Understanding Meanings of Interdisciplinary Science Inquiry in an Era of Next Generation Science Standards.

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Paper presented at the National Association for Research in Science Teaching
Annual Conference
Rio Grande, Puerto Rico
April, 2013

This paper is based upon work supported by the National Science Foundation under Grant No. DUE-1102998 . Any opinions, findings, and conclusions or recommendations expressed in the materials are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Abstract

Once again the new educational reform is dawning in the US and a framework for K-12 science education addresses need of science, engineering and technology, which permeates every aspect of our life. The framework focuses on integrating the ideas of science and engineering practices. The new framework demands interdisciplinary inquiry teaching with specific focus on the engineering practice in the classroom. The expectation of implementing interdisciplinary inquiry in the classroom is new for all the stakeholders including teachers. In response to need of how to support teachers we present a framework for understanding Interdisciplinary Science Inquiry (ISI) for science teaching and learning for K-12 science in the classroom. The current literature indicates the lack of consensus in the definition and understanding of interdisciplinarity specifically in terms of science in K-12 context. In this research paper we present a framework for Interdisciplinary Science Inquiry (ISI) and different dimensions of ISI based on scientists' interviews and pertinent literature. The four dimensions of ISI comprised of : (a) Science and Engineering Practices, (b) Crosscutting Concepts, (c) Disciplinary core ideas and (d) Drivers of Interdisciplinary Research.

Introduction

One of the most important messages of the Next Generation Science Standards (NGSS) for the all the stakeholders is that science is extremely important in addressing the problems we face at the beginning of the 21st century. The purpose of science education is broadly expressed as STEM literacy, is to equip our students with the knowledge and skills essential for addressing society's needs. These new set of standards also wants to motivate students to fully engage in the practices of science and engineering similar to scientists and engineers who work together to address different societal challenges. NGSS is committed to fully integrate engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction. In the K-12 context, NGSS uses the terms "engineering" and "technology" in the broad sense by engaging students to learn unified concepts and systematic practices to design to achieve solutions to human problems. This expectation of integrating different disciplines of science, engineering and technology in K-12 context raises need for clarifying meaning of "integration" and interdisciplinary inquiry for teachers, parents and students, especially when for most of the twentieth century, the question of knowledge has been framed by disciplinarily (Klein, 2000).

In recent decades research has become increasingly interdisciplinary and constant demand of addressing societal issues have altered the academic landscape, practices and disciplinary relations. As a result, even the most basic terms-'discipline' and 'interdisciplinary'- are no longer adequate (Klein, 2000). A new conceptual vocabulary is needed. Unfortunately, policymakers, educators, and researchers do not have a common definition of interdisciplinary inquiry and do not consistently agree or understand what interdisciplinary inquiry (ISI) should really be about in K–12 settings. The aim of this paper is to clarify meaning and nature of interdisciplinary inquiry (ISI) at K-12 level. More specifically we want to define different dimensions of interdisciplinary inquiry and describe how these dimensions can be enacted in the classroom. Therefore, the purpose of this study is to articulate vision for Interdisciplinary Science Inquiry (ISI) teaching and learning at K-12 grade level. From this understanding of different dimensions of ISI, we believe Next Generation Science Standards can be implemented more effectively in the classroom and this framework will also act as an anchor for developing teachers' understanding of ISI and expectations of reform documents such as NGGS, common core standards that expect crossing of borders within disciplines.
To serve this purpose following research questions guided our study.

(1) What are scientists' views about different dimensions of the new framework for K-12 science education?
(2) How do scientists envision their roles in supporting teachers in order to implement ISI in the classroom?
(3) What is the nature of Interdisciplinary science inquiry and how does scientists' conceptions about ISI contribute to the framework?

Theoretical Framework

Many researchers have contributed to the literature of integrated science or interdisciplinary science inquiry (Fogarty, 1991; Klein, 1990, 1996; Petrie, 1996; Lederman and Niess, 1997). In order to present clearer picture of ISI in K-12 context, we draw our understanding of scientific inquiry and interdisciplinary inquiry through multiple theoretical underpinnings, but Petrie's (1992) work along with National

Academics Committee on Science, Engineering, and Public Policy (COSEPUP, 2005)' report entitled "Facilitating Interdisciplinary Research", served as a theoretical framework for our study, as it allowed us to interpret our data epistemologically, as well as practically to understand nature of interdisciplinary inquiry and define different dimensions of ISI. Petrie (1992) distinguishes disciplinarity, multidisciplinarity, interdisciplinarity and transdisciplinarity. This distinction between terminologies allowed us to clarify the meaning of interdisciplinary science inquiry in K-12 context. He mentions interdisciplinarity cannot be understood unless we understand the concept of disciplinarity. He explains disciplinarity as, (a) a specialized knowledge; (b) unity of common set of concepts, specialized methods, and (c) an organized group of people who study the discipline, train other practitioners, and form the social mechanism for deciding among varying truth claims within the discipline.

He further explains multidisciplinarity as "the idea of a number of disciplines working together on a problem, an educational program, or a research study. The effect is additive rather than integrative" (p.303). Petrie explains multidisciplinarity as "group work" rather than "team work" (p.303). The report on facilitating interdisciplinary research describes multidisciplinary research as " research involves more than a single discipline in which each discipline makes a separate contribution. Investigators may share facilities and research approaches while working separately on distinct aspects of a problem" (p.27). He elaborated in interdisciplinarity "the integration of the work goes beyond the mere concatenation of disciplinary contributions" (p.304). The term of transdisciplinarity is explained as the desire to integrate knowledge into some meaningful way. After reviewing these explanations by Patrie and the report on facilitating interdisciplinary research, it is evident that these definitions are comparable. The report on facilitating interdisciplinary research helps clarifying definition of interdisciplinary research. It mentions:

> Interdisciplinary research (IDR) is a mode of research by teams or individuals that integrates information, data, techniques, tools perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice.

These two pieces of literature serve as a theoretical framework of our study.

Review of Literature

While the literature on interdisciplinary inquiry or integrated science or multidsciplinarity is abundant, and plenty have focused on defining the terms related to integration of disciplines, there is lack of agreement on the meanings of the terms. Therefore, below we review articles relevant to the topic to help us understand what is known about intedsciplinarity and specifically about the curriculum integration at K-12 level.

Understanding Meaning of Interdisciplinary Inquiry

It is evident that researchers and educators haven't reached to a consensus about a clear definition and conceptualization meaning of integration or interdisciplinarity and especially with curriculum integration (Czerniak et al., 1999; Huntley, 1998). The confusion in the literature about the absence of a clear theoretical framework and unfocused definitions of integration are problematic in developing an understanding of consistent theoretical and practical understanding of curriculum integration. For example, many parallel terminologies are used in the literature such as: Interdisciplinary, trans disciplinary, multidisciplinary, thematic, integrated, connected, nested, sequenced, shared, webbed, networked. In educational literature term integration also have been used differently by different researchers. For example, Cohen (1990) explain integration as "Integration is generally applied to the relationships within and between subjects more often taught separately, so that it refers to a horizontal relationship within a curriculum at a particular educational year level. A key intent of those supporting the concept of integration is to provide a unified view " (p.10). (Hopkins, 1937, as cited in Beane, 1996) explain integration as "cooperatively planned, problem-centered, and integrated knowledge" (p. 8). Although, researchers have attempted to clarify meaning of integration and to distinguish between different terminologies, confusion still remains especially in terms of implementing interdisciplinary inquiry in the K-12 context.

Many educators support complex and challenging process of curriculum integration for improving students' conceptual understanding of subject knowledge. One of the reasoning behind this push is the idea of science being unified and in the real world problems are not divided into separate disciplines (Beane, 1995; Czerniak, Weber, Sandmann & Ahern, 1999; Jacobs, 1989). While tackling practical problems, scientists usually draw concepts and skills that cut across disciplines. Curriculum integration has been a topic of discussion since the turn of the 20th century. The National Council of Teachers of English (NCTE) defined curriculum integration in 1935 as follows:

> Correlation may be as slight as casual attention to related materials in other subject areas . . . a bit more intense when teachers plan it to make the materials of one subject interpret the problems or topics of another.
>
> Fusion designates the combination of two subjects, usually under the same instructor or instructors.
>
> Integration: the unification of all subjects and experiences.

Wang (2012) defines curriculum integration as an approach, or teaching strategy, that purposefully compiles knowledge, skills, and values from different subject areas to teach a concept in more meaningful way. Rutherford and Gardner (1971) give similar explanation for integrating science with other subjects by mentioning, "the concept of teaching integrated science is based on the parallel assumptions that the universe has inherent unity and that science as an attempt to provide an understanding of the natural world has a unity of purpose, content and process that is far more significant than the differences in language or focus between individual sciences.

