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AC 2010-1218: TEACHING INQUIRY-BASED STEM IN THE ELEMENTARY GRADES USING MANIPULATIVES: A SYSTEMIC SOLUTION REPORT

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Introduction

Young learners come to school holding myriad conceptions about how the world works, particularly in the areas of science, technology, engineering, and mathematics, or *STEM* .[1-3] Further, young students' conceptions are commonly based on fragmented knowledge or naïve perspectives that contribute to the importance of early exposure to and practice with scrutinizing situations scientifically.[1,3] An important part of helping children gain the skills necessary to approach situations scientifically involves preparing them to conduct scientific inquiry.[3] The development of critical thinking skills and scientific approaches to problem solving should begin early in education.[4] However, lack of elementary teacher comfort and familiarity with inquiry may be a significant barrier hindering early learner experience with and development of inquiry skills.[5] Additionally, although engineering topics are particularly well suited for teaching inquiry, most teachers, like the general public, are not well versed in engineering. Therefore, teachers are excellent candidates for participation in professional development that enhances their knowledge and comfort with teaching inquiry-based STEM curriculum and engineering content in particular.

Recognizing the importance of inquiry for learning STEM curriculum, and the potentially constrained levels of teacher comfort and experience with teaching inquiry, our project team at Boise State University developed a three-day summer institute for K-5 teachers that focused on enhancing their knowledge and skills for teaching inquiry-based STEM. The summer institute was part of a larger project, the Idaho SySTEMic Solution, a multi-year project funded by the U.S. Department of Education with the mission of increasing K-5 teacher understanding, comfort, and capacity to effectively teach STEM content. Further, we were seeking to enhance the teachers' awareness and ability to apply 21st century skills[6] in their inquiry-based instruction. The primary goal of the summer institute was to prepare teachers to teach STEM content using manipulatives, PCS BrickLabs®. During the summer institute the teachers gained experience with the BrickLabs®, developed and explored content aligned with STEM learning standards, engaged in activities that applied 21st century skills, and prepared to use the BrickLabs® to teach STEM concepts to their students. In addition to the professional development, the teachers were provided with curricular support materials (lessons activity books) as part of a PCS BrickLab® for each classroom to implement inquiry-based STEM lessons. PCS BrickLab®, supplied by educational products company PCS Edventures!, contains more than 5,000 Lego®-like construction bricks.

An important aspect of this project is investigating the effectiveness and influence of this professional development on teacher practices. Given our focus on inquiry during the summer institute we were interested in determining how the teachers were implementing inquiry-based instruction and what structure the inquiry took in their lessons, and the associated applications of 21st century skills, in particular collaboration. To answer this question we conducted classroom observations of all 38 summer institute participants teaching STEM lessons using the manipulatives. Our project is unique with respect to the extent of our data collection: 38 K-5 teachers teaching STEM lessons. The extent of our research allowed us to report both quantitative and qualitative outcomes for K-5 teacher use of inquiry-based instruction for teaching STEM concepts. Further, our research involved observing teachers teaching inquiry-based lessons using the same set of manipulatives at different grade levels and focused on different STEM content. Prior to presenting our methodology and results, we review the pertinent literature associated with defining and classifying inquiry-based learning, and develop a case for the effectiveness of inquiry-based learning in STEM. We also explore the research on professional development aimed at enhancing teacher STEM content knowledge and pedagogy. Following our reporting of the results we discuss our findings, offering interpretations and implications. We conclude with limitations and directions for future research.

Defining and Classifying Inquiry-Based Learning

The challenge with defining inquiry is that the same term can mean different things to people.[7] For example, Abd-El-Khalick and colleagues[8] contend that many interpret "inquiry" to be representative of good science instruction and yet, inquiry can be more specifically defined and identified as an approach to scientifically investigating phenomena. The definition of scientific inquiry offered by the National Research Council exemplifies the notion that inquiry is more than good science teaching as they write:

> *[Scientific inquiry refers to] the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.*[3] (p. 23)

Although the NRC[3] definition provides a broad overview of inquiry from the perspective of the scientist and the learner, the issue remains that inquiry can be interpreted and defined from many different perspectives.[7-9] In an effort to define inquiry in the context of education, Schwab[10] developed a two dimensional model (see Figure 1). One of the dimensions of Schwab's model represents the level of responsibility for the elements of inquiry by the teacher and student while the other dimension depicts three key elements of inquiry; posing research questions, developing and using a method of investigation, and interpreting results.

