Engineering teaching behaviors in PK-3 classrooms

Dr. Scott C Molitor, University of Toledo

Dr. Scott Molitor earned his B.S.E. in Engineering Science at the University of Michigan and later earned his Ph.D. in Biomedical Engineering at the Johns Hopkins University School of Medicine. Following his Ph.D., he completed two postdoctoral fellowships in otolaryngology - head and neck surgery; the first at the Johns Hopkins University School of Medicine and the second at the University of North Carolina at Chapel Hill. Dr. Molitor joined the University of Toledo Department of Bioengineering in 2000 and is currently an Associate Professor and the Bioengineering Undergraduate Program Director.

Dr. Molitor's research interests include molecular mechanisms of cellular excitability, computational modeling of neuronal function, auditory neuroscience and treatments for traumatic brain injury. He has supervised the thesis and dissertation work of numerous graduate students working in these research areas. His educational interests include preparing high school and first year college students to study engineering mathematics, and the teaching of science and mathematics to young children.

Dr. Joan N Kaderavek, University of Toledo

Joan Kaderavek, Ph.D., has been awarded the title "Distinguished University Professor" of Early Childhood Education at the University of Toledo. Dr. Kaderavek's research has focused on classroom discourse and linkages between discourse and academic achievement.

Hoangha Dao, University of Toledo
Nicholas J Liber
Regina Rotshtein, University of Toledo
Geoff Milewski, The University of Toledo
Dr. Charlene M Czerniak, The University of Toledo

Charlene M. Czerniak is a professor at The University of Toledo in the department of Curriculum and Instruction. She received her Ph.D. in science education from The Ohio State University. A former elementary teacher in Bowling Green, OH, she teaches classes in grant writing, elementary science education, and science teacher leadership. Professor Czerniak has authored and co-authored over 50 articles. Her publications have appeared in the Journal of Science Teacher Education, Journal of Research in Science Teaching, School Science and Mathematics, Science Scope, and Science and Children. Professor Czerniak is co-author of a textbook published by Routledge on project based science teaching. She also has five chapters in books and illustrated 12 children's science education books. Most recently, Czerniak authored a chapter entitled Interdisciplinary Science Teaching in the Handbook of Research on Science Education, published by Lawrence Erlbaum and Associates. Professor Czerniak has been an author and director of numerous grant funded projects in excess of $30 million dollars that targeted professional development of science teachers.She has made frequent presentations at national and regional conferences that focus on her research interests on teachers' beliefs about teaching science, professional development for elementary and middle grades teachers, science education reform, and school improvement. She is an active member in the Association for Science Teacher Education (ASTE), the National Association of Research in Science Teaching (NARST), the School Science and Mathematics Association (SSMA), and the National Science Teachers Association (NSTA) and reviews manuscripts for the journals associated with these organizations. For five years, she served as editor of the Journal of Science Teacher Education, the professional journal of the Association for Science Teacher Education. She has served on numerous committees for AETS, NARST, SSMA, and NSTA. Charlene Czerniak was the President of the School Science and Mathematics Association for two years, and she served as the President of the National Association for Research in Science Teaching (NARST) from 2008-2009. She received the 2008 Distinguished Alumni Award for Service from The University of Toledo Judith Herb College of Education and the 2008 Research Award from the Judith Herb College of Education. In 2010, she received the George Mallinson Distinguished Service Award from the School Science and Mathematics Association (SSMA), which is the highest award given by SSMA. In 2012, she was named Distinguished University Professor at The University of Toledo, which the highest award bestowed on faculty.

Engineering teaching behaviors in PK-3 classrooms

Paper type: Research to Practice

Paper strand: Addressing the NGSS: Supporting K-12 Teachers in Engineering Pedagogy and Engineering-Science Connections

Abstract

Guidelines provided by the National Research Council's (NRC) Framework for K-12 Science Education and subsequent implementation of the Next Generation Science Standards (NGSS) require that both science and engineering content be delivered in K-12 classrooms. Furthermore, this content must be delivered as students engage in science and engineering practices, and must point toward larger principles known as cross-cutting concepts that span multiple scientific and engineering disciplines.

As part of the NURTURES program, a 5 year project funded by a NSF Math-Science Partnership, we have developed and delivered summer institutes for PK-3 teachers to improve the quality of science and engineering education in early childhood classrooms and to facilitate the implementation of the NGSS in an urban school system. As part of this project, we have developed an instrument known as the Systematic Characterization of Inquiry Instruction in Early LearNing Classroom Environments, or SCIIENCE instrument, to measure the efficacy of our professional development and to improve pedagogical practices in PK-3 classrooms.

The SCIIENCE instrument was designed to objectively capture the presence of specific best practices outlined in the NRC Framework as they occur within a science lesson and focuses on teacher behaviors. The goals of the SCIIENCE instrument are (a) to provide a standardized tool based on the NRC Framework for assessing the quality of science and engineering instruction in PK-3 classrooms; (b) to capture the instructional practices that engage students in their science and engineering lessons, promote scientific and engineering practices, and encourage higher-level thinking; and (c) to provide a feedback mechanism for guiding professional development of PK-3 teachers designed to facilitate NGSS implementation.