Many researchers distinguish in curriculum integration approaches as multidisciplinary, intradisciplinary, interdisciplinary, and trandisciplinary For example, Drake, 1998, Drake & Burns, 2004). They explain multidisciplinary approach as focusing primarily on the disciplines, where teachers organize standards from the disciplines around a theme. They explain intradisciplinary approach as one of the subcategory of multidisciplinary approach where teachers integrate the sub disciplines within a subject area. For example, integrating, reading, writing and oral communication in language arts or integrating biology, chemistry and physics in earth/ space science. They explain in the multidisciplinary approach, "teachers fuse skills, knowledge, or even attitudes into regular curriculum" (p. 9). Authors also suggest another way of approaching multidisciplinary integration as developing and implementing 'theme-based' units, where two-three subjects are integrated around certain theme and unit ends with an integrated culminating activity. In an interdisciplinary approach, teachers organize the curriculum around common learning across disciplines. The teachers focus on big ideas and emphasize interdisciplinary skills and concepts. In a transdisciplinary approach, teachers organize curriculum around students' questions and concerns. Students develop life skills and apply interdisciplinary and disciplinary skills in a real-life context. Drake and colleagues state project based learning would be one of the instructional approaches that would align with transdisciplinary approach. They also state these three approaches of curriculum integration has the perceived degree of separation that existed between subject area and these approaches fir on an evolutionary continuum such as Fogarty, 1991; Jacobs, 1989). Fogarty (1991) presents a continuum of models for curriculum integration, beginning from exploration *within single discipline, integration across several disciplines* and the continuum ends with models that operate *within learners themselves* and *across networks of learners*. He divides these four models on the continuum into several subcategories as: the fragmented, connected and nested models (Single discipline), the sequenced, shared, webbed, threaded, and integrated models (integration across several disciplines) and the immersed (within learners) and networked models (across networks of learners). We summarize description of Fogarty's 10 models in a table below.

<Insert Table 1 About here>

Lederman and Niess (1997) explain the differences between multidisciplinary and interdisciplinary by comparing the metaphor of chicken noodle soup with tomato soup. According to them, multidisciplinary approaches can be characterized as a bowl of chicken noodle soup, where each ingredient maintained its identity within a heterogeneous mixture. On the other hand, tomato soup represented interdisciplinary approaches, in which all ingredients/subjects are mixed together and cannot be distinguished apart from one another—a homogeneous mixture.

Lonning & DeFranco (1997) presented the continuum model of integration that possessed characteristics as: (a) enhancement of meaningfulness of both subjects through the context in which the material is presented. (b) attention to be given not only to "what" is being integrated but also to "what extent" each subject is integrated (c) attention to be given on designing meaningful activities that are appropriate for grade level. Lonning & DeFranco explain meaningful as, "activities that are relevant, engaging, and follow the recommendations of national standards" (p. 212). Lonning & DeFranco's continuum model of integration for mathematics and science concepts is mainly useful in curriculum development They place the activities that are independent from each other are at the two ends of the continuum. The second category they define as science or math focus. The content that meets the curricular goals and objectives for a particular grade level in one of the disciplines but includes concepts from the other discipline that are not at the same grade level are classified as "mathematical focus" or "science focus". The last category on the continuum is more balanced approach, which gets created when the mathematics and science content both part of the curriculum for particular grade level, and instruction is delivered in a meaningful way, the activities created are classified as "balanced" on the continuum.

<Insert Figure 1 About here>

As stated above, Drake (1991, 1998) researched the idea of curriculum integration through multidisciplinary, interdisciplinary, and transdisciplinary approaches. His idea of a multidisciplinary approach had very similar concepts to Fogarty‘s webbed and sequenced model, which stated that curriculum integration should happen either by rearranging the curriculum or by using a theme to make connections among different disciplines. An interdisciplinary approach corresponded with the connected, nested, shared, threaded, and integrated models that emphasized concepts and skills practices in an integrated curriculum. As for the immersed and network models, which use real-life issues that address personal experiences and interests, a transdisciplinary approach could be a possible match with these two models. Fogarty‘s immersed and networked models suggested personal ownership as an important focus in curriculum integration. Similarly, Beane (1991) and Brook, and Brooks (1993) believed successful curriculum integration needs to address real-life questions and genuine learning will occur when students will be able to connect their life experiences with the learning that is occurring in the classroom. Beane emphasizes that meaningful learning cannot be separated from real-world contexts and personal experiences for students. Educators and researchers supporting approach of curriculum integration believe that this kind of learning experience becomes more meaningful for students because they can connect their life experiences with content they are learning. (Beane, 1991, 1995; Burrows, Capraro & Slough, 2008; Childress, 1996; Jacobs, 1989; Mathison & Freeman, 1997; Sweller, 1989). Thus, integrated curriculum or interdisciplinary inquiry created an environment where students can apply their knowledge in the new situation. Thus, curriculum integration mainly focuses on developing students understanding of science discipline as wholeness, unity rather than compartmentalization as different disciplines. The curriculum integration also focuses on developing students' problem solving skills and helps them see how different subjects are tied together in order to address real world problems. Integration as a curriculum design requires that teachers organize curriculum around problems and issues that are of personal and social significance in the real world. Simply put, curriculum integration involves real-world applications to develop the process of real-world problem solving.

K–12 Science and Mathematics Integration

Just as there is a no general consensus on the nature of curriculum integration, there is also no generalized consensus about the usefulness of integrated science and mathematics (Berlin, 1991). Davison et al. (1995) recommended several ways that science and mathematics instruction could be integrated. These authors believe science and mathematics should be integrated in ways that make mathematics and science relevant and meaningful to students. They suggested five types of science and mathematics integration: discipline specific, content, process, methodological, and thematic. Discipline specific integration focuses attention on specific subdisciplines of mathematics or science, such as algebra and geometry in mathematics and biology and physics in science. It seemed Davison et al. believed as long as a teacher integrated different subdisciplines within single disciplines regardless the content, concepts, skills and procedures, it was discipline specific integration. This view corresponded with Fogarty‘s fragmented, connected, and nested models. Content specific integration focused on topics, such as speed in science and measurement in mathematics. In a content specific integration, a teacher purposefully aligned the content to infuse the objectives from both mathematics and science. Davison et al. suggested, for example, if the science content objective is the study of dinosaurs and the content objective for mathematics is measurement, a teacher could integrate these two content objectives by creating a life-size dinosaur. Process integration focused particularly on the scientific and mathematical process. For example, Davison et al. defined observing, predicting, and controlling variables as scientific process skills. Reasoning and problem solving were mathematical process skills, and communication was overlapped between scientific and mathematical process skills. These were the skills that should be considered as the primary learning goals when implementing process integration. An example of process integration may involve asking students to make a prediction about polar bear population size based on the weather model in the Arctic. This involves predicting, which is the skills that teachers want to emphasize in process integration. Furthermore, methodological integration looked at how people learn science and math in order to develop an activity that addresses science and mathematics teaching and learning methods such as inquiry-based teaching or experiential learning. The final type of integration was thematic integration. The thematic integration approach starts with solving a problem or an issue as a way of connecting multiple disciplines.

Berlin and White (1995) constructed their ideas of mathematics and science integration based on their early work, Berlin-White Integrated Science and Mathematics (BWISM) Models (1994). The following six aspects were discussed in their ideas of mathematics and science integration: 1) learning, 2) ways of knowing, 3) process and thinking skills, 4) conceptual knowledge, 5) attitudes and perceptions, and 6) teaching. Depending on different needs, teachers could integrate mathematics and science from very specific scientific and mathematical concepts (such as balance and matter in science and ratios and fractions in math), with process and thinking skills (such as observing and inferring in science and reasoning and problem solving in mathematics), to overlap conceptual knowledge both in science and mathematics (such as measuring patterns and relationships), to promote scientific and mathematical learning attitudes (such as being skeptical and accepting ambiguity), and to teaching strategies that teachers used to help students develop scientific and mathematical literacy (such as inquiry-based teaching and student-centered learning). Berlin and White‘s (1995) ideas were quite similar to those of Davison and his colleagues (1995) view of integrating mathematics and science. Content, process and thinking skills, and methodological integration (teaching strategies) were the three themes that overlapped in the integration models of Berlin and White, and Davison et al.