Inquiry Level	**Source of the question**	**Data Collection Methods**	**Interpretation of Results**
Level 0	Given by teacher	Given by teacher	Given by teacher
Level 1	Given by teacher	Given by teacher	***Open to student***
Level 2	Given by teacher	***Open to student***	***Open to student***
Level 3	***Open to student***	***Open to student***	***Open to student***

Figure 1. Schwab's model of inquiry.

Schwab's[10] model communicates a hierarchical perspective of inquiry in the classroom, suggesting that as the level of inquiry increases the student assumes greater responsibility for the inquiry activities. At Level 0 the teacher (or authority – such as a textbook) is responsible for posing the research questions, providing the investigative methods, and framing the interpretation of results. In contrast, at Level 3 inquiry the student is responsible for orchestrating and implementing all elements of the inquiry process. The benefit to utilizing Schwab's model when researching the instructional use of inquiry-based learning is the ability to consider and classify a wide range of instructional approaches and activities as inquiry.

Given our desire to consistently classify the level of inquiry-based instruction, we chose to endorse the model of inquiry developed by Schwab. Schwab's model takes into consideration the key elements involved in inquiry-based instruction and the variation in student and teacher responsibility for implementing these components. Further, Schwab's model has already been successfully used in research to classify levels of inquiry-based instruction.[11] The combination of effectiveness of the model to define and classify a range of activities as inquiry and the successful adoption and adaptation of Schwab's model in research provides the justification for using the model to classify the levels of inquiry-based instruction observed being taught by the participants in our research.

Inquiry-Based Learning

It is apparent from the definition offered by the NRC[3] that *inquiry* can represent the scientific investigation processes used by professional researchers as well as processes used by students when engaging in learning. For example, scientific researchers gather data through observation and experimentation and interpret the data to make meaning and increase understanding of the natural world,[12] essentially the same fundamental processes used by children as they learn.[13] This suggests that the curricular and instructional use of inquiry capitalizes on processes that young learners innately engage in as they learn.[4] Based on this premise there is justification for the expectation that children will develop deeper understanding of science, technology, engineering and mathematics (STEM) when they engage in inquiry-based learning activities associated with these domains.[4,13,10] It is the notion that active engagement in STEM learning environments increases student understanding of the content that has led to the popularization and expectation that *inquiry* should be integrated as both a curricular approach and instructional method when teaching STEM concepts.[14- 22]

When discussing inquiry learning in the context of STEM education, it is important to note that the "E" component, engineering, is not part of the learning standards in most states and school districts and therefore, is not a required subject. Precipitated by increasing national attention to educational methods that may better prepare U.S. students, engineering is being considered by K-12 institutions for inclusion into the curriculum. Indeed the engineering design process is well aligned with inquiry-based learning. In 2009 the National Academy of Engineering and National Research Council joint Committee on K-12 Engineering Education recommended that engineering has the potential to engage K-12 students, foster collaboration and creativity, and integrate mathematics, technology and scientific inquiry methods.[23] The committee concluded that engineering design has potential as a K-12 pedagogical strategy because it is:

> *(1) highly iterative; (2) open to the idea that a problem may have many possible solutions; (3) a meaningful context for learning scientific, mathematical, and technological concepts; and (4) a stimulus to systems thinking, modeling, and analysis.* [23]*(p.4)*

Inquiry-based curriculum and instruction is hypothesized to be effective for increasing learning because the associated processes raise students' interest and engagement, thereby enhancing their attention toward the task.[13, 24] Further, inquiry-based learning provides students with opportunities to apply and elaborate on their prior knowledge, developing understanding based on what they already know. Building on prior knowledge – the process of assimilation – is less cognitively demanding and more readily accomplished than accommodation–the case in which students learn material for which they have no prior knowledge.[13,24] Therefore, inquiry-based learning is effective because of the increased student attention toward the task, and because the conditions provide opportunity for students to apply their prior knowledge, effectively reducing the cognitive demands on learning. However, inquiry-based learning can also be overwhelming for students,[25- 27] making teacher support for the process critical to achieving learning success.