This paper describes the aspects of the SCIIENCE instrument that measure teacher behaviors associated with engineering practices specified by the NGSS that are appropriate for PK-3 classrooms. Furthermore, we show results from the application of the SCIIENCE instrument that demonstrate a substantial improvement in teaching practices with regards to NGSS engineering content and practices following completion of our summer institute. A comparison of these results to similar results for teaching behaviors associated with scientific inquiry shows that PK-3 teachers may be more amenable to the implementation of engineering practices in their classrooms.

Introduction

The Next Generation Science Standards (NGSS) and the Framework for K-12 Science Education (Frameworks) indicates that K-12 classroom instruction should focus on the intersection of scientific and engineering practices, disciplinary core ideas, and crosscutting concepts[1]. As such, high-quality science instruction should focus on teaching "how we come to know what we know” instead of only teaching just “what we know”. Furthermore, the NGSS and Frameworks indicate that science and engineering learning should begin during early childhood education (ECE; preschool – 3rd grade) and is an appropriate subject of study from the earliest years[1]. In fact, if we expect children to be able to become proficient in science by 12th grade, it is critical that the scope and sequence of science instruction should begin at the earliest point possible.

ECE science instruction is overlooked as the necessary foundation for eventually achieving high quality instruction[2]; and yet, science especially lends itself to inquiry, exploration, and curiosity essential for establishing young children’s positive attitudes towards school in general as well as towards reading, mathematics, and of course science. There is an unwritten expectation that students will naturally develop an interest in science when it is introduced in middle school or even later in junior high[3]. Furthermore, there is a need for early childhood science if our nation expects to improve science education at subsequent grade levels[4]. Eventual achievement levels in science begin in kindergarten and first grade[5]. Yet, many early childhood teachers are intimidated by science and not well prepared to teach science in early grades[6].

Interestingly, it has only been in recent years that educators have come to respect and acknowledge the significant contribution of domain-specific instruction in early childhood on children’s academic outcomes. For example, 20 years ago, educators refuted the idea that preschool and kindergarten children should be reading and writing. It was believed that children learned to read in 1st grade, before that point, children were not ready. Research now clearly indicates that children need both implicit (e.g., contextual, natural) and explicit (e.g., more didactic, formalized) literacy instruction - beginning in the preschool years - to optimize children’s learning outcomes.

Over the last 20 years of systematic literacy research experts have begun to identify exactly what literacy targets should be focused on with young children and how literacy instruction should be implemented in early childhood education (ECE) classrooms[7, 8]. Experts have concluded that literacy instruction with young children in ECE classrooms is qualitatively and quantitatively different than reading and writing instruction with older children[9]. However, in contrast to the significant body of literature that focuses on ECE literacy learning, there is a dearth of research focusing on ECE science instruction. The studies that have been completed have most often been small scale and/or utilize case study methodology[10]. There have been few, if any, studies of ECE science instruction with significant subject numbers permitting more statistical analytic approaches.

As part of our NURTURES grant to improve science and engineering instruction in ECE classrooms, we have developed an instrument known as the Systematic Coding Characterization of Inquiry Instruction in Early LearNing Classroom Environments (SCIIENCE)[11]. The SCIIENCE characterization instrument was designed to provide a standardized tool that objectively captures the presence and frequency of specific instructional practices as they occur within a science lesson. The instructional practices encoded by the SCIIENCE instrument were identified to support child proficiency with scientific and engineering practices outlined in the Frameworks. Furthermore, this instrument captures instructional practices that engage students in the lesson, promote scientific studies, and encourage higher-level thinking. Having tested the reliability and validity of this instrument[11], we are currently using the SCIIENCE instrument to provide a feedback mechanism for guiding the professional development of the PK-3 teachers that participate in our summer institutes.

One of the novel aspects of the Frameworks and NGSS is the inclusion of engineering practices, concepts and disciplinary core ideas in K-12 science education. Therefore the SCIIENCE instrument includes instructional practices that support child proficiency with specific aspects of the engineering design process. We will describe aspects of the SCIIENCE instrument that measure teacher behaviors associated with engineering practices specified by the NGSS that are appropriate for PK-3 classrooms. Furthermore, we show results from the SCIIENCE instrument to demonstrate how instructional practices specific to the engineering design process have changed following completion of our summer institute.

NURTURES project

The Networking Urban Resources with Teachers and University to enRich Early childhood Science (NURTURES) project is a five-year, $10M NSF Math Science Partnership grant to improve ECE science outcomes using the complementary education model[12]. A substantial focus of this project is to improve science instruction in ECE classrooms through two-week professional development (PD) institutes that will be attended by approximately 500 PK-3 teachers from the Toledo, OH public school district by the completion of this project in Fall 2016. To complete the complementary education framework, companion science activities are also being developed to promote ECE science education at home and with informal educational organizations such as museums, zoos, parks, and educational television programs. The delivery of science instruction, whether in classrooms, at home or at informal community science partners, is based on the Frameworks and NGSS to intertwine scientific and engineering practices and cross-cutting concepts with disciplinary core ideas.

