instruction and is consistent with the state, district, and school expectations for standards and curriculum [4].

Science and Engineering Practices

The science and engineering practices presented in the *Framework* [2] and the NGSS [3] include eight practices central to engaging students in science performances. The student science performances engage students in constructing explanations and developing arguments supported by crosscutting concepts and disciplinary core ideas. The seven crosscutting concepts provide a way for students to define phenomena in terms of systems, focus on cause and effect relationships, and recognize and use patterns as evidence to support explanations.

The use of evidence is central to the practices of constructing explanations and developing arguments; the role of evidence in student performances is featured throughout PESTL. Teachers develop skills to distinguish between gathering practices (e.g., investigations, observations, obtaining information) and reasoning practices (e.g., constructing explanations, designing solutions, analyzing data, developing arguments). The use of models across gathering, reasoning, and communicating receives specific attention as well as reflecting on instructional strategies to elicit student science performances.

PESTL provides teachers with a structure to engage students in a progression of learning across the science and engineering practices organized by: 1) Gathering, 2) Reasoning, and 3) Communicating. This structure is one feature that has contributed to significant changes in the nature of instruction by participating teachers. Instructional strategies are modeled as teachers engage in science performances and prepare to engage their students in a similar manner.

Science and Engineering Performances

The National Research Council describes science performances in the *Framework* as an intersection of the science and engineering practices, crosscutting concepts, and disciplinary core ideas. "Integration of the three dimensions will require that students be actively involved in the kinds of learning opportunities (performances) that classroom research suggests are important for their (students') understanding of science concepts" [1, 247]. Science performances that engage students in constructing explanations and developing arguments supported by evidence are the central focus of PESTL. These two practices require evidence; students develop evidence from core ideas, crosscutting concepts, or information from the gathering practices. The organization of the practices and clearly defining the role of core ideas and crosscutting concepts in student science and engineering performances is key to teachers understanding the movement of students' thinking from observations to science reasoning supported by evidence. Communicating solidifies students' reasoning and makes thinking visible. Engaging teachers in the practices across gathering, reasoning, and communicating provides instructional models for implementation in the classroom.

Connecting Literacy Principles from CCSS ELA and the *Framework*

Science writing and classroom discourse does not start with a question, but rather from wondering about phenomena and gathering information through reading, listening, and/or investigating. Just as gathering information to write about how a frog jumps is more engaging when sitting on the bank of a warm pond, with feet in mud and frog in hand, so too is gathering information when the student is engaged with the phenomena. Gathering information is an essential component of science; however, it must be contextualized within students' current and/or past experiences to have meaning [5]. Constructing understanding requires context connected to existing knowledge. Building that context requires engaging students in wondering about phenomena and developing strategies to investigate, in multiple ways, the evidence that can be used to support explanations of the phenomena. Classroom discourse only begins with gathering; students need to engage in reasoning practices that make sense of the phenomenon and then develop meaningful arguments supported by evidence to optimize science learning.
Gathering information through purposeful reading is best done when coupled with reasoning that connects evidence to explanations (see Table 1). Reasoning leads to productive student dialogue and meaningful writing [6]. Student science performances are not complete until students engage in communicating explanations supported by evidence and reflecting on connections from core ideas, crosscutting concepts, and observations/measurements from investigations. PESTL uses models purposely in all three phases of the practices (i.e., gathering, reasoning, communicating) to extend and make student thinking visible. Written and oral reflection on learning contributes to students' abilities to more fully engage in future science and engineering performances with novel phenomena.

Table 1: Organization of instruction across gathering, reasoning, and communicating.

Practices Phases	Science and Engineering Practices	Literacy Expectations
Gathering	• *Obtain Information* • *Ask Questions/Define Problems* • *Plan and Carry Out Investigations* • *Use Models to Gather Data* • *Use Mathematics & Computational Thinking*	*Ask questions to gain understanding.* *Obtain information* through careful reading and listening to reliable sources. • Develop and organize ideas, concepts, and observations.
Reasoning	• *Evaluate Information* • *Analyze Data* • *Use Mathematics and Computational Thinking* • *Construct Explanations/Solve Problems* • *Develop Arguments from Evidence* • *Use Models to Predict & Develop Evidence*	Evaluate information for evidence and relate *explanations and arguments to appropriate evidence.* • "Explain how an author uses reasons and evidence to support particular points in a text.
Communicating	• *Communicate Information* • *Use Argument from Evidence (written/oral)* • *Use Models to Communicate*	*Communicate* in meaningful ways through speaking and writing *that use evidence to support arguments.* • Write informative/explanatory texts. • Present information, findings, and supporting evidence.