Moving beyond interest and cognitive load, group based inquiry has been documented to be critical for effective and efficient problem solving.[28,29] In his research on scientific inquiry and problem solving, Dunbar has exposed the vital importance of collaboration between individuals during inquiry and problem solving as a means of providing different perspectives that lead to viable solutions and explanations. Dunbar reports that many times when working alone scientists will discard anomalous data and not seek deeper explanations. However, when working with others to discuss and debate irregular data, scientists were more readily able to find explanations or solutions. The work of Dunbar exemplifies the importance of collaboration when teaching and learning using inquiry-based approaches and clarifies why the ability to work with others is considered a 21st century skill. Further, expert teachers recognize the importance of students working together and the benefit it has on student learning.[30]

Because of the anticipated benefits to student learning there is increased emphasis being placed on teaching STEM using inquiry-based curriculum and instruction. Yet, student response to inquiry-based learning environments may vary, particularly in response to the structure or level of the inquiry. Further, the way that teachers group students in inquiry-based learning is fundamental to capitalizing on collaboration as a means for problem solving and achieving success with the inquiry process. The anticipated variation in students' response to inquiry-based learning, particularly with respect to the level or structure of the inquiry, provides justification for investigating the student response to inquiry based learning environments and how teachers structure student interactions during the inquiry process.

Teacher Preparation for Teaching Inquiry

Perhaps one of the greatest challenges associated with integrating inquiry-based learning into the elementary STEM curriculum is preparing these teachers to teach using inquiry-based instruction while increasing their understanding of and comfort with STEM content. As much as elementary teachers may believe that STEM teaching and learning should be student centered,[31] they tend to hold negative feelings about their ability and comfort for teaching scientific approaches.[32] The lack of comfort and confidence for teaching scientific practices and the priority that elementary teachers place on the importance of these practices in the curriculum are exemplified by the report of Dickinson et al.[33] In their report Dickenson and colleagues detail the journey of four first grade teachers' growth in knowledge and enthusiasm for teaching science. At the forefront of these teachers' concerns was their ability to effectively teach using "hands-on" methods. The lack of understanding and reluctance of elementary teachers to teach using hands-on methods (or "inquiry with manipulatives") offers justification for providing these educators with professional development designed to enhance their pedagogical content knowledge associated with STEM education. Therefore, in our summer institute we specifically focused attention toward using manipulatives to teach inquiry-based STEM curriculum and instruction. Also, engineering concepts were included to reinforce problem solving and help teachers create contextual relevance to foster student engagement.

Preparing teachers to teach using inquiry methods is strongly influenced by their beliefs.[34] Crawford reports that teachers' personal beliefs about teaching and STEM influence their approach to teaching using inquiry. Given the stability and tenacity of teachers' beliefs [35] there is justification for assuming that change in teacher practice is a long-term process. Given the influence of teacher beliefs on their practice and the dynamic nature of teacher belief systems, there is justification for conducting longitudinal observations of teachers as they teach inquiry-based STEM lessons. In this research project we have gathered (and report) initial data to determine the current configuration of the participating teachers' inquiry-based instructional practices.

Providing teachers with professional development for teaching using inquiry-based approaches is an important step in transforming their practice.[36] This is particularly true because the perceptions teachers hold of effective instruction and their ideals for effective learning may not be consistent with their practice.[5] As King and colleagues report, teacher beliefs and perceptions of their teaching using inquiry-based and the expository approach the teachers actually used in practice were inconsistent. The documented lack of continuity between belief and practice and the potential knowledge limitations of STEM content provide the impetus to offer professional development to address these conditions and to research the impact the intervention has on the structure of inquiry-based lessons.