In order to provide our teachers with examples of effective instructional practices, and in order to assess the efficacy of our PD, we are developing a database of teaching videos from all teachers that attend our summer PD. For each teacher, videos are obtained from an inquiry lesson taught before the teacher attends the PD, and then again from a second inquiry lesson after the teacher attends this PD. We are using these results to improve the outcomes of our subsequent PD sessions on the instructional practices of teachers that participate in this program[13]. Therefore we will have a large database of teaching samples (approximately 1,000 pre- and post-PD videos from 500 teachers) that could provide insight into instructional practices that are associated with positive student outcomes following inquiry instruction. We are currently in the process of collecting and analyzing videos from approximately 50 teachers that have attended the pilot and scale-up versions of our summer institute during the first two years of the NURTURES project.

SCIIENCE instrument

The SCIIENCE instrument objectively measures the presence and quality of instructional practices that are designed to promote inquiry instruction as described by the Frameworks and to enhance the ability of students to achieve performance expectations described by the NGSS. The SCIIENCE instrument consists of four types of measures: 1) binary codes, 2) frequency codes, 3) category of inquiry and 4) global ratings. The first two measures, binary and frequency codes, provide a micro-analysis of whether specified teacher behaviors occur during inquiry instruction.

The last two components, category of inquiry and global ratings, provide an overall evaluation of the type and quality of instruction that is provided during inquiry instruction.

Binary codes

Binary codes are identified as instructional practices or events that occur at any time during an inquiry lesson. These events are assumed to be teacher-directed, and binary codes are assigned regardless of whether teacher or students are engaged in these activities. In contrast to the frequency codes described below that are recorded within 30 second intervals, binary codes identify practices or events that are not momentary or brief occurrences. Instead, these events may span across multiple 30 second intervals, and in many cases comprise a substantial portion of the overall inquiry lesson. Therefore binary codes are recorded only as being present or absent within an individual lesson and are not coded across 30 second intervals. A total of 9 instructional practices are coded in this manner, and are organized by the eight scientific and engineering practices that comprise the first dimension of the Frameworks (table 1).

Table 1: SCIIENCE binary codes

Practice 1: Asking Questions (Science) and Defining Problems (Engineering)
Practice 2: Developing and Using Models
2.1 Student Model: students are engaged in the creation of models to represent scientific concepts or processes.
Practice 3: Planning and Carrying Out Investigations
3.1 Test Hypothesis: the teacher designs experiments or activities that seek to obtain evidence that will be used to support or not support an existing hypothesis.
3.2 Equipment: the activity incorporates the use of appropriate task-specific equipment. This includes mechanical equipment (e.g., balloon pump, or syringe) and/or equipment used to measure quantitative data (e.g., ruler, rain gauge, or thermometer).
3.3 Teacher Demonstration: the teacher provides students with a preview or example of the concepts they will exploring; or the teacher performs a demonstration/experiment for the class that explores some phenomenon/concept.
Practice 4: Analyzing and Interpreting Data
Practice 5: Using Mathematics and Computational Thinking
5.1 Numerical Summary: collected data are organized and aggregated; this could also include statistical or mathematical calculations (min, max, average, etc.).
5.2 Graphical Summary: collected data are organized and a graph of these values is created.
Practice 6: Constructing Explanations (science) and Designing Solutions (engineering)
Practice 7: Engaging in Argument From Evidence
Practice 8: Obtaining, Evaluating, and Communicating Information
8.1 Expository Text: the teacher integrates the use of expository text within the science lesson.
8.2 Technology: the teacher has students use technology during inquiry activities; or teacher uses the technology with student involvement.
8.3 Formative Assessment: the teacher integrates formative assessments into the lesson.

Frequency codes

Frequency codes are identified as momentary instructional practices or events that may occur repeatedly throughout a lesson. Furthermore, frequency codes are strictly identified as being teacher behaviors; the responses of students to these behaviors have no bearing on whether or not an instructional practice is coded. To complete the frequency coding process, videos of teacher lessons are broken into individual 30 second intervals, and frequency codes are recorded only as being present or absent within each 30 second interval. A total of 18 instructional practices are coded in this manner, and like binary codes, frequency codes are organized by the eight scientific and engineering practices that comprise the first dimension of the Frameworks (table 2).