Huntley (1998) built a theoretical framework for science and mathematics integration by using the following three terms: *intradisciplinary*, *interdisciplinary*, and *integrated*. Huntley suggested that intradisciplinary curriculum focused on only one discipline. In an intradisciplinary approach there was no other discipline involved besides the one that teachers exclusively wanted to focus on. On the other hand, an interdisciplinary approach involved one major discipline and one or more other disciplines to support the major discipline. Huntley explained this interdisciplinary approach by using the notion of ―foreground/background—that discipline that is to be mastered is foreground, and the discipline used to establish relevance or context is background (pp. 321). An example of an interdisciplinary approach is asking students to apply their mathematics skills to create a graph to explain the relationship between volume and weight. In this example, the relationship between volume and weight is the foreground and the mathematics skills that are used to create a graph are the background. Huntley believed that the idea of implicitly or explicitly integrating disciplines was an important thought to distinguish an integrated approach from an interdisciplinary approach. Interdisciplinary approaches implicitly connect between/among disciplines. However, in an integrated curriculum, teachers needed to explicitly make connections between/among disciplines by giving equal attention to two (or more) disciplines. For example, in an integrated curriculum, students needed to see the relationship between science and mathematics. Huntley used an example of determining the amount of energy that would be produced by calculating the surface area of a leaf to explain the idea of integrated discipline. She noted that this activity helped students to not only use their mathematics skills (calculating surface area for an irregularly shaped object) in a new situation, but also to learn the relationship between the surface area of a leaf and photosynthesis. Furthermore, the activity also asked students to use what they have learned to determine what would happen to a human‘s life if all rainforests disappeared. Therefore, the activity also could generate a whole new meaning of a leaf, photosynthesis, energy, and humans‘ lives to students. Huntley created her framework by combining her idea of science and mathematics integration with the Education Development Center‘s (1969) five integration models of mathematics and science: 1) mathematics for the sake of mathematics, 2) mathematics for the sake of science, 3) mathematics and science, 4) science for the sake of mathematics, and 5) science for the sake of science.

Some important concepts need to be addressed after summarizing curriculum integration and K–12 science and mathematics integration. First, one of the important features which many researchers use to distinguish different types of curriculum integration is within or cross-disciplines (Drake, 1991, 1998; Davison et al., 1995; Fogarty, 1991; Huntley, 1998). Second, overall content/concepts and process/skills are very important in curriculum integration regardless if they are within or cross-disciplines. However, some research particularly emphasizes the learning process/skills rather than content/concept delivery. Some of examples of this are Fogarty‘s (1991) nested and threaded models; Davison et al.‘s (1995) process integration approach; and Berlin and Whites‘ (1995) idea about process and thinking skills integration. Third, using problem-based projects or issues stands out as one of the critical elements in integrated curriculum. Some research specifically states that curriculum integration needs to use real-life problems or issues that address personal interests and experiences (Beane, 1991, 1995; Burrows et al., 1989; Capraro & Slough, 2008; Childress, 1996; Fogarty, 1991; Jacobs, 1989; Mathison & Freeman, 1997; Sweller, 1989). However, other studies do not mention addressing personal interests and experiences, but rather suggest using a problem or issue as a theme which acts as context to connect different disciplines (Drake, 1991, 1998; Davison et al., 1995; Fogarty, 1991; Huntley, 1998). Finally, teaching strategies, such as teaching and student-centered learning, cooperative learning, or experiential learning, could be major foci when using the curriculum integration approach.

Engineering in K-12 Education

Many professional organizations such as National Science Foundation, National Research Council, and National Academy of Science have promoted STEM education for K-12 level. This focus on STEM education is also evident in K-12 Science framework and Next Generation Science Standards (NGSS) in the form of science and engineering practices. The report, *Engineering in K–12 Education*, recently released by the National Academy of Engineering and the National Research Council (Katehi, Pearson, & Feder, 2009), provides insights about how to integrate engineering component at K-12 schools. This report explains three main components of K-12 engineering education as: (a) K–12 engineering education should emphasize engineering design. (b), K–12 engineering should incorporate important science, mathematics, and technology concepts and skills. And (c) K–12 engineering should align with systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations to promote engineering ―habits of mind (pp. 4–6). Although this report provides guidelines for how to include engineering component at K-12 level, it also concludes that there are no set ways to go about it, in terms of integrating engineering component in the classroom. Many researches support the idea of interdisciplinary inquiry when engineering component gets added in the curriculum, as it requires integration of knowledge components from various areas such as science, math, and technology. (Brophy, Klein, Portsmore, & Rogers, 2008; Douglas, Iversen, & Kalyandurg, 2004; Thornburg, 2009), as well as skills related to problem solving, creative thinking, and communication (Erwin, 1998; Katehi et al., 2009; Lewis, 2006; Roth, 2001; Thornburg, 2009). The current research suggests improved understanding of science and mathematical concepts for children if it gets situated within engineering context. (Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Katehi et al., 2009). Asking students to develop engineering designs has two benefits. First, it requires students to locate the problem and second, design a solution to address the issue using their prior knowledge from different disciplines. Different professional institutes and curriculum developers have suggested structure for engineering designs for students at K-12 level. For example, Accreditation Board for Engineering and Technology (ABET) defines engineering design as:

> The process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering science are applied to convert resources optimally to meet these stated needs (p.2).

Whereas the Engineering is Elementary (EiE) curricula developed by the Museum of Science–Boston, use five steps of the engineering design cycle: ask, imagine, plan, create, and improve for elementary science and engineering activities. An example for secondary education is the *Power of the Wind: How can we think like an engineer* program by the University of Illinois. The engineering design cycle has eight steps: 1) What is the challenge? 2) How have others solved this? 3) Brainstorm possible solutions: What are the design criteria and constraints? 4) Which of the possible solutions do you choose? 5) Build prototype. 6) How does it work? Try it and test again. 7) How do you learn from the design of others? and 8) How can you use your new ideas to improve your design? Although there are certain differences in the engineering designs proposed by different curriculum designers and professional organization, there are some striking similarities, such as, a design starts with an identification of the problem, analyzing the problem and proposing solutions, design solution creatively based upon knowledge components drawn from different disciplines. In summary, according to the existing research, engineering design has been treated as a pedagogical strategy to bridge science and mathematics concepts to solve open-ended problems, develop creative thinking, formulate solutions and make decisions, and consider alternative solutions to meet a variety of constraints.

Research Design

Participants

In designing the study, we chose to focus on scientists from various disciplines such as chemistry, botany, pathology and anatomical science to name few. As interdisciplinary inquiry crosses boundaries between different disciplines (Shulman, 1986), we believed that it was important for the interviewers, to ask specific examples to scientists within their research areas indicating interdisciplinary inquiry. In addition, we felt that greater insight about understanding the nature of interdisciplinary inquiry at K-12 would be gained by asking scientist for their interpretations about crosscutting concepts and science engineering practices in K-12 science framework. In this study we are focusing on a small group of scientists rather than studying a large cross-section of scientists. In this study, we used theoretical sampling, selecting participants based on their ability to contribute to the development of theory (Creswell, 1998). The scientists participated in our study guided middle school and secondary teachers during summer and mentored them to design and implement a research project. We have included all the scientists that guided teachers in the summer and allowed us to interview them to understand their views about interdisciplinary science inquiry. Between four researchers we interviewed 13 scientists. All of us established initial contact with scientists via email to set up a meeting time and venue. After being contacted, 13 scientists agreed to participate in the study. All the participants conducted their research in different science departments located in the large, public university in the Northeastern region of the United States. The participant scientists' working experience at the university level ranged from X to X years. Eleven of the scientists were Caucasian, and two were Asian.

<Insert Table 2 About here>[1]

Data Collection

Interviews with scientists and teachers and observations of teachers in the laboratories comprised our two main data sources. We initiated our data collection with an interview to explain the purpose of the study to the scientists and understand their views and interpretations about interdisciplinary science inquiry. Researchers via email contacted all the participating scientists. Once initial contact with the scientists was established we scheduled interviews with the scientists. The interview questions with scientists had three main sections. Section one focused on understanding how scientists differentiate between interdisciplinary science inquiry from discipline specific inquiry and what kind of examples do they provide. The purpose of this section was to understand scientists' interpretation of interdisciplinary science inquiry in order develop details of framework along with examples. The second section of the interview focuses on science and engineering practices and crosscutting concepts involved in the new K-12 science framework. We thought it would be insightful to understand how scientists, who perform authentic science inquiry interpret these practices and how do they see themselves performing these practices. The last section of the interview focused on understanding how scientists guided teachers who worked in their respective laboratories

[1] We have used pseudonyms for all the participants.

and how do they foresee their teachers implementing this research experience in the classroom. The purpose of this section was to understand how scientists have mentored their teachers to develop understanding of interdisciplinary science inquiry and how this understanding gets transferred in the classroom. Each interview lasted between 45 minutes to 120 minutes. Each researcher carried a summary sheet of science and engineering practices and crosscutting concepts during interview. The summary sheet also explained meaning of each practice and crosscutting concepts briefly if needed for scientists to elaborate their response. Responses to each question were probed until participants indicated that they had nothing additional to add or declined to elaborate. A team of four science educators reviewed the interview protocol for purposes of validity.