Teacher beliefs about how to teach inquiry-based lessons may be constrained by their misconceptions of scientific methods[12,37] which is commonly misunderstood to be a lockstep process that begins with defining a problem, moves to forming a hypothesis, progresses to testing the hypothesis, and culminates with analyzing results and drawing conclusions. However, when researchers use the engineering design process, scientific methods or inquiry in scientific investigations they frequently revisit, skip, or create new steps as they investigate phenomenon and do not adhere to research as a linear lockstep process.[12] Misconceptions of scientific methods and inquiry approaches may be changed through intervention. Weinburgh reports teachers' perceptions of inquiry can be changed to be less rigid and more realistic with professional development. This suggests that professional development is key to shifting teachers' understanding of inquiry-based instruction, again providing support for the focus on inquiry-based practices in our summer institute and subsequent research.

Goals and Research Questions

One goal of this multi-faceted research project was to determine the nature of the inquiry-based instructional approaches that a cadre of elementary teachers used to teach STEM content. These teachers participated in a summer institute that focused on the use of manipulatives to teach STEM content using inquiry-based approaches. We sought to determine, though observation, the approach the teachers took to teaching inquiry-based STEM lessons. Specifically, we wanted to assess the level of inquiry used for instruction, the STEM focus for the content that was taught, the groupings of the students, and the students' reactions to the lessons. Our goals led to the formation of the following research questions that we used to guide our investigation:

- *What level of inquiry did the participating elementary teachers use to teach STEM content?*
- *What were the content focus and student collaboration structures used for the lessons?*
- *How did the students respond to the inquiry-based STEM lessons?*

Participants

The 38 participants for our research project were recruited from the elementary grade level teachers from the Meridian (Idaho) Join School District who enrolled in our summer professional development program. Thirty-one of the participants were in their first year of the program and seven were returning for a second year of professional development. The teachers all worked in the same school district, averaged 32 years of age, one was a Pacific Islander, the remainder identified themselves as Caucasian, they had on average an educational level of a B.A. degree plus 32 credits, had on average been teaching for 9.6 years, with an average of 7.5 years teaching in Idaho, and an average of 4.0 years teaching in the school where they were currently working.

We combined the data from all observations in our analysis to form a single composite data set. Although we would have liked to determine how the first and second year participants approached inquiry-based instruction differently, our samples were of substantially different size. Making the comparison by program year with the substantial sample size differential would not have been valid and would have reduced the robustness of our study. However, the comparison of approaches by program year is certainly a direction we would like to consider for future research.

Methods

Summer Institute

A major component of the SySTEMic Solution project was a summer institute developed to enhance the participating elementary teachers' confidence, efficacy, and knowledge for using inquiry-based practices to teach STEM content using manipulatives. We used a combination of lecture, interactive classroom instruction, and small group activities to deliver the multiple sessions of the three-day professional development. Many of the sessions focused on how to use the BrickLab® manipulatives to teach a range of STEM concepts using inquiry-based approaches. As the project was initiated jointly by Boise State University's College of Education and College of Engineering, the summer institute emphasized engineering-related ideas. The goal for this summer institute was to prepare the participants to effectively teach grade level appropriate STEM content consistent with state STEM learning standards using the BrickLab® manipulatives and inquiry-based approaches.

Part of the SySTEMic Solution professional development program involved ongoing, school-year professional development and a series of associated assignments. The ongoing professional development was provided through feedback generated from classroom observations, support provided through our online course site, and periodic course meetings that occurred during the school year. Because this program was offered for college credit the participants were required to develop and submit a series of four lesson plans implementing inquiry-based approaches using the manipulatives to teach a concept related to each of the four STEM content areas. These lessons could have been adapted or adopted from extant lesson plans or developed as original work. The BrickLab® manipulatives are part of an educational product that also includes grade-level curriculum books from PCS Edventures!

Data Collection

The goal of our data collection was to gather evidence of how well we prepared our summer institute participants to teach using inquiry, evidence of lasting impact, and indicators of any potential gaps in our professional development program and support. To gather this data each of the participating teachers was observed teaching an inquiry-based STEM lesson using the BrickLab® manipulatives. To structure data collection during the classroom observations we developed an observation rubric. Our observation rubric (see Appendix) focused data collection on the structure of the inquiry-based lessons, the mechanics of the implementation, the nature of the various aspects of inquiry that took place, and the interactions between teacher and students and among students. In addition to utilizing rating scales, we included space for narration in our observation rubric. Teachers were not shown the observation rubric.