Table 2: SCIIENCE frequency codes

Practice 1: Asking Questions (Science) and Defining Problems (Engineering)	
1.1	Prior Knowledge: the teacher asks students to recall previously learned knowledge or past experiences.
1.2	Misconception: the teacher does not declare an inaccurate student response as wrong or tell the right answer.
1.3	Elicit Hypothesis: the teacher asks students to predict the outcome of a situation.
1.4	Elicit Specifications: the teacher asks students to provide criteria or constraints for a design that will be created to solve a specified problem.
Practice 2: Developing and Using Models	
2.2	Model Discourse: the teacher engages students in discourse about an existing model.
Practice 3: Planning and Carrying Out Investigations	
3.4	Observation: the teacher encourages students to describe what they hear, see, smell, touch, and if appropriate, taste; or teacher asks a question or makes a statement that encourages the student to look at the material or object in order to answer that question.
Practice 4: Analyzing and Interpreting Data	
4.1	Analysis/Interpretation: the teacher leads students to consolidate and interpret the results of their data/observations.
4.2	Overarching Relationships: the teacher encourages students to recognize relationships among concepts to obtain a “big picture” view of the underlying principles.
4.3	Move Past Misconception: the teacher uses strategies or creates learning situations to help students move past misunderstandings.
Practice 5: Using Mathematics and Computational Thinking	
5.3	Quantitative Analysis: the teacher guides students to interpret data and formulate conclusions from numerical or graphical representations.
Practice 6: Constructing Explanations (science) and Designing Solutions (engineering)	
6.1	Explanation/Evidence: the teacher questions and discourse guides students to generate their own explanations for observed or hypothetical phenomena; or teacher asks student to support statement with empirical evidence, prior knowledge, or logical reasoning.
6.2	New Situation: the teacher helps students relate previously-learned concepts to new content/situation.
6.3	Evaluate Understanding: the teacher initiates a discussion in which student/s may judge or articulate their success or failure with the science activity; or teacher gets students to assess their own level of understanding of a concept or to recognize flaws in their thinking.
Practice 7: Engaging in Argument From Evidence	
7.1	Disagreement: the teacher encourages or accepts student disagreement when obtaining

	multiple suggestions, explanations, or answers from different students.
Practice 8: Obtaining, Evaluating, and Communicating Information	
8.4	Documentation: the teacher uses a white board, chalk board, paper, or other resources to record the content of class discussions or has students record their own observations/ideas individually.
8.5	Vocabulary: the teacher uses science vocabulary in the context of the lesson, rather than simply stating the definition or asking students for a definition.
8.6	Open-ended Question: the teacher asks questions that encourage students' own thoughts and ideas.
8.7	Sequenced Questions: the teacher leads students to a solution through multiple questions, and questions move from general to more specific. The teacher's next question in a series must rely upon the previous answer.

Category of inquiry

One of the novel aspects of the NGSS is that students must be proficient in using practices associated with scientific investigation as well as using practices associated with engineering design. Therefore we felt it was important to classify whether hands-on activities encompass scientific investigation or capture aspects of the engineering design process. In addition, the binary and frequency codes focus on instructional practices implemented by teachers within their lesson plans. However, the performance expectations developed for the NGSS are predicated on the ability of students to demonstrate competencies with the various scientific and engineering practices.

To address these issues, the category of inquiry (table 3) is designed to identify the type of activity (scientific investigation, engineering design or testing a design) and then the level of scaffolding provided by the teacher and the level of participation of students in the design and execution of the activity. If present, a scientific investigation, design or testing activity is categorized as confirmation, structured, guided or open based on the input students provide in the construction and execution of the inquiry activity[14]:

Table 3: SCIIENCE category of inquiry

A.1 Scientific Investigation: students are engaged in a thought-provoking activity that examines a scientific concept, phenomenon, or theory.	
None	There is no scientific investigation occurring during this lesson.
Confirmation	Students are given a question, procedure, and conclusion. Activity confirms what is already known.
Structured	Students are given a question and procedure. Students reach their own conclusions.
Guided	Students are given only a question. Students create and use their own procedure and reach their own conclusions.
Open	Students create their own question(s) and procedure(s), effectively designing their own experiment.
A.2 Design Solution: students are given a situation or problem and asked to generate potential solutions.	
None	There is no engineering design activity occurring during this lesson.
Confirmation	Students are given the problem to solve, specifications and constraints for the

	solution, and specific instructions from the teacher on how to create the design.
Structured	Students are given the problem to solve, specifications and constraints for the solution, but create the design without being given specific instructions from on how to do so.
Guided	Students provide their own specifications and constraints for the solution, then develop and create their own design to solve a problem identified by the teacher.
Open	Students identify a problem to solve, provide their own specifications and constraints for the solution, then develop and create their own design to solve this problem.
A.3 Test Solution: students or the teacher test a proposed design or solution.	
None	There is no engineering test activity occurring during this lesson.
Confirmation	Students are given the procedure and outcome. Activity confirms what is already known.
Structured	Students are given the procedures but obtain their own results to reach a conclusion about how the design satisfies criteria identified by the teacher.
Guided	Students develop their own procedures and obtain their own results to reach a conclusion about how the design satisfies criteria identified by the teacher.
Open	Students identify their own criteria, develop their own procedures, and obtain their own results to reach a conclusion about how the design satisfies these criteria.

Global quality ratings

It is not clear whether the overall quality of an inquiry lesson will be determined by the presence of various instructional behaviors and with the implementation of inquiry activities that allow for more student input. For example, a teacher may employ the instructional practices we have chosen to identify at inappropriate times, or may allow for a more unstructured activity that required more scaffolding given the nature of the content. Therefore we have included six SCIIENCE global quality ratings measures to address the quality of the overall lesson (table 4).