We also conducted detailed interviews with teachers according to their convenience during school year to understand their views about ISI and how do they translate ISI in their classroom. During interview teachers were probed to elaborate upon their thinking about choosing certain activity, resources, handouts or questioning strategy to teach interdisciplinary inquiry in the classroom. Teachers' interviews provided us rich data and allowed us to understand their thinking, reasoning, beliefs and struggles about implementing ISI in the classroom.

Our second data source was observations of teachers' summer sessions. Each teacher was assigned in different laboratories either on the university campus or in the industrial setting. Teachers conducted their research projects for around 6 to 8 weeks under guidance of their mentors. Between team of four researches we conducted multiple observations. We observed each teacher at least once conducting his or her summer research or participating in the lecture session as part of his or her summer research project. The purpose of these observations was to mainly understand how scientists have mentored teachers to develop and conduct their interdisciplinary projects. These observations gave us insight into scientists' understanding of interdisciplinary inquiry at K-12 level.

Grounded Theory Analytic Framework: Data Analysis

We selected grounded theory as an analytic framework, as the primary goal of grounded theory is to generate theory inductively from data (Glaser & Strauss, 1967). Grounded theorists ask: what is happening? And what are people doing? Our intent was to generate a framework for interdisciplinary inquiry that can be applicable in K-12 classrooms based on developing an understanding of what scientists are doing and what is happening in their laboratories that will help us define meaning of interdisciplinary science inquiry. In grounded theory, researchers become familiar with existing theories to develop sensitivity to meanings in the data, but then set aside existing theory in order to collect and analyze data with a fresh perspective (Strauss & Corbin, 1998). After reviewing literature related to integrated science, interdisciplinary inquiry, it became apparent that researchers have proposed multiple clarifications about these terms and if analyzed some similarities can been drawn between these definitions, explanations and views. Although, we reviewed pertinent literature, we looked at the scientists' interviews through fresh analytical lens. All interviews were audio-recorded, transcribed, and analyzed for patterns with HyperResearch qualitative software. The interview transcripts were reviewed multiple times during the development of the initial open codes. We used the process of open coding (Glaser, 1992) to analyze the transcripts from the each interview and, developing initial categories of the participant's understanding of interdisciplinary science inquiry.

<Insert Figure 2 about here>

For examples some of the initial open codes that we generates were : Understanding problem, defining problem, team work, science inquiry is skepticism. As we developed categories, we used a constant comparative method of analysis (Glaser & Strauss, 1967).

<Insert Table 3 about here>

During the interview and initial data analysis phase, we focused on one participant at a time, comparing the participant's views about interdisciplinary science inquiry with the teachers' summer research projects performed in their laboratories. We also compared scientists' responses with each other to understand similarities and differences within their interpretation of interdisciplinary science inquiry. This also helped us understand if meanings and dimensions of interdisciplinary inquiry change according scientists' primary field of research. After each round of data collection and analysis, we constructed concept maps to represent scientists' understanding of the nature of interdisciplinary inquiry. These pictorial representations of each scientist's interpretation of interdisciplinary inquiry served as an analytic memo (Strauss & Corbin, 1998). After analyzing data from all the interviews from all the participants, it appeared new codes and patters are not getting generated and that theoretical saturation had been reached, as data were not adding anything to core categories, dimensions of categories, or relationships between categories (Strauss & Corbin, 1998). Data collection occurred June through August of 2001, with data analysis continuing through January of 2013. During data analysis phase, we continued to compare themes emerged from data, analytical memos with the science and engineering practices and crosscutting concepts of K-12 science framework to develop dimensions for interdisciplinary science inquiry in K-12 context and provide specific examples from the scientists' interviews and projects designed by teachers.

The final stage of data analysis in grounded theory is the development of a theory. In case of our study we wanted to develop the framework of interdisciplinary science inquiry by employing inductive analysis tools across participants. The individual participant's diagrams, thoroughly grounded in the data, helped us generate a framework for interdisciplinary inquiry with different dimensions and specific examples (Glaser & Strauss, 1967).

Findings and Interpretations

After reviewing the literature it is evident that there is no consensus about the meaning and nature of interdisciplinary inquiry and no clarification about what does interdisciplinary inquiry mean in science and how does it look like in K-12 classrooms. Many educators and researchers have attempted to classify meaning of interdisciplinarity based on tightness or looseness of integration between different disciplines but this classification doesn't suffice the need for clarification in terms of how does interdisciplinary science inquiry looks like in K-12 context. Our research questions deal with this issue. By answering our research questions we clarify and define interdisciplinary science inquiry based on scientist' interviews from various research areas and pertinent literature such as K-12 science framework (2012), Next Generation Science Standards (2012), report on *Facilitating Interdisciplinary Research* by committee on Facilitating Interdisciplinary Research, National Academy of Sciences, National Academy of Engineering, Institute of Medicine (2004) and Taking science to school by Duschl, Schweingruber, and Shouse (2007). From analyzing interviews it was evident that the scientists' research areas and collaborations with other scientists defined their views towards interdisciplinary inquiry. It also became evident that scientists' personal experiences as student, parent and involvement in the previous school-university partnerships contributed in their views about interdisciplinary inquiry and how it should be implemented in the classroom. The 12 scientists we interviewed displayed similar views about different aspects of interdisciplinary inquiry and how does their research overlap with the

Scientists' Views about Nature of Scientific Inquiry

This study sought to capture the conceptions and experiences of the scientists about discipline specific inquiry versus interdisciplinary inquiry. When asked to compare discipline specific inquiry with interdisciplinary inquiry, three main themes emerged: (1) Nature of problem, (2) Need to answer questions and generating hypothesis and (3) Nature of disciplines. Almost all the scientists when asked about the explanation of the term scientific inquiry or discipline specific inquiry mentioned that scientific inquiry starts with a question or problem. For examples, Dr. Sardar a scientist from Biomedical Engineering mentioned, "*scientific inquiry is to frame a question*". Similarly, Dr. Brown, a Chemist mentioned inquiry as " *to answer question that are related to humanity and that will address points that can benefit humanity*". For majority of scientist the nature of scientific inquiry was complex and they related it with addressing something that is unknown to us and will help mankind. Dr. Barbara, worked with viruses and explained when he does scientific inquiry he is "*trying to understand universe".* He further explained scientific inquiry starts with "*design experiments to test hypothesis*". On similar lines, Dr. Fena mentioned scientific inquiry as "*making hypothesis, designing experiment to address that hypothesis, and evaluating the results".* He provided example from his research related to fungi cell wall where, they attempt to understand if certain genes and protein products participate in cell wall. They approach this question with making mutants and characterizing the mutants. He explained sometimes their hypothesis about mutants is supported by the results they obtain and sometimes it leads to new set of experiments. Other scientists also explained asking question and generating hypothesis as first stepping-stone of the scientific inquiry. Dr. Saagger, an engineering scientist explained a concept of scientific inquiry from engineering standpoint as, "*you have a problem and you are trying to address a problem trying to come up with solutions to the problem from using your basic knowledge of science such as physics or math and try to address this problem*". He further explained how in many cases scientific investigation starts with a hypothesis and scientists do experiments to validate it. He also explained how scientific inquiry emerges from the needs of humankind. He mentioned, "*all the research is based on the society needs and so I think scientific inquiry is related to the need of the society".* The need for solving problems, understanding universe, designing solutions and helping human kind were some of the major reasons scientists mentioned driving their inquiries and as the first step in the scientific inquiry.