For this project we focused on the inquiry level as an indicator of teacher confidence, comfort, and experience with teaching inquiry-based lessons. The choice to examine the STEM content focus was based on the desire to determine if there were discernable trends in how the teachers were using the BrickLabs® and inquiry-based instruction to teach certain topics. We chose to examine student groupings because grouping may be considered a proxy for teachers' perceptions of inquiry as a collaborative process. Although seemingly distinct, STEM content and student grouping are both indicators of teacher willingness to experiment with inquiry-based instruction and diverge from traditional instructional approaches. Finally, we chose to examine the student responses as further evidence of the nature of the inquiry-based lessons and their effectiveness at engaging the learners.

Each teacher was observed teaching an inquiry-based STEM lesson using the BrickLab® manipulatives. The lessons lasted about 30 to 60 minutes. The lessons' content and structure, student and teacher roles, and the interactions were recorded using our observation rubric. To assure inter-rater reliability, some teachers were observed by two researchers, and the ratings on the observation rubrics were compared. Discrepancies in observations were discussed and resolved. The process of establishing inter-rater reliability increased the consistency of data collection and the validity of the collected data.

Results

Level of Inquiry

Our first research question asked: *What level of inquiry did the participating elementary teachers use to teach STEM content?* To answer this question we began with examining the observation data and scoring each lesson for the level of inquiry. To simplify our coding and maintain consistency we used Schwab's[10] model to score the level of inquiry on a scale from 0 to 3 (see

Figure 1). Our level of inquiry scoring required us to review each of the completed lesson observation sheets to ascertain whether the teacher or student posed the research questions, developed the data collection method, and interpreted the results, and then to use that data to determine the level of inquiry. For example, in one lesson observation the teacher provided all elements of the inquiry process, therefore we scored the inquiry as Level 0. As we examined our data and classified the levels of inquiry of the observed lessons we attempted to adhere to Schwab's model, however, not all of the observed lessons readily conformed to the model. For example, in one observation the teacher provided the context and question, but the students developed and implemented the investigative method, and then the teacher orchestrated the interpretation of results and conclusion. We scored this observed inquiry-based lesson as being Level 1, which is not fully consistent with Schwab's model, but since the students were primarily responsible for one key element of the inquiry process we determined it was justifiable to classify the lesson at Level 1 inquiry. The previous example illuminates the potential variation in the format of the inquiry-based lesson and our subsequent need to maintain flexibility as we classified the lessons the level of inquiry. Once we classified all observations we determine the frequency of occurrence of each inquiry level.

Our analysis revealed that over 85% of the observed STEM lessons were taught at Level 0 or Level 1 inquiry. Although four of the 38 observations were lessons implementing Level 2 inquiry, the vast majority of the observed lessons (approximately 90%) were at lower levels of inquiry-based instruction. The distribution of lessons by level of inquiry is presented in Table 1.

Table 1
The Count and Percentage for the Observed Lessons Levels of Inquiry

Inquiry Level	Count	Percent
Level 0	18	47.4%
Level 1	15	42.1%
Level 2	4	10.5%
Level 3	0	0.00%

The results indicate that about nine in ten of the observed inquiry-based STEM lessons could be classified at Level 0 or Level 1 inquiry. This suggests that the teachers tended to assume the majority of the responsibility for the creation and orchestration of the key elements in the inquiry process while the students were primarily responsible for following directions and completing assigned tasks.

Focus and Structure

Our second research question asked: *What were the content focus and student collaboration structures used for the lessons?* We begin answering this question by first examining the STEM content focus of the observed lessons. An examination of our coded observation rubrics revealed lessons focused on specific content areas (science, mathematics, etc) and integration of content areas (e.g. science and mathematics, engineering and mathematics). The distribution by content area and integration of content areas is presented in Table 2.