Table 4: SCIIENCE global quality ratings

G.1 Student Thinking
Signs of low-level student thinking include: yes or no answers; one-word and/or simple/low-level statements; reciting from memory; reliance on the teacher to obtain information
Signs of high-level student thinking include: extended, detailed, or high-level statements; students generate their own ideas; evidence of critical thinking; students demonstrate initiative to arrive at their own answers
1. little or no evidence of higher-order thinking
2. some evidence of higher-order thinking, but lower order thinking predominates
3. similar amounts of lower-order and higher-order thinking
4. substantially more higher-order thinking
G.2 Balanced Talk
Examples of unbalanced talk include: teacher lecture dominates discussion; teacher doesn't ask questions; little or no opportunity for students to ask questions and/or initiate discussion; little or no opportunity for peer to peer discussion
Examples of balanced talk include: discourse includes two-way communication between teacher

and students; teacher asks questions that facilitates discourse; students ask their own questions and/or initiate discussion; students are engaged in peer to peer discussion
1. less than 25% of the lesson demonstrates alternating teacher-student talk and/or there is no student-initiated talk within the lesson
2. between 25-50% of the lesson demonstrates alternating teacher-student talk and/or there is little student-initiated talk within the lesson
3. between 50-75% of the lesson demonstrates alternating teacher-student talk and/or there is some student-initiated talk within the lesson
4. more than 75% of the lesson demonstrates alternating teacher-student talk and/or there is significant student-initiated talk within the lesson
G.3 Student Engagement
Lack of student engagement includes: never or rarely raising hands to answer questions; engaging in other, unrelated activities during the lesson; not maintaining eye contact; appearing bored; daydreaming; demonstrating little or no interest in discussions or activities
High levels of student engagement include: raising hands to answer teacher questions or calling out answers without raising of hands; remaining on-task during the lesson; maintaining eye contact to show interest in topic; demonstrating interest in discussion or activities
1. less than 25% of students are actively engaged in discussions and activities within the lesson
2. between 25-50% of students are actively engaged in discussions and activities within the lesson
3. between 50-75% of students are actively engaged in discussions and activities within the lesson
4. more than 75% of students are actively engaged in discussions and activities within the lesson
G.4 Question Quality
Examples of low-quality questioning include: questions that are likely to elicit short and simple responses; or questions that do not encourage higher level thinking; do not relate to one another; do not extend the discussion; and do not contribute meaning to scientific and engineering Concepts
Examples of high-quality questioning include: questions that are likely to elicit extended answers; generate further discussion about the topic or concept and/or takes the discussion to a higher level; or contribute meaning to scientific and engineering concepts
1. teacher's questions do not contribute meaning to the lesson and/or are likely to elicit only simple, short responses from students
2. teacher's questions are somewhat meaningful to the lesson and are likely to elicit few extended responses from students
3. teacher's questions are generally meaningful to the lesson and are likely to elicit some high-level, extended responses from students
4. teacher's questions are highly meaningful to the lesson and are likely to elicit many high-level, extended responses from students
G.5 Inquiry/Engineering Quality
Features of low-quality inquiry/engineering activities include: teacher does not use scaffolding techniques to assist students during activity; activities are not likely to contribute to student understanding or knowledge of the scientific/engineering concepts being explored; no discussion of results from activities
Features of high-quality inquiry/engineering activities include: teacher uses scaffolding

techniques to assist students during activity; activities are focused on collecting data or obtaining evidence with a specific purpose or goal in mind; discussion of results after the activity is likely to contribute to student understanding of scientific/engineering concepts; the activity reflects scientific methods of investigation or principles of engineering design
1. inquiry/engineering activities are not goal-oriented and student understanding is not scaffolded by the teacher during the activities
2. inquiry/engineering activities are somewhat goal-oriented and student understanding is minimally scaffolded by the teacher during the activities
3. inquiry/engineering activities are generally goal-oriented and student understanding is moderately scaffolded by the teacher during the activities
4. inquiry/engineering activities are highly goal-oriented and student understanding is significantly scaffolded by the teacher during the activities
G.6 Discourse Techniques
Examples of low-quality discourse techniques include: teacher does not use adequate wait-time after questions; teacher answers his/her own questions; teacher does not ask follow-up questions; teacher obtains only one student's answer for each question; teacher provides little or no opportunity for students to ask questions
Examples of high-quality discourse techniques include: teacher uses adequate wait-time after questions; students are given opportunities to figure things out for themselves; teacher re-voices student responses; teacher asks students for clarification; teacher asks follow-up questions; teacher asks other students for additional thoughts; teacher encourages students to ask their own questions
1. teacher rarely or never uses discourse techniques during discussions
2. teacher occasionally uses discourse techniques during discussions
3. teacher often uses discourse techniques during discussions
4. teacher consistently uses optimal discourse techniques during discussions

Application of SCIIENCE instrument

The SCIIENCE instrument is applied to videotaped samples of teaching in ECE classrooms. Trained users of this instrument will initially watch the video to determine the category of inquiry activity and identify the presence of any binary codes. Following this initial viewing, users will watch an edited 20 minute version of the video to record frequency codes (see below). During frequency coding, the 20 minute edited video is coded in 30-second increments, and the teacher receives credit for a frequency code if the corresponding behavior occurred at least once at any time during the 30-second segment. The coder marks all codes observed during the 30-second segment, then moves to the next segment and repeats this process. Not all utterances or activities are coded, and a single utterance or activity may receive multiple codes. A third and final viewing of the entire lesson is then conducted for the assignment of various global quality ratings.