For some scientists explaining the meaning of scientific inquiry was not as straightforward. Dr. Benard, a scientist from biological science took a long pause when asked about his conception about scientific inquiry. He mentioned, "*I am not sure about this term. I do research, I do science. I never thought about it. The terms pretty much explains it—scientific inquiry –scientific knowledge I guess. I haven't used that term very much. This might be the first time*". Similarly Dr. Hach, a scientist and medical doctor from Pathology and Anatomical sciences explained, "*I am not sure, if I understand what is scientific inquiry. There are so many ways to look at it. You can look at it from pure basic science or and look at it from applied science".* For some scientists explaining their understanding and process of research they go through everyday was difficult to express in words. Dr. Agaskar, an analytical chemist explained it as " *science inquiry is not just reading or attending it, but actually doing it*". For some scientists scientific inquiry was equivalent to doing science and some scientists explained science inquiry as scientific method where it begins *"with making observations about the world, formulating hypothesis that either categorizes or explains the observations and then hypotheses should provide some kind of testable result or testable prediction. Then one needs to design the experiment to prove the predictions right or wrong. If predictions are right it strengthens the theory. If the predictions are wrong it indicates either one has to go back and find a model or look for another model"* (Dr. Moore). Although some scientists explained scientific inquiry as scientific method, they also other side of scientific inquiry as, "*science is no absolute truth because things change all the time"*. While explaining nature of scientific inquiry scientists also explained how things that we learn in science are not absolute and through experiments, observations and evidences we reach close to the truth but it not entirely true.

One of the questions in our interviews focused on understanding scientists' views about disciplinary inquiry. Our reasoning behind asking this question lies in our theoretical framework. Petrie (1992) mentioned need for understanding disciplinarity in order to understand nature of interdisciplinary inquiry. The focus of our research paper is to unfold different dimensions of interdisciplinary science inquiry and hence we asked scientists their views about discipline specific inquiry in comparison with interdisciplinary inquiry. Scientists took different routs while explaining relationship between disciplinary inquiries in comparison with interdisciplinary inquiry. Dr. Saagger said, " There is definitely relationship between discipline specific inquiry and interdisciplinary inquiry. *One needs depth in one field but also needs to be able to communicate with other fields so that teams can be formed. Each person on a team brings his/ her e expertise, the depth but still needs to carry out an investigation or conversation of other field and try to integrate the knowledge. So it needs depth and breadth"*. According to Dr. Saagger, discipline specific inquiry needed in-depth knowledge of a subject, but in order to conduct an investigation, every team member needed to have expertise in his discipline along with knowledge of other disciplines in order to converse and progress in the investigation. Similarly, Dr. Sardar, a scientist from biomedical engineering gave an example of kidney research and how all the researchers try to look at it from biology, chemistry, physics and engineering perspective to understand its functioning and fixing damage in the organ. He added,

> *I think the relationship between the field specific inquiry that we make from our perspective fits into the interdisciplinary angle. So yes, there is a definitely a very big*

> *relationship and not always these relationships are clear and sometime these interdisciplinary things gets very obscure, but it is very important that we recognize that every perspective from the field specific inquiry, at the end of the day needed to be brought together in an interdisciplinary approach and how they complement or supplement each other to come to the particular point…"*

His explanation about discipline specific inquiry in comparison with interdisciplinary inquiry aligned with many other scientists' views. Many scientists' mention it is hard to perform discipline specific inquiry in science because of the nature of problems we face. Scientists felt because problems are getting bigger and it is beyond capacity of one person to address it with single handedly and it becomes essential to bring expertise from different disciplines together to handle the problem. Dr. Barbara, added his views about discipline specific inquiry in comparison with interdisciplinary inquiry as, "*use of tools and structural approach that one does not normally use in one's discipline makes it interdisciplinary".* But he also questioned definition of disciplines by mentioning, *"What discipline would you say Isaac Newton fell in? He essentially contributed to every field of physics. So did Einstein. It's really arbitrary what we call discipline".* From the interviews it was clear that scientists viewed the relationship between discipline specific inquiry with interdisciplinary inquiry as a continuum. All the scientists' provided examples from their research field and explained how their research has crossed the boundaries of their disciplines and how it has become essential to conduct to interdisciplinary inquiry because of vastness of problems they are addressing and need of techniques to address them.

Scientists' Views about Science and Engineering Practices

The second set of questions involved understanding scientists views about different science and engineering practices explained in the K-12 science framework.

> If we understand the question then the answer becomes easy to find. I always tell this to all my student if you have 1 hour to solve a problem spend the first 55 minutes to frame your question and the 5 minutes is good to solve it. Einstein made this comment and I really believe it is important that we understand what we are asking…

The above quote represents scientists' views about place of asking questions and defining problems. Scientists believed it is extremely important to ask right questions in order to design experiments and build solutions. Dr. Sardar gave specific example of drug delivery to distinguish between asking questions and defining problems. He mentioned " *we try to understand the major problems in different areas and we use our engineering tools and techniques to solve these problems or at least come up with a better solution to these problems".* Although scientists believed in the importance of defining problems and asking questions, not necessarily they distinguished between these two processes as science and engineering. For that matter scientists saw these two processes complementing each other. Dr. Barbara took a different stand and shed light on the process of asking questions in science by stating,

> Scientific processes are lot less predictable than an average bureaucrat like it to be. I will ask a question and I will collect data. I interpret it and…what happens…I find this data is not answering my questions…things don't work the way you think. So you end up asking different question. This process is not in

> the linear fashion, it is not predictable, so try to make it as predictable, eventually is self defeating.

Scientists based on their research fields interpreted the second science and engineering process, developing and using model on a wide spectrum. For example, Dr. Benard, a botanist gave example of Maize and Amaranthus plants and how it gets used as a model in studying C4 plants. Whereas, Dr. Saagger, a civil engineer scientist gave example of model that they use based on observations and empirical data. Although some scientists felt that model development in science has been "overdone" and because of which we do not look at things from different perspectives assuming we already have model for it, majority of them agreed upon the importance of models in science as bridge from hypothesis to theory. For example, Dr. Fena gave an example of fungal infection. Usually these infections get treated giving series of antibiotics because this is the model that gets followed. But Russian scientists treated bacterial infection with bacterial phage (virus) to kill the bacteria instead of antibiotics. He mentioned because American scientists focused on just one model, they did not see alternative solution and this should be avoided. Scientists believed models help for visualization and to understand things better.

The next four sciences and engineering practices go hand in hand and there was lot of overlap when scientists interpreted it and gave examples. First one was, planning and carrying out investigations, second was, analyzing and interpreting data, third was, using mathematical and computational thinking and fourth, constructing explanations and Designing Solutions. Scientists believed in investing time to ask right questions in order to plan their investigations and carry them out. For example, Dr. Sardar mentioned, "*It is important to realize when we design experiments that if my experiment going to answer my questions completely or is it going to answer my question with some conditions or is it not going to answer any of my questions at all* ". On similar lines, Dr. Fena stated, "*Answers you are getting are limited by questions you ask and how you ask them. Good planning means all the different ways you can learn about the process you are looking at".* It was evident from scientists' interviews that they strongly believed in asking right questions in order to plan and carry out their investigation. When asked about analyzing and interpreting data, scientists mentioned, they pretty much do it everyday and some of them saw it as two different processes but some scientists felt it as the same. Some scientists' mention going back into the literature during analysis and interpretation process and validating their interpretations with statistics and other kind of tools. All scientists accepted importance of computational and mathematical thinking in scientific research by stating mainly they act as "tools" for analyzing and interpreting data. They mentioned how they used statistical tools in analyzing data and computational models for interpreting data obtained through research. Scientists did not see difference between constructing explanation and designing solution as two separate science and engineering practices. Dr. Fena mentioned, I do not design solutions, but I design future experiments based on explanations obtained from the research data. Although scientists saw this practice as important part of scientific inquiry, they did not see it very different from previous three practices and did not provide lot of explanation.

The last two practices in the series were, engaging in argument from evidence and obtaining evaluating, and communication Information. Some scientist did not prefer using the term argumentation. Dr. Fena, mentioned, "*I would not use the word argumentation. I think you want the present the results most honest way possible and* *then you can certainly suggest what you think most likely interpretation is and why. I won't call it argumentation. I will call it presentation of fact and likely explanation*". Dr. Barbara explained the purpose of argumentation as, "sometimes evidence contradicts scientists' claim.. that is the nature of science and engineering so they argue, so in the sense it is productive. Because it encourages people to prove things", but he also preferred using word presentation instead of argumentation. Scientists explained common ways of communication as presenting at the conferences and journals. Scientists felt it is essential to communicate using these mediums because then they can progress in their research by getting feedback at the same time other scientists can use their work to progress their research or improve models, engineering designs they are building.

Overall, all the scientists indicated importance of science and engineering practices in their research with examples and how they are interrelated. Not necessarily all the scientists made distinction between science and engineering process as indicated in K-12 framework, but during interviews they explained how certain aspects of these processes can be observed more with engineering aspect. The clarification of K-12 science and engineering practices from scientists' perspective helped us in unfolding the meaning, importance and complexity of these practices with each other and with other dimensions of proposed ISI framework.