Table 2
The Frequency and Percentage of Observed Lesson Content Area(s)

Content Area(s)	Frequency	Percentage
Science	2	5%
Math	4	11%
Engineering	6	16%
Technology	1	3%
Science & Math	4	11%
Science, Technology & Math	1	3%
Science & Engineering	1	3%
Engineering & Technology	4	11%
Engineering & Math	4	11%
Engineering, Math & Technology	6	16%
Technology & Math	1	3%
Science, Technology, Engineering & Math	4	11%

An examination of the frequency of the STEM content focus revealed that less than a third of the observed lessons were aimed at a specific content area, while over two thirds involved inquiry activities that integrated content from two or more of the STEM domains. Engineering and math and engineering and technology were the most frequent foci of the lessons, while technology, science and technology, and mathematics and technology were the least frequent.

We continued our analysis by compiling the individual and combined lesson foci to determine the frequency specific to each STEM content area. For example, the frequency for science was determined by counting the number of lessons focused on science or any combinations the included science, which resulted in 12 lessons. This process was repeated for math, engineering, and technology. The outcome of this analysis in presented in Table 3.

Our results indicate that math and engineering had a greater lesson frequency than science or technology, and that all STEM content areas were reasonably well addressed by the teacher cohort.

Table 3

The Frequency and Percentage of Observed Lessons by STEM Content Area

Content Area(s)	Frequency	Percentage
Science	12	15%
Math	24	31%
Engineering	25	32%
Technology	17	22%

Following our determination of the content area focus of the observed lessons we analyzed the observation data to determine the student group size configurations formed by the teachers when instructing their inquiry-based lessons. The distribution of the group size frequency and percentage are presented in Table 4.

Table 4

Frequency and Percentage of Observed Lesson Student Group Size

Group Size	Frequency	Percentage
1	20	53%
2	10	26%
3 or more	8	21%

Our analysis revealed that in over half of the observed lessons the teacher grouped students such that each learner was able to work independently to complete the observed task. This suggests that the teachers did not focus on collaboration and did not concentrate on using collaboration as a key focus when implementing their of the inquiry-based lessons.

Student Response

Our third research question asked: *How did the students respond to the inquiry-based STEM lessons?* To answer this question we compiled and coded the observer comments from the observation matrices. We were seeking to expose indicators of student engagement, interaction, and interest. We developed a list of prior codings representative of engagement and interaction such as "active," "on task," "participating," and "answering questions." However, we also realized as we explored the data that some post hoc codings would likely emerge. Therefore, we utilized both the planned and emergent codings in our analysis.

Our analysis revealed that nearly all students were observed as being engaged in the inquiry-based lessons. Narrative comments included "All children were on task and there was a constant smooth operation with teacher leading…," and "Almost all children were on task…,"and "chatty but focused class without anyone sitting out, students seemed able to work cooperatively and to share their ideas with each other in orderly chaos!" However, the levels of engagement varied and the extent of the anticipated learning taking place may have been inconsistent as well, which is made evident by this observation narrative, “At start, all children were on task, but as task repeated itself, they began to do other things,” and this narrative “All children on task, but task is not defined. Lots of fantasy play, children asked to use plans made earlier, many choose not to do this,” and this observation “There was quite a bit of irrelevant building at all times, with children off task. Instructions are not good enough to use without help.” These observation narratives make apparent the range of student engagement in the lessons and the nature of their engagement, both of which may reflect the learning that was anticipated to be taking place.

Through our coding of observation narratives it also became apparent there were a range of interactions among students and between students and teacher. For example, during one lesson the observation was made, “Focus and joy in classroom were obvious. Lots of give and take with students, and emphasis on doing and re-doing to make things work,” and in another “When students were turned loose, they designed their own methods and tested them with constant monitoring and suggesting from teacher. Novel ideas encouraged but help also given to make it work.” It is apparent from these observation passages that the teachers may have acted as scaffolding agents for the students, while the students interacted with the manipulatives and each other to create and complete their the inquiry task. However, in other instances the lack of interaction left the children unsure of what to do as the teacher failed to provide adequate direction and support, as made evident by this observation narrative “Most children are on task, but task is poorly defined. No teacher evaluation or suggestions,” and by this passage “…lack of direction makes this mostly a play activity.” These passages make apparent the association between student engagement and teacher support (scaffolding) and the wide variation in the structure and student response to the inquiry-based lessons.