The videotaped science lessons had durations ranging from 20 minutes to over an hour. For frequency coding, each video was edited to provide a 20 minute format that captured the best possible observation of a teacher's science lesson and to standardize the amount of time that a teacher was observed. This edited segment is obtained by identifying portions of the lesson that occur before, during and after an inquiry or hands-on activity. The rationale for this classification is that it is likely that certain frequency codes are more likely to appear at certain times. For example, it is more likely that prior knowledge will be reviewed or a hypothesis elicited before an experiment, whereas analysis of data and explanation of results are activities associated with the discussion following an inquiry activity.

Based on the proportions of the before, during, and after segments, the user selects specific points of the lesson within each of the segments to (a) identify the video sections with the highest code density and variety to obtain a teacher's best example of instructional practice, (b) maintain the proportion of the before, during, and after segments to reflect the overall structure of the entire unedited lesson, and (c) maintain the continuity of the lesson so that segments were never less than two minutes in length. As an example of this editing process, if a teacher's entire 40 minute lesson consisted of 15 minutes of before activity, 20 minutes of during, and 5 minutes of after activity, the 20 minute edited version would consist of 7.5, 10, and 2.5 minutes from each respective activity. To retain continuity, additional video was selected, if needed, to provide necessary context and/or to reach the minimum of a two-minute duration for the before, during and after phases of the inquiry process.

Given the complexity in applying this instrument, a process for training reliable users of the SCIIENCE instrument has been developed. For frequency and binary codes, a series of video clips have been prepared to highlight the various practices that are being identified. For category of inquiry and global ratings, details of the types of behaviors and/or longer video clips that exhibit these types of behaviors are given. Once the user is comfortable with coding following a few practice sessions, a certification process is provided in which the user applies the instrument to a video standard and compares their results to a video that has been coded and discussed among a master group of coders. In addition to the training and certification process, we have developed a detailed coding manual to guide certified coders in their evaluation of teacher videos. The code definitions provided in tables 1 – 4 were obtained from the coding manual, which also includes elaborations on these definitions, examples, counter-examples and any additional notes.

Results

The original version of the SCIIENCE instrument contained 33 frequency codes but no binary codes, category of inquiry or global ratings[11]. These original 33 frequency codes contained all of the current binary codes and all but one of the current frequency codes (1.4 Elicit Specifications). The original version of the SCIIENCE instrument also contained seven additional codes that have since been removed or folded into other codes. Three certified coders demonstrated high to near-perfect inter-rater reliability[11] when applying this original version of the SCIIENCE instrument to post-PD videos from six teachers that attended our first NURTURES summer institute.

Results from our pilot study showed that measures obtained using the original version of the SCIIENCE instrument showed good agreement with the Classroom Assessment Scoring System (CLASS) that provides a framework for observing dimensions of classroom processes such as emotional and instructional support that contribute to the quality of PK-3 classroom settings[15]. Results from our pilot study also demonstrated good agreement with the Horizon Local Systemic Change Classroom Observational Protocol, which was developed to observe K-12 science or mathematics classrooms and measure the quality of the lesson design and implementation, mathematics and science content, classroom culture, and the likely impact of instruction on student understanding[16].

To determine the efficacy of the first year of our NURTURES summer institute, a subsequent study compared measures from the original version of our SCIIENCE instrument applied to pre-PD and post-PD samples of inquiry instruction from six teachers that attended the first summer institute[13]. Table 5 shows results for frequency codes in the original version of the SCIIENCE instrument that remain in the current version. Note that the frequency codes 6.1a Explanation and 6.1b Evidence were coded separately in the original version, but have since been combined into a single frequency code 6.1 Explanation / Evidence in the current version of our instrument.

Table 5: comparison of frequency code frequencies before and after PD

SCIIENCE code		pre-PD videos	post-PD videos
1.1	Prior knowledge	2.5	4.6
1.2	Misconception	6.3	5.4
1.3	Elicit hypothesis	3.8**	0.0
2.2	Model discourse	0.0	0.0
3.4	Observation	16.7	16.3
4.1	Analysis/interpretation	3.8*	0.8
4.2	Overarching relationships	0.8	0.0
4.3	Move past misconception	1.3	1.7
5.3	Quantitative analysis	0.0	0.0
6.1a	Explanation	7.1	11.7
6.1b	Evidence	1.3	6.7**
6.2	New situation	0.0	0.0
6.3	Evaluate understanding	0.0	0.0
7.1	Disagreement	2.1	4.6
8.4	Documentation	32.9	27.5
8.5	Vocabulary	32.5	28.3
8.6	Open-ended question	49.6	68.3***
8.7	Sequenced questions	13.8	18.3

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

One emphasis of this original summer institute was questioning and discourse strategies, which was reflected in more frequent instructional behaviors to elicit evidence for student responses (6.1b) and open ended-questions (8.6). However, there was no significant increase in many other instructional behaviors, and we even observed a significant decrease in eliciting hypotheses (1.3) and analysis and interpretation of results (4.1). We found these results to be unsatisfactory, and this led to a redesign of our remaining NURTURES summer institutes to increase emphasis on non-discourse scientific and engineering practices and disciplinary core ideas.