Scientists' Views about Crosscutting Concepts

The third set of questions revolved around understanding scientists' conceptions about different crosscutting explained in the K-12 science framework. In K-12 framework, crosscutting concepts have been explained as "concepts that bridge disciplinary boundaries, having explanatory value throughout much of science and engineering" (p.83). The first crosscutting concept focused on observing patterns in scientific data and developing questions. Scientists gave different examples from their research indicating patterns in their data. Dr. Adel, explained patterns from her research as, "*We mine a lot of this data to find patterns of behavior. For example we are trying to understand what to predict traffic volume at the border crossings so we have some historical data and we are doing some analysis to find trends and patterns and I think that applies here*". Dr. Fena, a biologist provided example of review paper he is writing for a journal and how he is seeing a patterns in the literature pieces that are helping him to understand other research pieces in different light. Scientists commonly provided examples from their data and explained how they look for correlations, relationships in data to explain patterns. The second crosscutting concepts was investigating and explaining causal relationships and mechanisms. Scientists connected this crosscutting concepts with the previous one by mentioning, *"it goes back to the same things…we always look for relationships in different mechanisms and relationships in our work and so we try to understand different things from a different perspective…"* (Dr. Sardar). Dr. Fena gave example from his experience describing how use of wrong models can affect scientists' capacity to explain cause and effect relationships and prediction of events. He explained an example from the history of ulcers.

> Fifty years or so, everyone thought ulcers are caused by stress and treated them in particular way with antacids and then about 10 years ago, scientists from New Zeland and Australia proved that ulcers are caused by bacteria and now we treat ulcers very differently but because we had that model for long time, it took us

probably forty years longer than it should have to demonstrate the ulcers are caused by bacteria. Wrong model leads to bad science.

Thus scientists agreed upon using information to explain cause and effect relationships and also agreed upon its importance in understanding meaning of data better.

The next two crosscutting concepts focused on recognizing relevant measures of size, time and energy and recognizing how changes in scale, proportion or quantity affects systems structure and performance and tracking fluxes of energy and matter into, out of, and within a system to understand the systems possibilities and limitations. Scientists saw overlap between these two crosscutting concepts. For example, Dr. Barbara gave specific example from viruses where scientists attempt to understand biological clock of bacterial cells and how it requires understanding of cyclic changes. He explained how concentration of certain reagents in the cell needs to be calculated and how certain mathematical models need to be used to understand the system (here bacterial cell) under study. Dr. Sardar gave example of different models such as mouse and human being. He mentioned choosing relevant models is essential because things happening and molecular level cannot be compared as is in the real physiological condition. By giving example of mouse and human being he explained how it is essential to understand constraints and limitation of certain system. Dr. Benard, mentioned biology is complex in nature and system biologist tries to understand processes in organisms by isolating them but ultimately to understand how things work, one needs to understand the complete system. Overall scientists' thought it is very important to understand boundaries of system in order to understand it better. Dr. Fena mentioned, " *You cannot do research if you do not know what temperature to grow your fungus at, you do not what the life cycle is, what nutrients are, you are not going to grow fungus and if it grows poorly, it is not going to perform well in the phenomenon you are interested in studying*"

The next set of crosscutting concepts was: understanding the properties and functions of an object or a system under your study, and understanding conditions of stability and determinants of rate of change or evolution of system. All the scientists believed the necessity of understanding the system under study and how that helps in understanding the system. Scientists also mentioned that they try to understand the conditions and factors affecting the system. Dr. Fena gave example of fungal colonies and mentioned in order to understand how fungal colonies work and movements of metabolites in fungal colonies, one need to understand the processes fungus performs. He stated, " In order to study how cell works, I need to know something about how cells work". Dr. Salmone gave example Earthquake and mentioned, "When I teach I talk about energy and wave in the structure. This wave is actually an energy that travels through the structure it is like an earthquake, an earthquake is energy that travels through the ground and pull it through the earth". Overall, scientists explained crosscutting concepts as core science concepts translating through different disciplines and bridging gaps between different disciplines.

Teachers' Views about Interdisciplinary Science Inquiry

We interviewed around thirteen teachers from different schools to understand their views about interdisciplinary science inquiry. For many teachers the concept of interdisciplinary science inquiry was new and when asked to explain their understanding about the concept, they replied with a question, "interdisciplinary?" or "interdisciplinary science inquiry?" or "what do you mean?" For many teachers the term interdisciplinary science inquiry was unknown and even if they experienced different activities and researched in science laboratories in summer, they did not see it as ISI. Mrs. Yin was a biology teacher teaching seniors. She explained her understanding of ISI as, "*inquiry based science program including all the sciences*". She followed her facilitators' outlook for research in her teaching. She wanted her students to come up with the answer and I see viewed it as inquiry based learning. Mrs. Yin explained, she views ISI as "*more inquiry rather than including all the disciplines*". Similar to Mrs. Yin, Mrs. Hard also believed ISI being equivalent to inquiry. In her interview she explained, "*I do not do lot of inquiry because one needs certain level of understanding and skills to do inquiry, but for freshman level it is hard for me to do it because my students can't stay on task and they do not have skills.*" When asked about the skills she expects her students to have, she gave her example during summer research and explained, her mentor could ask her and her colleague to perform different inquiry based activities because they had certain level of content understanding and skills that are necessary to perform laboratory experiments. It was evident that some teachers did not see difference between ISI and inquiry.

Other set of teachers believed ISI is mainly "*Integration of different disciplines but mainly technology and engineering*. Mrs. Yin integrated different probes and equipment such as thermo-cycler in gel electrophoresis laboratory and she saw it as integration of technology in her teaching. Similarly, Mr. Maltese integrated physics in his engineering projects with his students and viewed it as interdisciplinary science inquiry. He explained, "*science is included in everything and science is everything, so interdisciplinary science inquiry is integrating different science areas in the discussion".* In his discussions with students, he talked about different physics concepts while designing projects, building projects and improving their designs. When some teachers explained ISI as mainly integration of different disciplines of science, Mr. Nare explained characteristics of ISI and why is it necessary to perform ISI in the classroom. He mentioned, "*ISI is collaborative approach. Different disciplines offer their perspective, their viewpoint and approach for solving problems or examining situations*" He gave an example of body systems unit which he developed with other teachers during his summer research experience. He mentioned, "*There is lot of physics involved in biology. For example, when we talk about circulatory system and about heart, we can talk about electric pace maker that is physics or heartbeat per minute. So if we can involve bits of knowledge from different disciplines in the discussion then we can make the entire experience richer for our students".* Many teachers provided examples from their daily teaching and explained their understanding of ISI mainly as integrations of different disciplines. Very few teachers discussed about purpose of ISI in teaching and its impact on students' conceptual understanding. Many teachers focused either on integration of disciplines or inquiry process skills, but very few teachers talked them together and fewer discussed these aspects explicitly with their students in the classroom.

Nature of Interdisciplinary Science Inquiry: Definitions and Dimensions

Based on scientists' interviews, it is evident that they believed in complexity of interdisciplinary science inquiry and its importance in today's science. All the scientists from all disciplines agreed upon nature of today's science being interdisciplinary and also mentioned how it is driven by the nature of problems, questions and constant development of technology. All the scientists believed that in today's science it is almost impossible to solve any societal issue without integrating more than one discipline.

Scientists provided examples from their disciplines to explain, how do they address issues related to environment or develop solutions on some disease or try to develop understanding of a virus or bacteria using variety of techniques, approaches and by collaborating with scientists from different disciplines. Dr. Hach, a medical doctor mentioned interdisciplinary science inquiry as translational research where all disciplines come together to find solution of a problem. Dr. Barbara brought another aspect of interdisciplinary science inquiry where he collaborates with other scientists to push his research further. Dr. Brown gave example of soccer while explaining importance of teamwork in interdisciplinary science inquiry. It was evident that scientists believed need to address unresolved questions and develop solutions to problems as driving forces of interdisciplinary inquiry. Similarly, collaboration was second critical piece in making interdisciplinary science inquiry successful.