Developing Meaningful Classroom Discourse

Effective classroom discourse does not just happen; it is carefully planned and executed. Development of a clear vision for the use of core ideas and crosscutting concepts, central to student arguments, must be considered during instructional planning and lesson development. The hierarchies of questions teachers pose must be carefully crafted to provoke students to ask relevant questions, gather additional information, construct explanations, or relate relevant evidence to arguments. Instructional planning has manifold purposes; not the least of which is keeping the focus on core ideas and crosscutting concepts central to the phenomenon. Using carefully selected questions is equally important for teachers to avoid telling the "punch line" of the student performance. Presenting phenomena and questions in ways that give students time and space to use core ideas such as, matter is made of particles, forces are transferred in collisions, or for every action there is an equal and opposite reaction (e.g., the paper floats more slowly to the floor when it is flat because air is made of particles and the paper must move the air particles and this requires a force), requires posing questions that engage students in connecting the cause and effect of phenomena to core ideas. Science education should engage students in applying science concepts, ideas, and practices to make sense of novel phenomena with underlying principles related to other phenomenon they have engaged in previously. Utilizing classroom discourse in ways that focus on students making sense of new phenomena requires careful planning to develop deeper understanding of fewer science concepts [7].

PESTL Classroom Observations

PESTL measures instructional changes using the PESTL Observation Protocol. The protocol provides insights into the degree to which teachers engage students in science and engineering across four scales of student performance: 1) Engaging in "Talk and Argument" as described in *Ready, Set, Science!* [8]; 2) Using Models to communicate; 3) Using Core Ideas as evidence supporting explanation; and, 4) Engaging in investigations to gather information. Instructional changes related to Talk and Argument and Models reveals insights into students' science and literacy skills. The Talk and Argument section of the protocol has four sub-scales: a) ratio of student/teacher interaction; b) number of times the teacher extends student thinking during classroom discourse; c) the extent of inter-student discourse; and d) students' use of evidence to support explanations. The "Using Models" section of the protocol has four sub-scales: a) Use of models/representations connected to crosscutting concepts and core ideas; b) Use of examples and analogies effectively; c) Use of models to assess student understanding; and, d) Science writing and/or representations by students.

Students and teachers in the experimental and control groups are observed annually in 45-minutes of science instruction. The sub-scales are rated on a five-point rubric. The performance of teachers in the experimental group was found to be significantly higher during years two and three (See Table 2).

Table 2: Mean Difference in Ratings by Experimental Condition for all Three Years Combined

	Treatment Group (n = 117)			Control Group (n = 39)						
Dependent Variable	Mean	Standard Deviation		Mean	Standard Deviation	Mean Diff.	Levine's Test	**t*	Diff.	Sig.
Composite Scales										
Talk & Argument	3.64	1.12		2.17	1.08	1.47	Yes	7.15	154	< .0001
Investigation	3.09	1.22		1.75	1.00	1.34	Yes	6.22	154	< .0001
Modeling	2.67	1.25		1.48	1.10	1.19	Yes	5.31	154	< .0001
Summary Judgment	3.34	1.13		1.90	0.85	1.44		8.40	86	< .0001

*Note: Since Levine's test indicated that the variances were significantly heterogeneous for the Summary Judgment variable; the *t*-test formula with adjusted degrees of freedom was used to test whether the mean difference between the two groups for this variable was statistically significant.

Conclusions from PESTL

Sustained professional development changes classroom instruction. Instructional strategies to engage students in using evidence to support explanations resulted in significant differences from observed classrooms of teachers not receiving professional development. The changes were significant after two years of professional development and continued to increase after three years. Structuring the science practices in ways that lead to communicating science reasoning provides a useful platform for teachers to engage students in developing skills across many of the expectations of the Common Core State Standards for English Language Arts and Literacy in Science. Engaging students in meaningful science performances requires: 1) instructional strategies and structures that support student investigation of phenomena, 2) clear expectations for student use of evidence to support reasoning, and 3) norms for communicating through written and oral discourse.

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