In addition, the current version of the SCIIENCE instrument contains a number of binary and activity codes that were measured as frequency codes in the original version. A comparison of pre-PD and post-PD binary code frequencies is shown in Table 6 and a comparison of pre-PD and post-PD activity code frequencies is shown in Table 7. These results were similar to those found in Table 5, in which teachers that attended our initial PD did not show any gains in many of the instructional behaviors identified by the Frameworks and NGSS. Of particular concern was a significant decrease in eliciting hypotheses (1.3 in Table 5), testing hypotheses (3.1 in Table 6) and student inquiry (A.1 in Table 7). Taken together, these results suggested that our teachers were spending less time eliciting student ideas about scientific outcomes, and students were spending less time with hands-on activities to test these ideas.

Table 6: comparison of binary code frequencies before and after PD

binary code		pre-PD videos	post-PD videos
2.1	Student model	3.3	2.1
3.1	Test hypothesis	5.4**	0.0
3.2	Equipment	4.6	5.0
3.3	Teacher demonstration	2.9	2.9
5.1	Numerical summary	0.0	0.0
5.2	Graphical summary	0.0	0.0
8.1	Expository text	4.2**	0.0
8.2	Technology	0.0	0.0
8.3	Formative Assessment	0.0	0.0

** $p < 0.01$

Table 7: comparison of activity type frequencies before and after PD

SCIIENCE code		pre-PD videos	post-PD videos
A.1	Student inquiry	40.0***	18.3
A.2	Design solution	1.3	3.3
A.3	Test solution	1.3	5.4*

* $p < 0.05$
*** $p < 0.001$

However, we were pleased to see that teachers did spend more time on engineering activities. In contrast to the aforementioned decrease in scientific investigation, there was a slight albeit non-significant increase in activities devoted to designing solutions (A.2 in Table 7) and a significant increase in activities devoted to testing designed solutions (A.3 in Table 7). Anecdotal evidence from coaching and academic year PD sessions with teachers that attended the first NURTURES summer institute supported this result.

The teachers felt that these young children were more comfortable engaging in engineering design which had more practical and concrete applications, such as the design of musical instruments. This is in contrast to scientific investigation, which resulted in more abstract and theoretical results, such as the physical origins and characteristics of sound waves that result in music. Although further study is warranted, we believe that the introduction of engineering practices and engineering core content into the NGSS will facilitate improved inquiry instruction and student outcomes in ECE classrooms due to the more concrete applications associated with engineering design.

Discussion

With the recent release of the NGSS, it is important to develop reliable observational systems for documenting the use of high-quality instructional practices by teachers for evaluation and professional development. Furthermore, such observational systems can provide insight into which educational practices lead to improved outcomes for students in science classrooms. These observational systems should include a number of elements provided in the SCIIENCE instrument, including the development of a theoretically strong and reliable tool to observe teacher behavior in a specific domain, a specified rater training program, and a scoring system that allows clear interpretation of observed instructional behaviors[17].

The SCIIENCE instrument is an important first step to facilitate implementation of inquiry instruction as described by the Frameworks and was developed in keeping with the specific instructional behaviors that are identified in the Frameworks. Therefore, the SCIIENCE instrument should be useful for research and teacher development. Since there has been limited research regarding early childhood instruction, and to our knowledge no observational tools focusing on preschool science instruction, it is imperative that well-designed tools document the level at which inquiry teaching behaviors occur in ECE classrooms. The strengths of this tool include objective descriptions of each coded behavior, a rich data source that results from direct observations, the ability to incorporate results into professional development and teacher evaluation, and the utility of the SCIIENCE instrument for future research.

In addition to improving the content of our NURTURES summer institutes, the results of these studies also were used to improve the SCIIENCE instrument. In particular, the decrease in activities associated with scientific inquiry may have been offset by an increase in activities associated with engineering design. In other words, there was still the same amount of hands-on inquiry pre-PD and post-PD, but the nature of this activity changed from exclusively scientific investigation to a combination of scientific investigation and engineering design. This observation led to the category of inquiry codes to characterize the type of hands-on activity and the role of students in the design and execution of these activities. Therefore we now have a measure regarding the types of inquiry activities teachers will engage in before and after attending NURTURES summer institutes. We also have incorporate instructional practices associated with distinct processes associated with scientific investigation and engineering design.

We constructed the SCIIENCE instrument to objectively measure instructional practices that we believe would support student achievement of performance expectations provided by the NGSS. Although our instrument shows good agreement with the CLASS and Horizon instruments, there is no direct evidence to suggest that the instructional practices identified by the SCIIENCE instrument will support improved student outcomes as specified by the NGSS. There are assessment principles associated with developmentally appropriate practice in ECE classrooms. Specifically, the National Association for the Education of Young Children (NAEYC) states that assessment for young children should (a) enable children to demonstrate their competence through a variety of assessment protocols (e.g., observations, work samples), (b) document children’s performance during authentic activities, and (c) consider what children can do independently and also what children can do with assistance[17]. In addition, there are assessment requirements specific to inquiry instruction; the Frameworks mandate that assessment of children's science learning must include their ability to use scientific and engineering practices along with knowledge of disciplinary core ideas.