Overall, the narratives revealed students were engaged and eager to participate, however, the level of involvement and the extent of student attention toward the tasks appeared to be highly correlated to the skills, interest, and engagement of the teachers. These data make apparent the inextricable link between the inquiry-based instructional skills of the teacher and student interest and engagement in learning. Although the link between teacher skills with inquiry-based instruction and student engagement may seem obvious, it does make apparent the notion that students are not likely to gain much from the use of these manipulatives in terms of STEM content without sufficient direction and support from the teachers.

Discussion

We set out to determine to what extent that cadre of elementary teachers who had participated in a summer professional development course focused on teaching inquiry-based STEM content using manipulatives were able to implement inquiry-based lessons. Inquiry-based instruction has become widely accepted as an principal method for teaching STEM content[4] and has been promoted as an essential part of many STEM learning standards.[3,18,20] Yet, inquiry is challenging to teach and challenging to learn from without sufficient support.[26,27] Therefore, there is justification to continue to provide professional development to support teacher development of inquiry-based teaching abilities and to increase their understanding of how students learn in these conditions. The challenges associated with teaching and learning using inquiry are reasons for determining the extent to which our professional development course prepared the participating elementary teachers to implement inquiry-based STEM lessons and how their students respond to these lessons.

Our analysis revealed the participating elementary teachers tended to overwhelmingly implement inquiry-based lessons at level 0 or level 1. The lower levels of inquiry observed in the lesson implementation may be attributed to the limited experience of the teachers teaching and the students learning using inquiry-based learning. The implementation of inquiry-based lessons at level 0 or level 1 may also suggest teachers are seeking to maintain control of the learning environment or may perceive their students as unprepared to engage at inquiry at above level 1. The desire to maintain control indicates that we may not have adequately prepared the teachers to teach inquiry-based STEM lessons at higher levels of inquiry. Further, as Settlage[27] and Mayer [26] contend, high level inquiry requires a vast amount of experience and knowledge and therefore teachers may require guided or scaffolded support to effectively implement higher levels of inquiry-based instruction. Further, inquiry instruction requires high levels of pedagogical content knowledge and experience with high levels of inquiry. Both these aspects might not have been acquired by elementary teachers in their teacher preparation programs.[38] We have offered multiple probable explanations for teacher choice of level 0 or level 1 inquiry. However, it is apparent that if we expect teachers to teach high level inquiry-based lessons, we need to allocate more time and attention toward preparing them to do so. Determining the most effective method for accomplishing the preparation of elementary teachers' to teach high level inquiry is an important research question that warrants continued attention and investigation.

Our analysis of the content areas that the teachers choose to teach in their lessons revealed mathematics and engineering topics covered almost twice as frequently as science topics. At least in part this outcome may be explained by the elementary curriculum which has shifted in response to No Child Left Behind (NCLB) to focus primarily on English language arts and mathematics.[39] Therefore, the teachers may be more readily prepared for, comfortable and familiar with integrating inquiry-based lessons using manipulatives into mathematics lessons. Further, teachers are frequently compelled to spend time a significant amount of instructional time on mathematics and therefore may be motivated to seek opportunities to use the manipulatives to teach math content. However, NCLB requirements cannot be used to explain the higher level of attention toward engineering. We attribute this outcome to the nature of the manipulatives and the associated curricular materials (activity guides). The PCS BrickLab® manipulatives, plastic Lego®-like building blocks, naturally lend themselves to building and other engineering activities, and the associated curricular activity books capitalize on this situation. We speculate that the combination of the nature of the manipulatives and the curricular support materials increased the teachers' propensity to teach lessons with an engineering focus. Further, the summer institute did have a strong emphasis on engineering, which may have had a lasting impact and may have lead to the increased attention toward engineering in the lessons. What was particularly interesting was the lack of focus on science in the lessons. This may perhaps be explained by the limited attention paid toward science in our summer institute – or else is a result of the emphasis on design, or engineering – discovery. It is apparent from our analysis of lesson foci that combinations of content areas are preferred by teachers to a focus on single subject areas. This result reinforces the conclusion reached in the "Engineering in K-12 Education" report that the way "engineering in STEM education... [addresses] the interconnections in STEM teaching and learning could be extremely important."[23] Thus, engineering as an integrative method for teaching STEM is well suited as a focus for inquiry-based teaching. The integration may also have been a manifestation of the creativity and knowledge of the teachers, the nature of the elementary curriculum, and the way in which the manipulatives promote multidisciplinary approaches to teaching and learning. Since the summer institute was hosted by the College of Engineering, the reason for the engineering focus may have rested simply on this aspect. In any case, determining the underlying reason for the teachers' lesson content choices is an interesting possible future research question.