<Insert Figure 3 About Here>

The report on facilitating interdisciplinary science research (2004) discusses a concept of "drivers", which is defined as "kinds of motivation a scientist might respond to in undertaking interdisciplinary research" (p. 30). The report lists four such drivers that pushes interdisciplinary science inquiry as: (a) The Inherent Complexity of Nature and Society, (b) The Drive to Explore Basic Research Problems at the Interfaces of Disciplines, (c) The Need to Solve Societal Problems, (d) The Stimulus of Generative Technologies. We believe these four drivers explained in the report summarize scientists' reasons for collaboration and establishing interdisciplinary teams. We also believe these four drivers help us understand the need of interdisciplinary science inquiry in broader context and helps us situate interdisciplinary science inquiry in K-12 context. Based on scientists' views and the report we define first dimension of interdisciplinary science inquiry as: (1) Drivers of Interdisciplinary Science Inquiry.

The next three dimensions of interdisciplinary science inquiry emerge from K-12 Science framework and scientists' views about different practices related to science and engineering as well as their views about crosscutting concepts. From the interviews it was clear that scientists believed need of asking good question, defining problem and proposing hypothesis as first step of interdisciplinary science inquiry. Also, scientists believed in the relationship between discipline specific inquiry and interdisciplinary inquiry as a continuum. Scientists' believed in having in-depth knowledge of one discipline but also believed in having knowledge on broader spectrum to be able to communicate and integrate techniques, processes, knowledge and approaches to understand issue under study. Scientists elaboration on different science and engineering practices and crosscutting concepts within context of their disciplinary research parameter defines our next three dimensions of interdisciplinary science inquiry as: (2) Science and Engineering practices, (3) Crosscutting concepts, and (4) Disciplinary core ideas. We define these three dimensions based on K-12 science framework because they applicable in K-12 school context and also push science teaching in the classrooms with integrated approach. In the framework, disciplinary core ideas have been subdivided into four domains as (i) the physical sciences, (ii) life sciences, (iii) earth and space science and (iv) engineering, technology and application of science. The framework acknowledges connections between four domains and states, "scientists work in interdisciplinary teams that blur traditional boundaries. As a consequence, in some instances core ideas, or elements of core ideas, appear in several disciplines (e.g., energy, human impact on the planet) (p. 31). On similar note, framework also expects to integrate science and engineering practices, crosscutting concepts and disciplinary core ideas. We believe adding fourth dimension of drivers of interdisciplinary inquiry acts as context for studying other three dimensions in the integrated fashion. The figure below represents the framework for Interdisciplinary science Inquiry.

<Insert Figure 4 About Here>

Implications

The proposed framework for ISI would guide classroom instruction at K-12 level as well can act as benchmark for assessing students understanding of ISI. This ISI framework complements well with Next Generation Science Standards and Common Core standards for math and English Language Arts (ELA). The design of ISI framework around different topics of NGSS and grade level gives specific indicator of what content should be taught at particular grade level. Another important aspect of our Interdisciplinary science framework is it's mapping over scientific proficiencies explained by Duschl, Schweingruber, and Shouse (2004). The current K-12 science framework is based on the report by Duschl, Schweingruber, and Shouse (2004) entitled Taking Science to School: Learning and Teaching Science in Grades K-8. This report explains four proficiencies of science that students should achieve in science without getting caught into dichotomy of learning science content versus science process skills. These four proficiencies are: (a) know, use, and interpret scientific explanations of the natural world; (b) generate and evaluate scientific evidence and explanations; (c) understand the nature and development of scientific knowledge; and (d) participate productively in scientific practices and discourse. Because of familiarity of science proficiencies to teachers and educators for long time, we feel it is essential to map ISI framework over these proficiencies. We have mapped different performance expectations mentioned in the Next Generation Science Standards over proficiencies, which will allow teachers to understand cross section of performance expectation with proficiency. This will also act as resource guide for teachers to see math and ELA common core connection in relation with science proficiency.

Currently teachers focus on teaching discipline specific concepts to the students and although different disciplinary core ideas are embedded within different science concepts, teachers do not discuss it explicitly. The discussed ISI framework will act as an anchor for teachers to see the overlap between content as well as practices explicitly. The current ISI framework introduces a fourth dimension of "drivers" (Facilitating interdisciplinary science research, 2004) which will act as context or purpose for conducting interdisciplinary science inquiry in the classrooms. It is very essential to connect science concepts and experiences to students' lives to make it more meaningful to them. The fourth dimension of driver will serve this purpose and will help teachers to design and implement inquiries around need of society, challenges in the nature and addressing pros and cons of new technologies.

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Table 1

Summary of Fogarty's Models.

	Model	Subcategory	Elements of Integration
	Within Single Discipline	Fragmented	left students with a fragmented view of the curriculum
		Connected	makes explicit connections with each subject area being taught and connects one topic or one skill. The idea of the connected model is that teachers should make the connection rather than assume that students automatically understand the connection.
		Nested	emphasizes integrating multiple skills, such as a thinking skill, a social skill, and a mathematics skill, that take place in each subject area.
	Across Several Disciplines	Sequenced	the topic or unit is purposefully arranged to coincide with one another. Although the topic or unit is taught in different classrooms, the sequenced model aims to strategically arrange curriculum to provide a broad view that relates concepts.
		Shared	The shared model puts two disciplines into one focus. This model also focuses on concepts and skills development.
		Webbed	attempts to use a theme to web different disciplines together**.** A similar conceptual theme is used to provide a fertile ground for cross-discipline units.
		Threaded	supersedes all subject matter content (pp.64) to focus on different skills, such as thinking skills, study skills, technology skills, mathematics skills, and so forth that need to be learned.
		Integrated	emphasizes overlapping concepts and skills in different disciplines. However, the integrated model needs to integrate more than 3 disciplines rather than just 2.
		Immersed	learners play a critical role in integration.
		Networked	learners themselves can direct the integration process, because the integration process is highly associated with learners' interests, expertise, and experiences.

Table 2

Background information on scientists.

Scientists' Names (pseudonyms)	Departmental Affiliation	Research Interest
Dr. Dionne Agaskar	Department of Chemistry	Analytical Chemistry applied to environment (pollution)
Dr. Jack Gerald	Department of Chemistry	Analytical Chemistry, Surface Chemistry, Environmental Chemistry, Polymer Materials Chemistry
Dr. Fred Brown	Department of Chemistry	Chemical Sensing and Spectro-Chemical Analysis
Dr. Alan Fena	Department of Biological Sciences	Molecular, Cellular, and Developmental Biology of the filamentous fungi.
Dr. Joseph Barbara	Department of Biological Sciences	Molecular Virology
Dr. James Benard	Department of Biological Sciences	C4 photosynthetic pathway in Amaranth plant
Dr. Jack Caufield	Department of Physics	Condensed Matter
Dr. Li Xao	Department of Physics	Spin effects and nanomagnetism
Dr. Robin Hach	Department of Pathology and Anatomical Sciences	Signal Transduction of Doublecortin Kinases
Dr. Ana Saagger	Civil Structural and Environmental Engineering	Transportations Systems Engineering
Dr. Deep Sardar	Biomedical Engineering	Develop polymers with the aim to manipulate physiological and pathological systems like tissue regeneration and drug delivery
Dr. Sally Salvio	Civil and Structural and Environmental Engineering	Structural monitoring
Ted Moore	Global Hydrogen group at Praxair	Analyst at the Praxair

Table 3:

Open Coding for Participants' Interpretation of Interdisciplinary Inquiry				
Participants	***Example Quotes***	***Open Coding***	***Patterns***	***Category***
Dr. Hach	" To tackle a problem that is beyond any one of our abilities or capabilities and working as a team, you can make much more progress" "We were trying to find ways for epithelium to grow faster and heal. Dr. H makes membrane, Dr. B measured protein molecules released by the epithelium, because eventually we want to develop a screen"	Understanding problem/ defining problem Team work	In order to find solution to problem teamwork is necessary. Each person brings different expertise to the team.	The need to solve societal problems
Dr. Barbara	"We are trying to find out how plants adapt or not adapt to the contaminants in the environment, but it requires interdisciplinary approach and collaboration"	Environmental issue, Collaboration	Collaboration is important component of interdisciplinary inquiry.	The need to solve societal problems
Dr. Agaskar	"I study pharmaceutical pollution in the environment. In the waste-water treatment plant there are pharmaceuticals that are removed efficiently during certain times of the year but on another time it does not get removed. So this is a problem and we formulate hypothesis." "If it turns out that your hypothesis is correct then you can solve it that problem, so this is interdisciplinary"	Understanding problem based on observations Proposing hypothesis	Formulating hypothesis is important step in finding solution.	The need to solve societal problems

Table 4:

Representative Responses of Scientists About Perceptions of Interdisciplinary Science Inquiry in Classrooms

Themes	Quotes
Supports needed for implementing Interdisciplinary inquiry in the classroom	"We need teachers to think across disciplinary boundaries and look at the common ideas and reinforce" " We need to give them freedom to pursue that and not constantly be forcing them to examine students" "Create environment where students can be creative and be able to explore what they are good at". "Part of the problem is we change our teaching so slowly and we don't really think about the evolution of how we do science and trying to keep up with teaching it". " By having United States government specifying what is going to be taught and evaluating teachers on how well students do on standardized testing is counterproductive. It forces teachers to teach students for test and not to the interest of the teacher and now teacher evaluation process is flawed because different school districts have different clienteles. So I think whole approach is terribly flawed and it needs to go away.
Nature of Science	" Today is science is not structured" "Nobody really knows enough to solve all the problems" "Successful scientists integrate approaches"
Discipline Vs. Interdisciplinary science teaching in the classroom	"Implementing interdisciplinary teaching approach in the classroom might be counterproductive. Traditional teaching methods work better as long as teachers are good quality teachers."