At present, there is no assessment tool that evaluates a child's development of scientific and engineering practices along with his or her knowledge of disciplinary core ideas in authentic contexts for ECE classrooms. Therefore our next goal is to create a developmentally-appropriate and NGSS-based tool for assessing student outcomes following inquiry instruction in ECE classrooms. At present, we are working to develop a discourse-based tool to assess student outcomes for ECE inquiry instruction. Careful analysis of what children say in response to adult actions and verbal prompts has been used to evaluate and understand children's early literacy development[18, 19] and also their use of concrete versus inferential (i.e., high level, abstract) language[20]. Children make their thinking visible through what they say and do; discourse assessment allows the educator to determine a child's acquisition of content knowledge and reasoning.

Once this child assessment tool has been developed, evaluated for reliability, and validated against existing child assessment tools, we will analyze changes in child outcomes in the context of instructional practices used by their teachers as characterized by the SCIIENCE instrument. The ultimate goal of this research is to identify instructional practices that are most likely to support positive and developmentally-appropriate child outcomes following NGSS-based inquiry instruction in ECE classrooms.

Bibliography

1. Committee on Conceptual Framework for the New K-12 Science Education Standards, National Research Council. (2012). A framework for K-12 science education: practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.
2. Pratt, H. (2007). Science education's 'overlooked ingredient': Why the path to global competitiveness begins in elementary school. NSTA Express, October 10. Retrieved July 25, 2009 at: http://science.nsta.org/nstaexpress/nstaexpress_2007_10_29.htm.
3. Keeley, P. (2009). Elementary science education in the K-12 system. NSTA Webnews Digest, April 22. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=55954.
4. McCormack, A. (2010). It's time for more early childhood science. NSTA Reports, December. Retrieved from http://www.nsta.org/publications/news/story.aspx?id=58029.
5. Chapin, J.R. (2006). The achievement gap in social studies and science starts early: Evidence from the early childhood longitudinal study. Social Studies, 97, 231-238.
6. Wenner, G. (1993). Relationship between science knowledge levels and beliefs toward science instruction held by pre-service elementary teachers. Journal of Science Education and Technology, 2, 461-468.
7. Dickinson, D.K., & Neuman, S.B. (Eds.). (2007). Handbook of early literacy research (Vol. 2). Guilford Press.
8. Morrow, L. (2001). Literacy development in the early years. Needham Heights, MA.
9. Saracho, O.N., & Spodek, B. (Eds.). (2013). Handbook of research on the education of young children. Routledge.
10. Peterson, S. M., & French, L. (2008). Supporting young children's explanations through inquiry science in preschool. Early Childhood Research Quarterly, 23(3), 395-408.
11. Kaderavek, J.N., North, T., Rotshtein, R., Dao, H., Liber, N., Milewski, G., Molitor, S.C., & Czerniak, C.M. (2013). SCIIENCE: the creation of a coding system to evaluate early childhood science teaching. Proceedings

of the 2013 annual meeting of the National Association for Research in Science Teaching (NARST), Rio Grande, Puerto Rico, April 2013.

12. Harvard Family Research Project (2008). What is complementary learning? Retrieved from www.hfrp.org.
13. Kaderavek, J.N., Molitor, S.C., Milewski, G., Rotshtein, R., North, T., Dao, H., Liber, N., & Czerniak, C.M. (2014). Teacher change in primary grades inquiry science classroom practices following professional development. Proceedings of the 2014 annual meeting of the National Association for Research in Science Teaching (NARST), Pittsburgh, PA, April 2014.
14. Banchi, H., & Bell, R. (2008). The many levels of inquiry. Science and Children, 46(2), 26-29.
15. Pianta, R., Karen, M., Paro, L., & Hambre, B. (2008). Classroom assessment scoring system (CLASS) manual, pre-k. Baltimore: Paul H. Brookes Publishing Company.
16. Horizon Research, Inc. (2005). Local systemic change through teacher enhancement data collection manual. Retrieved from http://www.horizon-research.com/LSC/manual/.
17. Hill, H.C., Charalambos, Y.C., & Kraft, M.A. (2012). When rater reliability is not enough: Teacher observation systems and a case for the generalizability study. Educational Researcher, 41, 56-64.
18. National Association for the Education of Young Children (2009). Where we stand on curriculum, assessment, and program evaluation. Retrieved from http://www.naeyc.org/files/naeyc/file/positions/StandCurrAss.pdf.
19. Aram, D., & Levin, I. (2002). Mother-child joint writing and storybook reading: Relations with literacy among low SES kindergartners. Merrill-Palmer Quarterly, 48(2), 202-224.
20. Curenton, S.M., & Justice, L.M. (2004). African American and Caucasian preschoolers' use of decontextualized language: Literate language features in oral narratives. Language, Speech, and Hearing Services in Schools, 35(3), 240.
21. Dunst, C.J., Williams, A.L., Trivette, C.M., Simkus, A., & Hamby, D.W. (2012). Relationships between inferential book reading strategies and young children’s language and literacy competence. Center for Early Literacy Learning, 5(10).