The size of the student groups that the teachers used in their observed lessons was dominated by students working individually (over half of the observed lessons involves students working by themselves). This may be due to the desire by the children to each be actively involved in handling the manipulatives and the associated challenges of having students work in groups. As one observation narrative makes apparent, this can lead to reduced task completion, "…groups of 3 have some difficulties, especially during free-build when they are trying to build a room in the house." Although working independently may increase student completion of tasks and may be easier to manage, a critical component of inquiry-based learning is communication and collaboration.[19,28,29] The beneficial use of groups for teaching inquiry-based STEM lessons thus needs to be emphasized in our professional development institute if we are to achieve the goal of preparing teachers to implement collaboration in their inquiry-based lessons.

Our analysis of the observation narratives revealed that students were eager and interested in working with the manipulatives. However, there was wide variation in the nature of the involvement of the students which may then influence the anticipated STEM content learning taking place. Again, the extent to which the students are focused and engaged seemed to be dependent on the ability, comfort, knowledge, and experience of the teacher. The reliance of the students on the teachers for direction and learning focus provides further justification for assuring we are adequately preparing teachers are prepared to effectively teach inquiry-based STEM lessons.

Limitations

As we observed the lessons being taught we sought to collect data regarding teacher approach to inquiry and content focus. However, we did not ask the teachers why they chose to teach certain topics and why they structured their lessons in specific ways. Although our data collection provided some insight into the nature of the inquiry-based lessons, it did not allow us to actually explain why the teachers made the choices they did. This is certainly an excellent direction for future research. Similarly, our observations of the students did not actually involve collecting learning data. Therefore, we cannot determine the impact the lessons had on their knowledge acquisition or conceptual understanding and cannot draw definitive conclusions regarding the structure of the inquiry and the learning gains of the students. Again, this is an excellent direction for future research.

Concluding Remarks

Inquiry-based learning is now recognized as a principal method for teaching and learning STEM and is also critical for developing the skills needed to scientifically investigate a wide range of phenomena. As a result, inquiry has become an area of emphasis in STEM education. However, many elementary teachers may be inadequately prepared to teach STEM content using inquiry-based approaches. The likelihood of this condition provides the justification for providing on-going professional development for elementary teachers focused on teaching using inquiry-based methods. This situation also provides the justification to continue to research how professional development may be influencing how elementary teachers are implementing inquiry-based lessons and how their students respond to these learning conditions.

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Appendix

Observation Rubric SySTEMic Solution Lessons using BrickLabs®

Research Question Information: **Date of observation:** ________________

Teacher Name and School: _____________________________________

Observer: A _____ **B** _____

Grade Level: _____

Number of students: _____Male _____Female

Grouping of students for BrickLab®

□Individual □Pairs □Larger groups

Type of lesson

□Introductory activity □Intermediate activity □Culminating activity

STEM areas addressed

□Science □Technology □Engineering □Math

Question	**Teacher**	**Mixed**	**Mixed**	**Student**
Who sets the question?				
Who sets the method?				
Who runs the discussion?				
	Yes, thoroughly	**Mixed**	**Mixed**	**No, none**
Is context provided?				
Are standards addressed?				
Are further questions encouraged in discussion?				

Anecdotal class information

Possible areas	Observer Comments
Classroom management: (how many children are on task, who is responding to questions, what children are leading, what children are following, what happens to children who are faster or slower than the others)	
Content instruction (direct instruction at start of lesson, intermediate instruction at difficult points, individual help from teacher, individual or group assessment, summary and discussion of lesson)	
Use of materials: (parent or other helper, pre-packaging, cleanup ideas, documentation of work, documentation of assessment)	
Other?	