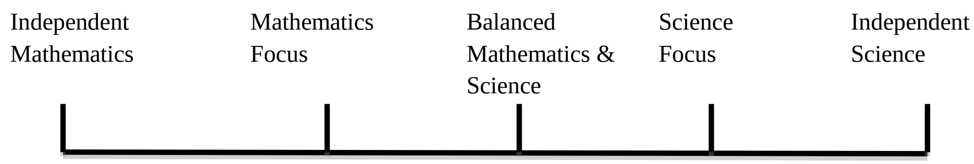

Figure 1: Lonning & DeFranco's continuum model of integration for mathematics and science concepts

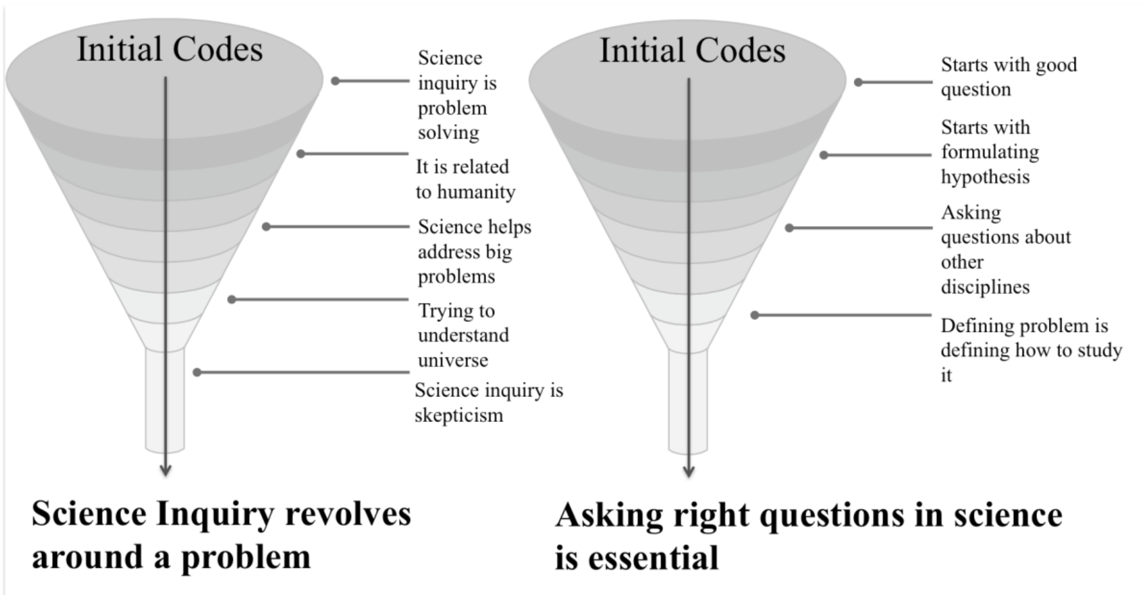

Figure 2: Example of codes and theme development

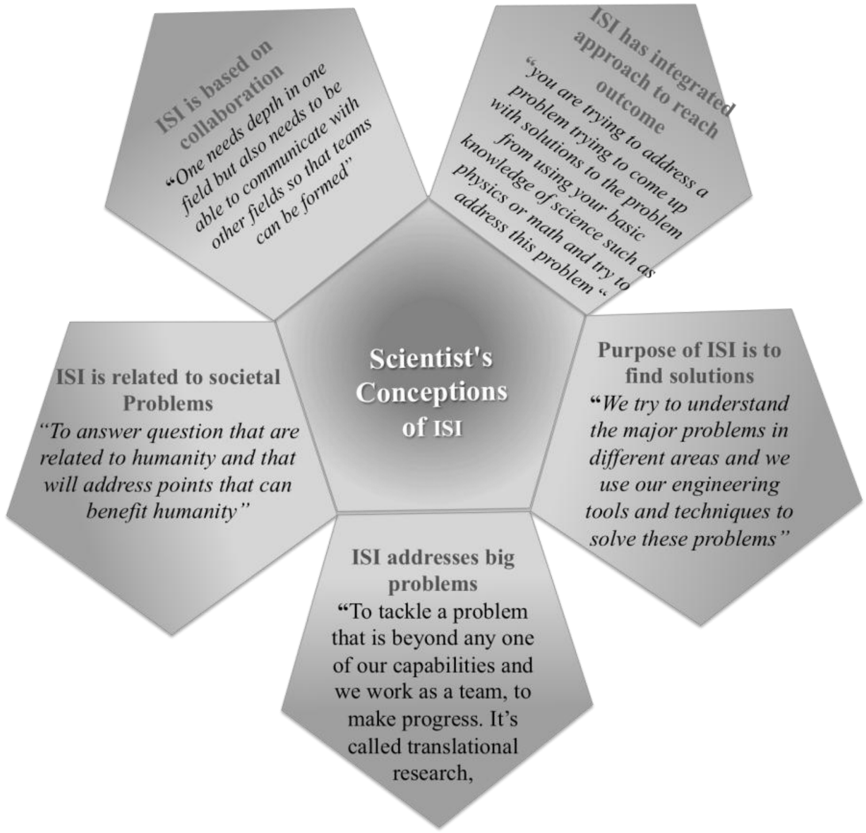

Figure 3: Scientists' conceptions of ISI

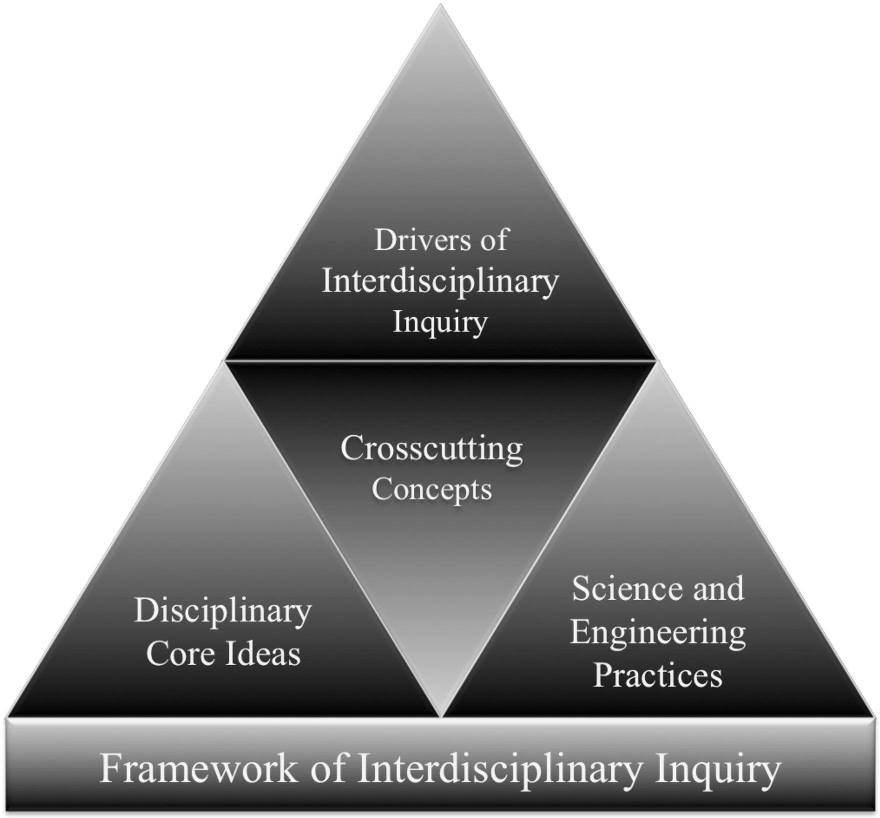

Figure 4: Framework of Interdisciplinary Science Inquiry